IPBES Global assessment Chapter 2.2 – Supplementary material
Indicators of Status & Trends in Nature

Contents

S 2.2.1. Methodology

S 2.2.1.1. Selection of indicators

We selected only data that could be viewed as quantitative representations of the state of nature (rather than of pressures or responses) across the globe or at least across multiple regions. We began by considering all IPBES Core and Highlighted indicators (though we did not always follow the Indicator Task Force's assignments of indicators to pressure/state/response). Because the Core and Highlighted indicators are predominantly concerned with just two of the classes of Essential Biodiversity Variable (community composition and species populations), we sought additional status and trend data for other aspects of nature from the recent peer-reviewed literature and other authoritative assessments, including the most recent global synthesis (Tittensor et al. 2014). We required either (a) global estimates with at least two time points covering a time span of at least 10 years or (b) at least one global estimate of recent status that could be expressed as a percentage of the value expected or estimates for a pristine or at least much less impacted world. For some facets of nature, multiple estimates were available; in such cases, we generally took the most recent high-quality estimate available except when such estimates show qualitatively different trends (e.g., terrestrial NPP), in which cases we used two divergent estimates. Data for some Core indicators were provided by the IPBES Knowledge & Data TSU; other data were taken from publications (including supplementary information), provided by their authors on request, or produced by participants in a global biodiversity modelling intercomparison exercise (Kim et al. 2018).

Some indicators are subsets of others. For example, as well as the overall *Red List Index*, there are Red List Indices estimated for several different subsets of species. When calculating a median status or trend from multiple indicators, we include only those indicators that are not subsets, so as to avoid double-counting.

The accounts of indicators that follow draw on the source papers for each indicator, on accounts in Tittensor et al. (2014) and on fact sheets provided by indicator producers and by the Knowledge & Data TSU.

S 2.2.1.2. Assignment to EBV classes and sub-categories

Although EBVs and indicators are not conceptually identical, the EBV framework (Pereira et al. 2013) provides a useful way of conceptualising data on the status and trends of nature. We therefore assigned each indicator to an appropriate EBV class. Boundaries between EBV classes are not always clear-cut, and others might make different choices. (For example, we view above-ground biomass as a measure of ecosystem structure, but Pettorelli et al., 2016, list it as a measure of ecosystem function.) Within community composition, we have differentiated between indicators of local (alpha) diversity and regional (gamma) diversity, because of the expectation that trends may differ (McGill et al. 2015). Within species population, we have differentiated between indicators based on global extinction, extinction risk or extinction debt and those based on changes in geographic range size or change in numbers of individuals within populations. This differentiation is because extinction, risk and debt are estimated on a relatively coarse temporal and spatial scale, so indicators derived from them may fail to capture gradual declines of widespread species, which might be reflected more quickly in indicators derived from data on species' abundances or geographic range sizes (Butchart et al. 2005).

S 2.2.1.3. Assignment to indicator types - underpin NCP, representative/fundamental, and sensitive

Indicators not only represent different EBV classes but also differ in their focus. Some are focused on components of nature that directly underpin specific Nature's Contributions to People (NCPs). For example, the *Red List Index for pollinating species* reports on trends in the conservation status of vertebrate species that are pollinators. Some indicators instead aim to report on a subset of Nature that can be viewed as more broadly representative; e.g., the overall *Red List Index* reports on trends in the conservation status of species in a range of taxonomic groups having different ecologies. Others report on aspects of nature that are so basic and fundamental that they influence many other facets of ecosystems and the potential flow of many NCPs from them; an example is *above-ground biomass*, which strongly influences habitat and food availability for many animals, influences a wide range of ecosystem processes, and places constraints on flows of many NCPs. Lastly, some indicators focus on components of nature likely to be sensitive to human impacts. The extent of *live coral cover* provides an example, because corals have narrow environmental tolerances. The *Living Planet Index* is another example, because a given change in population size receives more weight in the index calculation if it takes place in a small population rather than a large one (because geometric means are used in the calculation rather than arithmetic means); the index therefore tends to reflect the trends seen in species that are already rare (Buckland et al. 2011). Unlike assignment to EBV classes, indicators can fit into multiple of these categories. Note that the subchapter focusing on NCP derives a number of indicators of nature from those presented here, each aiming to capture nature's potential to support a particular class of NCP; see that subchapter for further information.

S 2.2.1.4 Alignment of indicators

To facilitate synthesis, we aligned all indicators such that (i) ecosystem function measures are expressed as process rates and all other measures as stocks; and (ii) larger values are associated with there being more of the indicated component of nature. This required transformation of the original data for some indicators. For example, *number of mammalian and avian extinctions* is an indicator which we assigned to the species population EBV class, but is expressed as a number per 25 years (i.e., as a rate rather than a stock), and higher values mean nature is reduced rather than increasing. We therefore re-cast this indicator as *number of extant mammalian and avian species*, subtracting the cumulative number of extinctions since 1500 from the numbers of species extant at 1500. Note that a larger value of an indicator does not necessarily mean the status of nature is 'better'; for example, higher values of *net primary production* has both pros and cons from the perspective of nature, and larger numbers of *invasive alien species* cause more problems for ecosystems. The alignment simply means that larger numbers mean there is more of what is being indicated; it does not judge whether more or less would be better from the perspective of either nature or society.

S 2.2.1.5 Treatment of uncertainty

Although many of the indicators we selected have associated estimates of uncertainty, far fewer estimates of uncertainty are sufficiently detailed to be used appropriately in the analysis of their trend or percentage remaining, or when synthesising multiple indicators together. We have therefore not attempted to do so.

S 2.2.1.6 Estimation of trend since 1970

Although some indicators go back before 1970, this sub-chapter concentrates on trends since 1970. Trends could not be estimated for indicators with only a single value since 1970. For time series with at least two points since 1970, we estimated the per-decade rate of change as follows.

For time series with two points since 1970: The data were multiplied by a common scaling factor such that the earlier data point became 100. The change between rescaled values was divided by the number of decades between the two dates to provide a per-decade rate of change, expressed relative to the value at the earliest time point included in the analysis.

For time series with 3-5 points since 1970: For each year since 1970 with a value, a fitted value was estimated from a straight unweighted ordinary least-squares regression line of indicator value against year; using fits rather than raw values makes trends less sensitive to values in the first year (Buckland et al. 2017). Fits were then multiplied by a common scaling factor such that the earliest fit became 100. The change between first and last rescaled fitted values was divided by the number of decades between their dates to provide a per-decade rate of change, expressed relative to the fitted value at the earlier time point. Although the p-value of the regression provides an estimate of the trend's significance, it does not consider the uncertainty associated with each point; for example, a very precisely-measured indicator might show a net change that, while not significant as judged by the regression, greatly exceeds the uncertainty associated with each year's estimated value.

For time series with at least 6 points since 1970: For each year since 1970 with a value, a fitted value was estimated from an unweighted generalised additive model (Wood 2006) of indicator value against year, estimated using the *mgcv* package in R, with a gamma parameter of 1.4 to avoid overfitting (Wood 2006). Use of fitted rather than observed values makes trends less sensitive to values in the first year (Buckland et al. 2017). If the analysis included at least 10 points, the basis dimension (*k* parameter, constraining the maximum complexity of the smooth) was set to its default value; otherwise, *k* was set to 3. Fits were then multiplied by a common scaling factor such that the earliest fit became 100. The change between first and last rescaled fitted values was divided between the number of decades between their dates to provide a per-decade rate of change, expressed relative to the fitted value in the earliest included year; note that this is the average rate of net change over the time span being considered, whether or not the change was linear. An approximation of the significance of this change can be had from the confidence interval associated with the GAM.

S 2.2.1.7 Estimation of percentage remaining

A novel feature of this assessment is that, where possible, indicators have been expressed on an axis where 0 means nature has been maximally degraded or wiped out and 100 corresponds to the value in a world with minimal or no human impacts. Some indicators already fit this scale (e.g., the *Red List Index* takes a value of 100% if all species are at minimal risk of extinction – which, without any human influence, very nearly all species would be – but would fall to zero if all species went extinct), whereas others need rescaling – sometimes with ancillary information from other sources – in order to put them on this axis. Returning to an example used above, numbers of mammalian and avian extinctions per 25-year time bin can be combined with information on how many mammalian and avian species were extant at 1500 to yield time-varying estimates of the proportion of mammalian and avian species remaining. This example highlights the general issue of inferring the value of the indicator in a world with no human impacts. Such estimates may come from earth system models (e.g., the TRENDY model used to infer terrestrial NPP for the 1860s, the earliest decade for which the model was run), or from the earliest time for which sufficiently reliable data are available, if that comfortably precedes the ‘Great Acceleration’ of drivers (e.g., the date of 1500 in the example of mammalian and avian species).

S 2.2.1.8 Intersections with hotspots of narrowly-distributed species and Indigenous lands

It was possible to assess status and trends of a few indicators within the hotspots of endemism and rarity (as demarcated in Section 2.2.3.4.2) and/or within the Indigenous lands mapped by Garnett et al. (2018), for comparison with the global status and trends. This was usually done by intersecting suitably fine-scale rasters of indicator values with shapefiles of the hotspots or Indigenous lands, for multiple years so that a trend could be estimated. For the Biodiversity Habitat Index, which is scale-dependent, the modelling framework was re-run for the set of hotspots of endemism and rarity. This indicator was not computed for Indigenous lands because many of them are too small for it to meaningfully calculated within them. In Table 1, indicator names with the suffix “Hotspots” are computed within hotspots of endemism and rarity, while those suffixed “Indigenous Lands” are computed within the lands mapped by Garnett et al. (2018). In both cases, these indicators are treated as subsets of their corresponding global versions.

S 2.2.1.9 Plots for each indicator

In the accounts that follow, each indicator is shown in up to three plots. The first shows the full time series for the indicator, after alignment (i.e., transformation if necessary to express ecosystem functions as process rates and other indicators as levels of stock, with larger values indicating higher levels of stock or higher rates). The y-axis on this plot is in the units and on the scale of the aligned indicator. The second plot, for indicators where the percentage remaining can be estimated, shows the full time series for the indicator transformed to the percentage scale, with a line of best fit for the period since 1970; this line of best fit is obtained using the same sample-size dependent approach as described for estimation of trend since 1970 (above). The third plot shows the data since 1970, rescaled such that the fitted value (which, with noisy time series, may differ considerably from the recorded value) for the earliest year shown is 100. The fitted line is also shown (solid line) together with 95% confidence intervals (dashed lines).

S 2.2.1.10 Synthesis plots and summary statistics

Within each EBV class (and, for community composition and species populations, within each sub-class separately), indicators are arrayed in order of decadal rate of change – most positive at the top, most negative at the bottom – and, for indicators lacking estimates of rates of change, in order of percentage remaining. Indicators that are subsets of others are plotted as semi-transparent symbols.

Medians are used to summarise the trends or status estimates within an EBV class or subclass. Indicators that are subsets of others are omitted when estimating medians, to avoid double-counting. We recognise that different indicators sometimes share more subtle dependencies (e.g., they may be derived from the same satellite imagery or across overlapping sets of species) but have not attempted to account for these when synthesising results from multiple indicators.

Summary of indicators

Table 1: Summary of indicators used in this synthesis, organised alphabetically within EBV class (and, where relevant, EBV scale). Core/Highlight/Other denotes the Knowledge & Data TSU's evaluation of each indicator. Whole or Part of indicator denotes whether the row of the table refers to an overall indicator (e.g., Red List Index) or a subset (e.g., Red List Index of pollinators).

Indicator	**Status (%)**	**Decadal trend (%)**	**Years**	**Years with estimates**	**Estimates since 1970**	**Is indicator Core, Highlight or Other?**	**Whole or Part of indicator?**	**Representative or fundamental?**	**Sensitive?**	**Directly underpins NCP?**
Ecosystem structure										
Aboveground biomass	–	-0.09	1993-2012	20	20	Other	Whole	Yes	No	Yes
BHI (overall habitat integrity)	70.0	-0.11	2005-2015	2	2	Core	Whole	Yes	No	No
BHI (overall habitat integrity) - Hotspots	58.0	-0.88	2005-2015	2	2	Core	Part	Yes	No	No
Coastal carbon-rich habitat	–	-5.61	1980-2017	7	7	Other	Part	Yes	Yes	Yes
Coastal protection habitats	–	-3.56	1980-2017	7	7	Other	Whole	Yes	Yes	Yes
Extent of forests	68.1	-1.24	1990-2015	5	5	Core	Whole	No	No	Yes
Extent of intact forest landscapes	20.1	-5.52	2000-2013	2	2	Other	Whole	No	Yes	No
Extent of marine wilderness	13.2	–	2013	1	1	Other	Whole	No	Yes	No
Extent of terrestrial wilderness	23.2	-4.49	1993-2015	2	2	Other	Whole	No	Yes	No
Fraction of ocean not fished per year	45.0	–	2016	1	1	Other	Whole	Yes	Yes	No
Land not cultivated or urban (global)	76.7	-0.57	1992-2015	24	24	Other	Whole	Yes	No	No
Land not cultivated or urban (Hotspots)	71.4	-0.57	1992-2015	24	24	Other	Part	Yes	No	No
Land not cultivated or urban (Indigenous Lands)	93.2	-0.19	1992-2015	24	24	Other	Part	Yes	No	No
Leaf Area Index	–	4.95	1982-2011	30	30	Other	Whole	Yes	No	No
Mangrove forest area	23.5	-1.73	2000-2014	15	15	Other	Whole	Yes	Yes	No

Natural habitat extent	62.3	-1.00	1961-2011	51	42	Other	Whole	Yes	No	No
Percentage live coral cover	53.2	-4.01	1972-2016	41	41	Other	Whole	Yes	Yes	No
Permanent surface water extent	–	0.62	1984-2015	2	2	Other	Whole	Yes	No	Yes
Remaining primary vegetation	38.6	-4.12	850-2015	1166	46	Other	Whole	Yes	No	No
Remaining primary vegetation (Hotspots)	35.2	-5.12	1970-2015	2	2	Other	Part	Yes	No	No
Remaining primary vegetation (Indigenous Lands)	49.9	-2.79	1970-2015	2	2	Other	Part	Yes	No	No
Seagrass meadow area	53.0	-10.89	1879-2000	9	4	Other	Whole	Yes	Yes	No
Soil organic carbon (correlative model)	92.0	–	2010	1	1	Other	Whole	Yes	No	No
Soil organic carbon (mechanistic models)	103.5	0.47	1860-2015	156	46	Other	Whole	Yes	No	No
Tree cover	54.2	2.09	1982-2016	2	2	Other	Whole	Yes	No	No
Vegetation biomass (mechanistic models)	49.1	1.20	1860-2015	156	46	Other	Whole	Yes	No	No
Wetland Extent Trends Index	–	-7.74	1970-2015	46	46	Highlight	Whole	Yes	Yes	No
Ecosystem function										
Biological pump efficiency	–	-0.42	1982-2014	33	33	Other	Whole	Yes	No	No
Biomass turnover rate	194.4	–	2000	1	1	Other	Whole	Yes	No	No
Evapotranspiration (model ensemble)	99.0	0.27	1860-2015	156	46	Other	Whole	Yes	No	No
Marine NPP (remote sensing)	–	4.71	1998-2007	10	10	Other	Whole	Yes	No	Yes
NPP remaining in ecosystems	86.2	1.26	1910-2005	9	5	Other	Whole	Yes	No	No
Oceanic carbon sequestration	–	28.78	1970-2010	41	41	Other	Whole	Yes	No	Yes
Terrestrial C sequestration (model ensemble)	–	25.34	1860-2015	156	46	Other	Whole	Yes	No	Yes
Terrestrial NPP (model ensemble)	129.3	2.88	1860-2015	156	46	Other	Whole	Yes	No	No
Terrestrial NPP (remote-sensing)	–	0.59	2000-2015	16	16	Other	Whole	Yes	No	Yes
Community composition - local										
Biodiversity Intactness Index (Hotspots)	76.2	-1.58	1970-2014	2	2	Core	Part	Yes	No	No

Biodiversity Intactness Index (Indigenous Lands)	84.6	-0.91	1970-2014	2	2	Core	Part	Yes	No	No
Biodiversity Intactness Index (overall)	78.6	-0.83	900-2014	53	18	Core	Whole	Yes	No	No
Local species richness (BioTime)	–	1.22	1960-2015	12	10	Highlight	Whole	Yes	No	No
Local species richness (PREDICTS)	91.1	-0.34	900-2014	53	18	Other	Whole	Yes	No	No
Mean Species Abundance index	76.1	-1.90	1850-2015	3	2	Other	Whole	Yes	No	No
Mean Species Abundance index (Hotspots)	64.7	-3.31	1850-2015	3	2	Other	Part	Yes	No	No
Mean Species Abundance index (Indigenous Lands)	85.5	-1.52	1850-2015	3	2	Other	Part	Yes	No	No
Tropical forest BII (hotspots)	60.1	-3.01	2001-2012	12	12	Core	Part	Yes	No	No
Tropical forest BII (Indigenous Lands)	68.1	-1.90	2001-2012	12	12	Core	Part	Yes	No	No
Tropical forest BII (overall)	61.7	-2.79	2001-2012	12	12	Core	Whole	Yes	No	No
Community composition - regional										
Bird species per grid cell (cSAR)	–	0.14	1910-2015	12	6	Other	Whole	Yes	No	No
Cumulative introduced invasive aliens	–	11.43	1500-2012	247	43	Highlight	Whole	Yes	No	No
Cumulative number of alien species	–	13.15	1970-2005	36	36	Other	Whole	Yes	No	No
Forest-specialist bird species per grid cell (cSAR)	–	-0.39	1910-2015	12	6	Other	Part	No	Yes	No
Functional intactness (Madingley)	–	-0.55	1901-2005	22	8	Other	Whole	Yes	No	No
Species richness per grid cell (AIM)	–	-0.02	1900-2015	3	2	Other	Whole	Yes	No	No
Species populations – species persistence										
BHI (species persisting) - Hotspots	87.3	-0.22	2005-2015	2	2	Core	Part	Yes	No	No
Biodiversity Habitat Index (species persisting)	91.5	-0.03	2005-2015	2	2	Core	Whole	Yes	No	No
Global bird richness (cSAR)	97.6	-0.12	1900-2015	13	6	Other	Whole	Yes	No	No
Global forest-specialist bird richness (cSAR)	94.9	-0.32	1900-2015	13	6	Other	Part	No	Yes	No
Global mammal & bird species remaning	98.6	-0.06	1500-2017	10	3	Highlight	Whole	Yes	No	No

Red List Index (overall)	74.6	-4.25	1994-2016	7	7	Core	Whole	Yes	No	No
RLI (forest specialists)	72.0	-1.08	1988-2016	8	8	Core	Part	No	Yes	No
RLI (internationally traded birds)	93.3	-0.28	1988-2016	8	8	Core	Part	No	No	Yes
RLI (pollinators)	90.2	-0.47	1988-2016	8	8	Core	Part	No	No	Yes
RLI (species used in food & medicine)	80.4	-1.70	1988-2012	6	6	Core	Part	No	No	Yes
RLI (wild relatives)	77.5	-0.80	1988-2016	8	8	Core	Part	No	No	Yes
Species populations – geographic distribution										
Extent of suitable habitat (mammals)	–	-5.43	1970-2010	2	2	Other	Whole	Yes	No	No
Mammalian range size	82.7	–	2008	1	1	Other	Whole	Yes	No	No
Megafaunal range size	27.7	–	2008	1	1	Other	Part	No	Yes	No
Species Habitat Index	–	-1.03	2001-2014	14	14	Core	Whole	Yes	No	No
Species populations – population size										
Fish stocks biologically sustainable	68.9	-6.23	1974-2013	19	19	Core	Whole	No	No	Yes
Living Planet Index (freshwater)	–	-19.13	1970-2014	45	45	Other	Part	Yes	Yes	No
Living Planet Index (marine)	–	-8.26	1970-2012	43	43	Other	Part	Yes	Yes	No
Living Planet Index (overall)	–	-13.76	1970-2014	45	45	Highlight	Whole	Yes	Yes	No
Living Planet Index (terrestrial)	–	-9.16	1970-2014	45	45	Other	Part	Yes	Yes	No
Predatory fish biomass	–	-14.12	1880-2010	4	3	Other	Whole	No	Yes	Yes
Prey fish biomass	–	10.13	1880-2010	4	3	Other	Whole	Yes	No	No
Wild Bird Index (habitat specialists)	–	-9.04	1968-2014	47	45	Other	Whole	No	Yes	No
Wild mammal biomass	17.5	–	2018	1	1	Other	Whole	No	No	Yes
Species traits										
Functional richness (Madingley)	–	-0.36	1901-2005	22	8	Other	Whole	Yes	No	No
Mammalian body mass	81.7	–	2009	1	1	Other	Whole	Yes	Yes	No
Marine Trophic Index	–	-0.93	1956-2014	59	45	Core	Whole	No	No	Yes

S 2.2.2 Indicators of ecosystem structure

S 2.2.2.1 Aboveground biomass

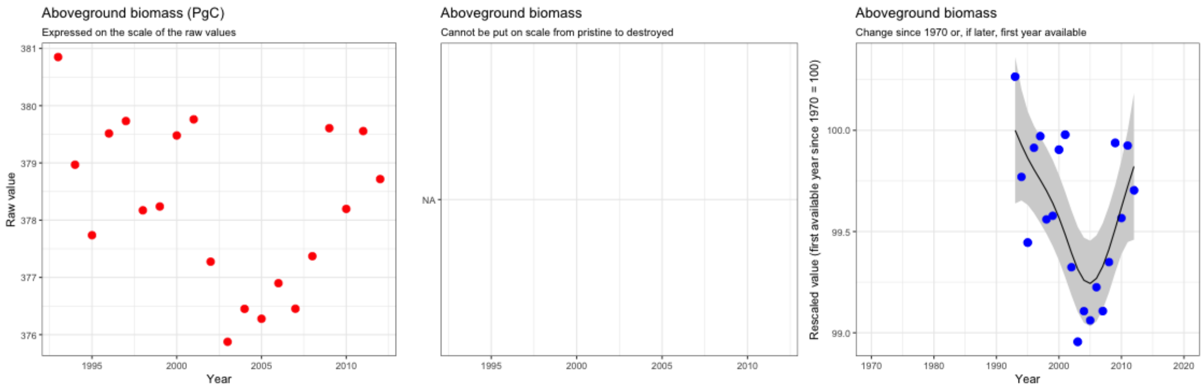
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator measures changes to biomass.
Indicator type: Representative, Underpin NCP
This indicator shows likely changes to the natural capital supported by aboveground biomass through the use of globally representative data.
Years covered: 1993-2012, annual time-steps

Aboveground biomass has shown a non-linear change since 1990, with a minimum in the mid-2000s followed by a partial recovery.

Overview

The trend in aboveground biomass shows how macroecological vegetation patterns have been altered by anthropogenic processes over time. Humans have directly altered aboveground biomass, harvesting trees and replacing forests with croplands, pasture and urban areas, but have also indirectly altered aboveground biomass through climate change. These changes are not only detrimental to terrestrial biodiversity but also to the ecosystem services that our natural vegetation provides.

Status and trend



Aboveground biomass status and trend. A) Total terrestrial aboveground biomass (PgC). B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 1993.

From 1993 to 2012 there was an overall decrease in global aboveground biomass but this was not distributed evenly across the globe with greater losses in tropical areas and overall gains in temperate areas (Liu et al. 2015). Since 2003 total global aboveground biomass has been recovering - this is due to declines in the rate of deforestation within the tropics, Russia and China along with wetter conditions leading to increased biomass in savannah regions (Liu et al. 2015). These gains have led to a low average rate of change per decade, but only show recent trends and estimates suggest that aboveground biomass is approximately half of that which would be expected in the absence of anthropogenic land-use change (Erb et al. 2017).

Sampling methodology and data selection

Aboveground biomass estimates are based upon satellite-based passive microwave data which are then calibrated against plot-based measurements of aboveground biomass (Liu et al. 2015). This methodology provides a global estimate of aboveground biomass which is able to distinguish variations even within areas of high biomass density, but at a relatively coarse spatial resolution (>10km) (Liu et al. 2015).

References

Liu, Y.Y., van Dijk, A.I.J.M., de Jeu, R.A.M., Canadell, J.G., McCabe, M.F., Evans, J.P., Wang, G., 2015, Recent reversal in loss of global terrestrial biomass. Nature Climate Change.5, 470-474.

S 2.2.2.2.Biodiversity Habitat Index (overall habitat integrity)

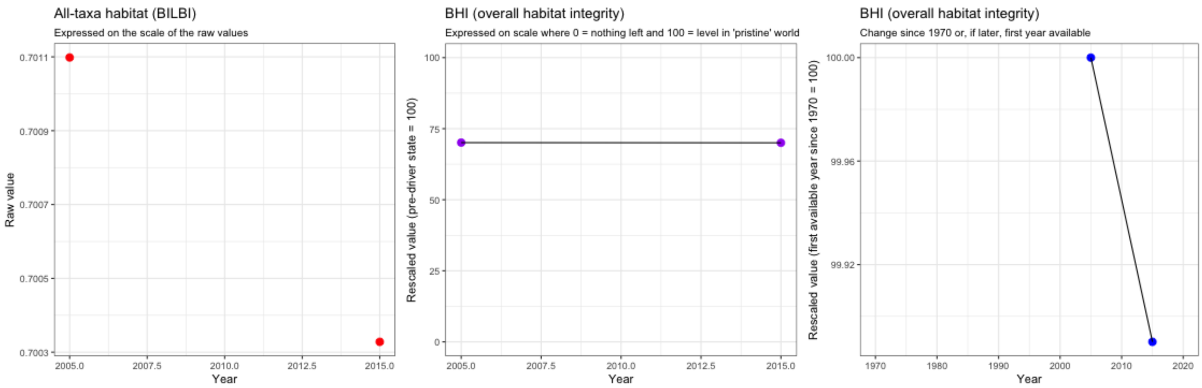
Indicator status: Core indicator
EBV class: Ecosystem structure
Measures habitat condition
Indicator type: Representative
Indicator uses global data sources for plant, invertebrate and vertebrate species
Years covered: 2005-2015, single time step

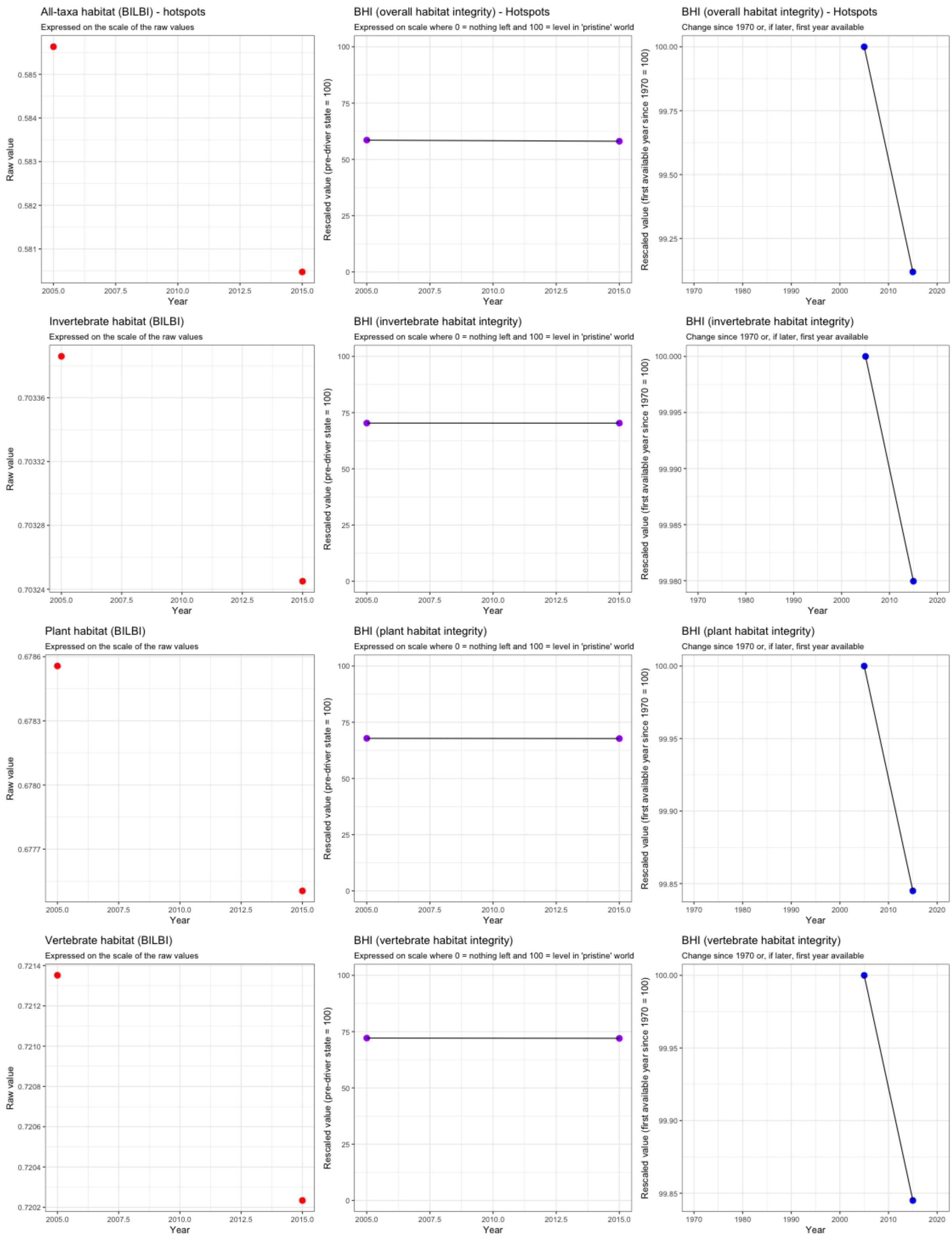
The Biodiversity Habitat Index reveals a downward trend and now stands at about 70% of its level in a pristine world.

Overview

The Biodiversity Habitat Index has been developed to provide data on global progress towards the reduction of habitat loss with relevance to Target 5 of the Aichi Targets. The index estimates the impacts of habitat loss and degradation on the retention of habitat for different assemblages of plant, invertebrate and vertebrate species, through the linkage of high resolution remotely-sensed datasets with ecological models.

Status and trend





Biodiversity Habitat Index (habitat integrity) status and trend. Top row: A) Modelled index data. B) Trendline for rescaled data where 100% represents pristine. C) Trendline for rescaled data showing change from 2005. Second row: as top row, but for land encompassed by the hotspots of endemic species. Third row: as top row, but for invertebrates only. Fourth row: as top row, but for plants only. Fifth row: as top row, but for vertebrates only.

Habitat loss and degradation has continued since 2005, resulting in a decrease in global habitat integrity. Habitat integrity decline is greater within hotspots of narrowly-distributed species. Habitat integrity is declining faster for plants and vertebrates than it is for invertebrates.

Sampling methodology and data selection

Hoskins et al. (2018) estimate the indicator of habitat extent and condition through the combination of fine-scale gridded data on the similarity of habitats and a habitat condition score assessed through tree cover data (Hansen et al. 2013). For each cell in the grid an estimate is derived of the proportion of habitat remaining across all cells that are ecologically similar to this cell of interest, using the technique of Allnutt et al. (2008). Ecological similarity between cells is predicted as a function of abiotic environmental surfaces (describing climate, terrain, and soils) scaled using generalised dissimilarity modelling (Ferrier et al. 2007) to reflect observed patterns of spatial turnover in species composition, based on best-available occurrence records for plants, vertebrates and invertebrates globally (Hoskins et al. 2018). The aggregate score of the BHI is calculated as a geometric mean of the proportion of habitat remaining, supporting relatively distinct assemblages of species, across different regions and environments globally (https://www.bipindicators.net/indicators/biodiversity-habitat-index).

References

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Ferrier, S., Manion, G., Elith, J., and Richardson, K., 2007. Using generalised dissimilarity modelling to analyse and predict patterns of beta-diversity in regional biodiversity assessment. Diversity and Distributions, 13, pp.252-264.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. Science, 342(6160), pp.850-853. Data available online from http://earthenginepartners.appspot.com/science-2013-global-forest.

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S 2.2.2.3 Coastal protection habitats

Indicator status: Other indicator
EBV class: Ecosystem structure

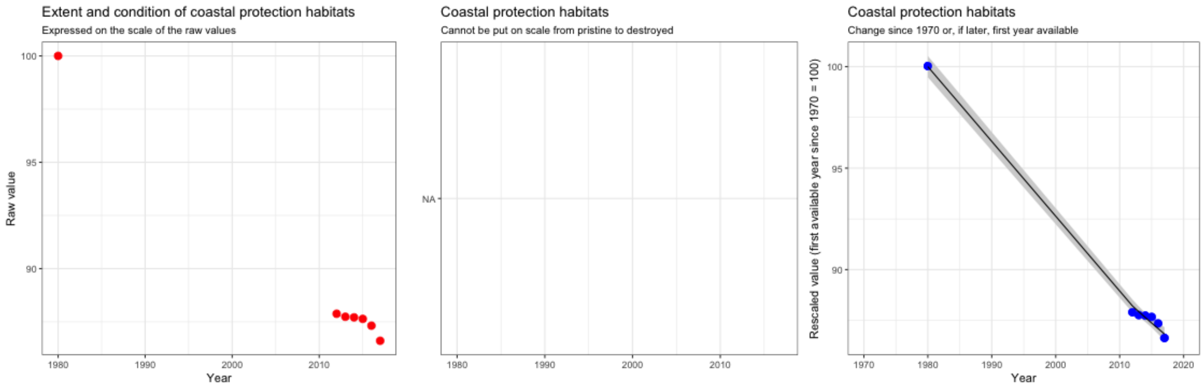
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Representative/Fundamental/Sensitive/Underpin NCP
This indicator provides information on various components of importance - it is representative of habitats throughout the globe, many of the habitats it tracks are particularly sensitive as well as being particularly important sources of natural capital
Years covered: 1980-2017, single time-step before 2012

The coastal protection habitat score has decreased since 1980, indicating that the habitats assessed by this indicator have decreased in condition or extent.

Overview

This indicator assesses the condition and extent of habitats that protect our coastal areas against storm damage. This ecosystem service is vitally important for the health and economy of coastal communities but the habitats assessed (mangrove forests, seagrass meadows, salt marshes, tropical coral reefs and sea ice) not only provide protection against storms but contain high levels of biodiversity, for instance, coral reefs alone support 25% of all marine life (www.oceanhealthindex.org).

Status and trend



Coastal protection habitats: status and trend. A) Index value for extent and condition of coastal protection habitats in 1980 (baseline) and from 2012 to 2017. B) Trendline not possible as Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 1980.

The current day score is 87, indicating a drop from the baseline score assessed in 1980.

Sampling methodology and data selection

The Coastal Protection Habitats score assesses change in habitat condition and extent of targeted coastal habitats since the early 1980’s (with the exception of sea ice, which is compared with the average extent from 1979-2000). The score is compiled within the Ocean Health Index framework from a range of datasets covering four dimensions: status (current value compared to reference point), trend (average percent change over the most recent five years), pressures (ecological and social factors that decrease status), and resilience (ecological factors and social initiatives that increase status). Status and Trend comprise 83% of the goal score and Pressures and Resilience each contribute 8.5%. This indicator draws together a large range of data sources to provide a complete picture of how coastal protection habitats have been altered over time. However, the computation of this compound indicator is complex and relies upon the comparison of disparate data sources collected using different methodologies within different areas. For instance, to calculate the change in coral reef extent, present-day coral reef extent was taken from Burke et al. (2011) and compared against two datasets detailing coral reef cover in 1975: Bruno & Selig (2007) report on Indo-Pacific coral reef cover, and Schutte et al. (2010) report on Caribbean coral reef cover. Coral reef condition was also extracted from these papers although they measured different metrics of condition.

S 2.2.2.3.1 Subset: Coastal carbon-rich habitat

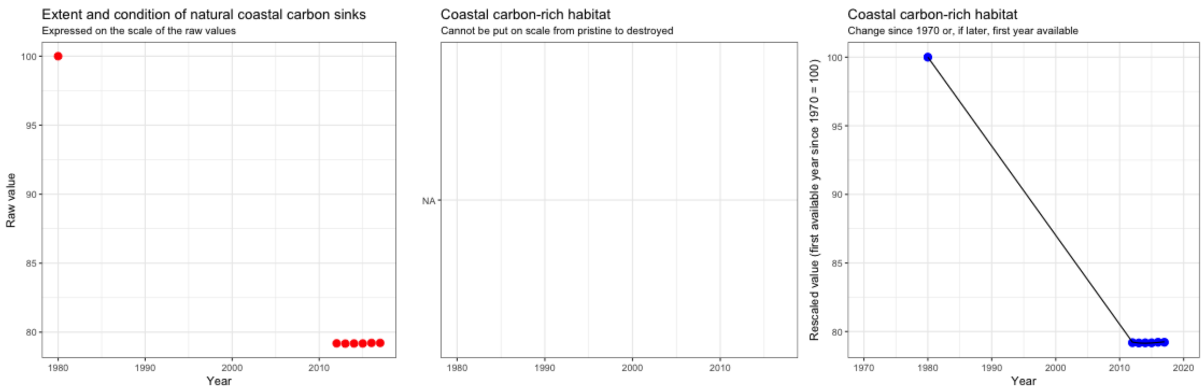
Indicator status: Other indicator
EBV class: Ecosystem structure
Measures the extent and condition of habitats able to store carbon
Indicator type: Representative/Sensitive/Underpin NCP
This indicator is based upon globally representative data targeted at habitats that are known to be both sensitive and direct contributors to climate regulation through carbon sequestration.
Years covered: 1980-2017, single time-step before 2012

The coastal carbon-rich habitat score has decreased since 1980, indicating that the habitats assessed by this indicator have decreased in condition or extent.

Overview

Similar to the Coastal Protections Habitat score (of which it is a subset), this indicator is taken from the Carbon Storage score compiled by the Ocean Health Index. The score is based upon the current extent and condition of CO_2 storing habitats in the marine realm, here defined as mangrove forests, seagrass meadows and salt marshes. These habitats provide a range of ecosystem services and also support high levels of biodiversity.

Status and trend



Coastal carbon-rich habitats: status and trend. A) Index value for extent and condition of coastal protection habitats in 1980 (baseline) and from 2012 to 2017. B) Trendline not possible Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 1980.

The most recent score (2017) is 79, indicating a drop from the baseline score of 100 inferred for 1980.

Sampling methodology and data selection

The Coastal Carbon-Rich Habitats indicator is based upon the Carbon Storage score of the Ocean Health Index (www.oceanhealthindex.org). This score assesses change in habitat condition and extent of targeted coastal habitats since 1980. The score is compiled within the Ocean Health Index framework from a range of datasets covering four dimensions: status (current value compared to reference point), trend (average percent change over the most recent five years), pressures (ecological and social factors that decrease status), and resilience (ecological factors and social initiatives that increase status). Status and Trend comprise 83% of the goal score and Pressures and Resilience each contribute 8.5%. This indicator draws together a large range of data sources to provide a complete picture of how carbon storage habitats have been altered over time. However, the computation of this compound indicator is complex and relies upon the comparison of disparate data sources collected using different methodologies within different areas. For instance, present-day mangrove extent was based on methods described in Hamilton & Casey (2016), but then FAO data was utilized to calculate extent for the years 1980, 1990, 2000 and 2005 (FAO 2007) and data described in Giri et al. (2011) was used to calculate extent in 2010.

References

Burke, L, Reytar, K., Spalding, M., Perry, A., 2011, Reefs at Risk Revisted. WRI, Washington.

Bruno, J.F., Selig, E.R., 2007, Regional decline of coral cover in the Indo-Pacific: Timing, extent and subregional comparisons. PLoS ONE, 2(80, e711.
Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J., Duke, N. 2010, Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography, 20(1), 154-159.

Hamilton, S., Casey, D., 2016, Creation of a high spatiotemporal resolution global database of continuous mangrove forest cover for the 21st Century (CGMFC-21).Global Ecology and Biogeography, 25(6), 729-738.

Schutte, V.G.W., Selig, E.R., Bruno, J.F., 2010, Regional spatio-temporal trends in Caribbean coral reef benthic communities. Marine Ecology Progress Series, 402, 115-122.

www.oceanhealthindex.org/methodology/goals/carbon-storage

www.oceanhealthindex.org/methodology/goals/coastal-protection

S 2.2.2.4 Extent of forests

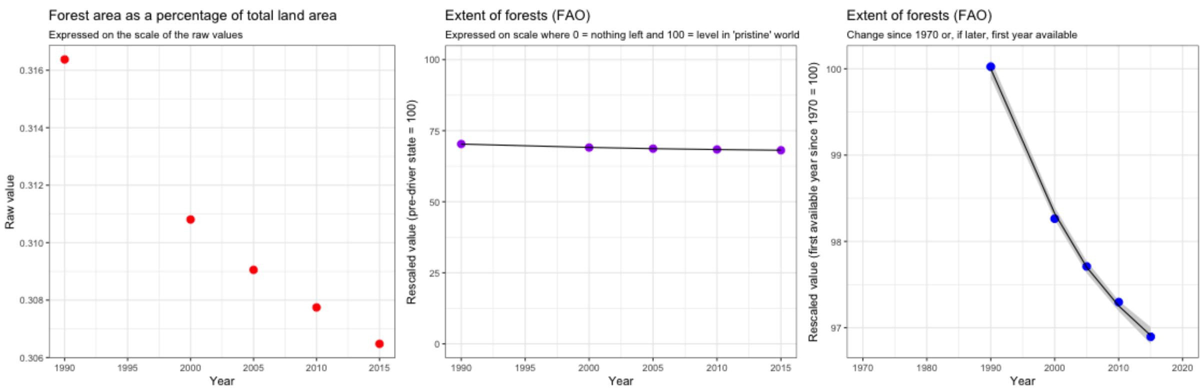
Indicator status: Core indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Underpin NCP
Forests provide many services including carbon sequestration, timber, water and soil management and cultural services.
Years covered: 1990-2015, 5-year time steps from 2000

The extent of natural forests, based on an aggregation of national statistics, shows that forest area has declined since 1990 but the rate of loss has slowed.

Overview

The extent of forests dataset provides an indication of the area of forests which are not managed for timber or agricultural extraction. This is in contrast to other forest extent indicators based on remote-sensed data such as the Extent of Intact Forest Landscapes or the Extent of Forests (remote sensing). This indicator measures the trends in the conversion of natural or recovering forest to anthropogenic land uses. The removal of forested land not only impacts forest biodiversity, especially as the majority of forest removal occurs in high biodiverse tropical areas, but also threatens the vital ecosystem services that forests supply such as carbon capture, prevention of soil and coastal erosion, provision of goods, and hydrological management.

Status and trend



Extent of forests: status and trend. A) Forest area as a proportion of total land area. B) Trendline for rescaled data where 100% represents the estimated pre-industrial extent (FAO 2012). C) Trendline for rescaled data showing change since 1990.

Forest area has declined since 1990 but the rate of loss has slowed, with current rates (2005-2015) approximately half of those experienced in the 1990-2000 assessment period. (http://www.fao.org/sustainable-development-goals/indicators/forestarea). Comparison of the extent of forest area with the estimated pre-industrial extent (FAO 2012), reveals that human activities have decreased global forest area by nearly one third, from 45% of the total land area to less than 31%. This indicator compiles area of natural habitat at the national level and cannot provide information on landscape-level influences such as fragmentation. Land can have considerable loss (or gain) of trees and habitat fragmentation (or restoration) while still being classified as forest in this indicator (see definition below), making this indicator likely to be less sensitive to changes than either tree cover or the extent of intact forest landscapes.

Sampling methodology and data selection

According to the FAO definitions, forest is defined as: "land spanning more than 0.5ha with trees higher than 5m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use". Data for this indicator is submitted by nations to the FAO. This indicator provides one of the few global datasets which is able to exclude tree plantations from its totals as the data is collected directly from nations, and does not rely upon remote-sensed data. However, this reliance upon data from nations results in incomplete data coverage. Although 234 nations have been included in the most recent FAO report (FAO 2016) the national-level reporting is patchy, resulting in missing data. For instance, in the dataset compiled for the 2015 report, 79 of the 234 countries had missing data. When a nation's data is missing the indicator is calculated using the last-reported data or data compiled from literature searches. Another weakness with the methodology is that even if a nation provides data at regular intervals, it is possible that the national-level data is out of date or highly estimated.

References

http://www.fao.org/sustainable-development-goals/indicators/forestarea

FAO, 2012, State of the World's Forests 2012. FAO, Rome.

FAO, 2016, Global Forest Resources 2015. FAO, Rome.

S 2.2.2.5 Extent of intact forest landscapes

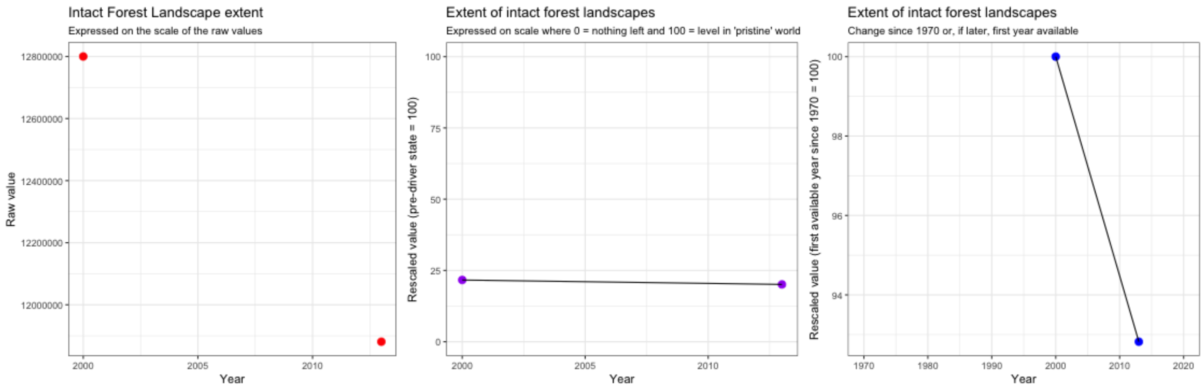
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Sensitive
Intact forest landscapes are inherently sensitive because a localised disturbance reduces their extent by far more than the extent of the disturbance
Years covered: 2000-2013, single time step

Few intact forest landscapes remain, and losses continue.

Overview

Intact forest landscapes, areas with no signs of human activity, provide refuge to biodiversity but also provide a variety of ecosystem services, including the stabilization of terrestrial carbon storage, and the regulation of hydrological regimes. This indicator measures the removal of intact landscapes through the removal of habitat or through fragmentation. The minimum intact area unit is 500km^2 as smaller areas, even if pristine, have lower resilience to natural disturbance and the effect of climate change and less potential for preserving wide-range species (Potapov et al. 2017).

Status and trend



Intact forest landscapes: status and trend. A) Total area of intact forest landscapes in 2000 and 2013. B) Trendline for rescaled data where 100% represents the area of all forested biomes (Olson et al. 2001). C) Trendline for rescaled data showing change since 2000.

The extent of intact forest landscapes has decreased by 7.2% since 2000. 52% of the loss was concentrated in just three countries (Russia, Canada and Brazil) with the majority of decline due to industrial logging, agricultural expansion, fire and mining/resource extraction.

Sampling methodology and data selection

Potapov et al. (2017) compiled a map of forest landscapes using remote-sensed data where a forest landscape was considered to be present if at least 20% of a 30m x 30m grid cell was forested in 2000 (Hansen et al. 2013). This threshold allows for ‘natural’ non-forested areas within forested landscapes. Areas were then removed from this forest landscape map if there were remotely-sensed indications of habitat alteration (such as agriculture, logging or mining) or fragmentation (areas within 1km of all infrastructure were removed). An IFL patch must have (i) a minimum size of 500 km^2, (ii) a minimum width of 10 km, and (iii) a minimum corridor/appendage width of 2 km (Potapov et al. 2017). Note that landscapes classed as IFL may nonetheless have longstanding and ongoing influence and management by IPLC.

References

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Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., Kassem, K. R. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51(11):933-938.

Potapov, P., Hansen, M. C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., … Esipova, E., 2017. The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. 6208 Science Advances, 3(1), e1600821. http://doi.org/10.1126/sciadv.1600821

S 2.2.2.6 Extent of marine wilderness

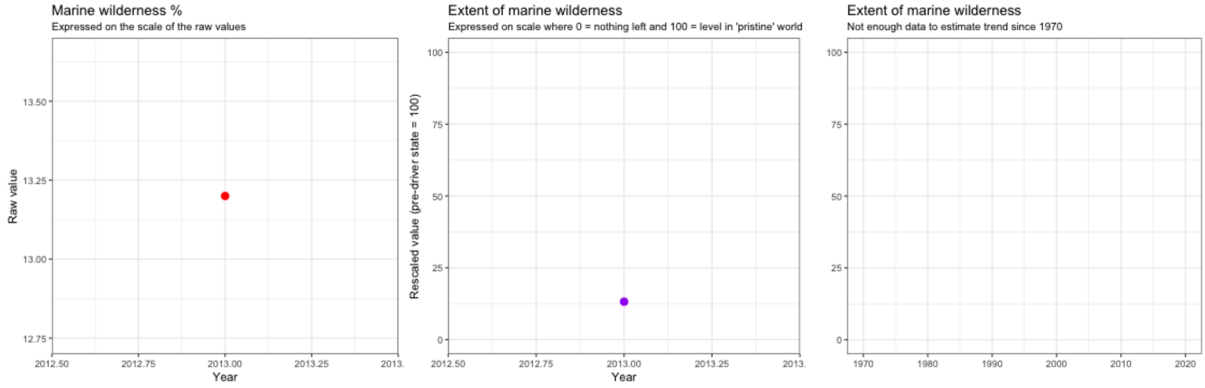
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation
Indicator type: Sensitive
This indicator highlights the extent of human encroachment into the marine realm
Years covered: 2013

Only 13% of the world's oceans can be classified as essentially free from human disturbances.

Overview

Humanity has encroached upon the marine realm for millennia through the harvesting of marine life for food as well as the transport of passengers and cargo. We have also inadvertently impacted marine life through pollution, climate change, the construction of benthic structures, and the introduction of alien species. This indicator measures the extent of our encroachment upon our oceans through the identification of areas that are mostly free from such human disturbances. These areas may provide vital refugia in which functional and genetic diversity are sustained and sensitive or endemic species are conserved (Jones et al. 2018).

Status and trend



Extent of marine wilderness: status and trend. A) Extent of marine wilderness. B) Extent of marine wilderness on a scale where 100% represents a world in which all ocean is wilderness. C) No trendline data available.

The extent of marine wilderness reveals that only approximately 13.2% of our oceans remain mostly free from human disturbances. This equates to around 55 million km^2 located mostly at the poles or in the high seas of the southern hemisphere (Jones et al. 2018). Temperate regions are the most extensively impacted, with over 99% of the realm experiencing human disturbance in realms such as the temperate northern

Atlantic, the temperate northern Pacific, and the temperate southern Africa (Jones et al. 2018).

Sampling methodology and data selection

Gridded maps of 15 human stressors including fishing, shipping, benthic structures, invasive species, pollution, and direct impacts were compiled by Jones et al. (2018). For each stressor, grid cell values were normalised and rescaled from 0-1. Potential marine wilderness areas were identified as those grid cells that scored within the bottom 10% for all of the 15 stressors. A further four stressors were assessed pertaining to climate change impacts (sea surface temperature anomalies, UV radiation, ocean acidification, and sea level rise) and a cumulative impact score across all 19 stressors was calculated. Only those cells which scored within the bottom 10% for all 15 stressors as well as scoring within the bottom 10% for the cumulative impact score were included in the final selection.

References

Jones, K.R, Klein, C.J., Halpern, B.S., Venter, O., Grantham, H., Kuempel, C.D., Shumway, N., Friedlander, A.M., Possingham, H.P., and Watson, J.E.M. 2018. The Location and Protection Status of Earth's Diminishing Marine Wilderness. *Current Biology*, 28(15): 2506-2512.e3, https://doi.org/10.1016/j.cub.2018.06.010.

S 2.2.2.7 Extent of terrestrial wilderness

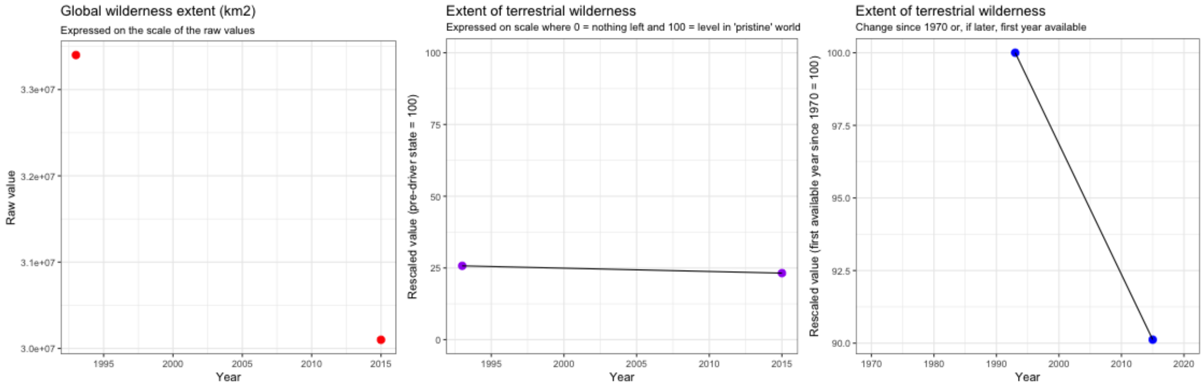
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Sensitive
Extent of remaining wilderness is a sensitive indicator because of how wilderness is defined: a single road can reduce the extent of wilderness by very many times more than the area of the road itself.
Years covered: 1993-2015, single time step

The extent of terrestrial wilderness areas has fallen by 3.3 million km^2 in the last two decades - such dramatic losses may threaten intrinsically sensitive specialist species and compromise NCPs.

Overview

Wilderness areas are defined as areas where natural ecological and evolutionary processes operate with minimal human disturbance (Watson et al. 2016). Such areas gather little attention from international conservation bodies yet such areas may provide vital refugia to sensitive species as well as underpinning ecosystem services such as carbon storage and sequestration, and climate regulation. Such areas are relatively untouched yet may still provide shelter and food to indigenous communities. This indicator was first calculated in 1993 and has recently been updated to examine how wilderness extent has changed over the last two decades.

Status and trend



Extent of terrestrial wilderness: status and trend. A) Total area of remaining wilderness for 1993 and 2015. B) Trendline for rescaled data where 100% represents a pristine world (data on pristine area from Watson et al. 2016). C) Trendline for rescaled data showing change since 1970.

The extent of remaining wilderness has fallen by 3.3 million km^2 since 1993. Although the extent of loss is vast, the loss is minimal compared to that which occurred prior to 1993 where it is estimated that approximately three quarters of all wilderness areas were removed. Such loss represents a global decrease of about 10% over the 12 years, but some regions have experienced much greater losses; for instance, the wilderness areas in the Amazon have decreased by 30% (Watson et al. 2016).

Sampling methodology and data selection

The extent of remaining wilderness is calculated using an analysis of eight pressure layers: built environments, intensive agriculture, pasture lands, human population density of greater than 4 people per km^2, night time lights, and roads, railways and navigable waterways (Watson et al. 2016). The presence of any of these pressures discounted the 1km^2 grid cell for inclusion as wilderness. This is a more repeatable definition, and applied at a finer spatial scale, that that applied by Mittermeier et al. (2003), who estimated that 44% of the world's land surface could still be termed wilderness. Note that land classed as wilderness by this definition may still have been influenced by longstanding use and management by Indigenous Peoples and local communities.

References

Mittermeier, R. A., Mittermeier, C. G., Brooks, T. M., Pilgrim, J. D., Konstant, W. R., da Fonseca, G. A. B., & Kormos, C. (2003). Wilderness and biodiversity conservation. Proceedings of the National Academy of Sciences of the United States of America, 100(18), 10309-10313. Retrieved from <Go to ISI>://WOS:000185119300033. doi:10.1073/pnas.1732458100

Watson, J.E.M, Shanahan, D.F., Di Marco, M., Allan, J., Laurance, W.F., Sanderson, E.W., Mackey, B., Venter, O., (2016) Catastrophic Declines in Wilderness Areas Undermine Global Environment Targets, Current Biology 26:21, 2929-2934.

S 2.2.2.8 Fraction of ocean not fished per year

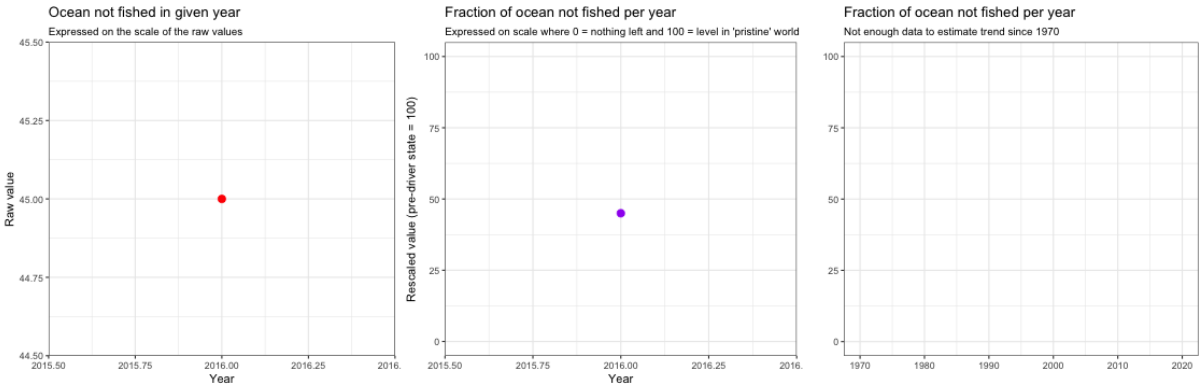
Indicator status: Other indicator
EBV class: Ecosystem structure
Fraction of ocean not fished measures fundamental changes to ecosystems
Indicator type: Representative/Sensitive
This indicator is based upon extensive global datasets and is sensitive because any fishing detected within an 0.5º grid cell means that cell is classed as fished.
Years covered: 2016

We are removing fish on an industrial scale from over half of the surface area of our oceans each year – a spatial extent that is four times greater than that of agriculture.

Overview

The natural resources of our seas have been harvested for millennia and fishing is significant for humanity not only as a food source, but also through our cultural ties with fishing and the sea. Fishing activity has traditionally been monitored through records kept in vessel logbooks and landed catch registers; however, data is open to under-recording or misrecording especially when areas beyond national jurisdiction are harvested or catches are landed in countries with lax reporting. This indicator provides data gathered using a technological advance in quantifying fishing effort - the use of the automatic identification system (AIS).

Status and trend



Fraction of ocean not fished per year: status. A) The fraction of ocean not fished in 2016. B) Percentage of ocean not fished in 2016 (100% corresponds to a world without any ocean fishing). C) No trendline data available.

Industrial fishing boats are harvesting fish from at least 55% of the surface area of our oceans. However, this number could be as much as 70% due to the presence of zones with low AIS reception or use (Kroodsma et al. 2018). Even when using the most conservative estimates, the spatial extent of fishing is currently four times greater than that of agriculture.

Sampling methodology and data selection

The indicator is based on 22 billion AIS positions broadcast from 70 000 fishing vessels across the world between 2012 and 2016 (Kroodsma et al. 2018). Using convolutional neural networks vessel type and activity were characterised. Vessels were recorded in 55% of the ocean in 2016 using a grid size of about 55km on a side, or 0.5^o at the equator. The grid size was chosen to reflect the area of the ecosystems providing fish. The area physically swept by fishing gear (such as trawlers or longlines) is very much less, meaning that analysis conducted at a smaller spatial grain would inevitably estimate a much lower fraction as being fished (e.g., only around 4% of 1km^2 cells are fished in a given year: Amoroso et al. 2018). However, a larger extent would be estimated if all fishing vessels were required to carry broadcast AIS signals; likewise, some areas of the ocean did not have sufficient satellite coverage to use AIS.

References

Amoroso, R. O., Parma, A. M., Pitcher, C. R., McConnaughey, R. A., & Jennings, S. (2018). Comment on “Tracking the global footprint of fisheries”. Science, 361(6404), eaat6713. Retrieved from http://science.sciencemag.org/content/361/6404/eaat6713.abstract.

Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A.., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C., Worm, B., 2018, Tracking the global footprint of fisheries, Science, 359(6378), 904-908.

S 2.2.2.9 Land not cultivated or urban

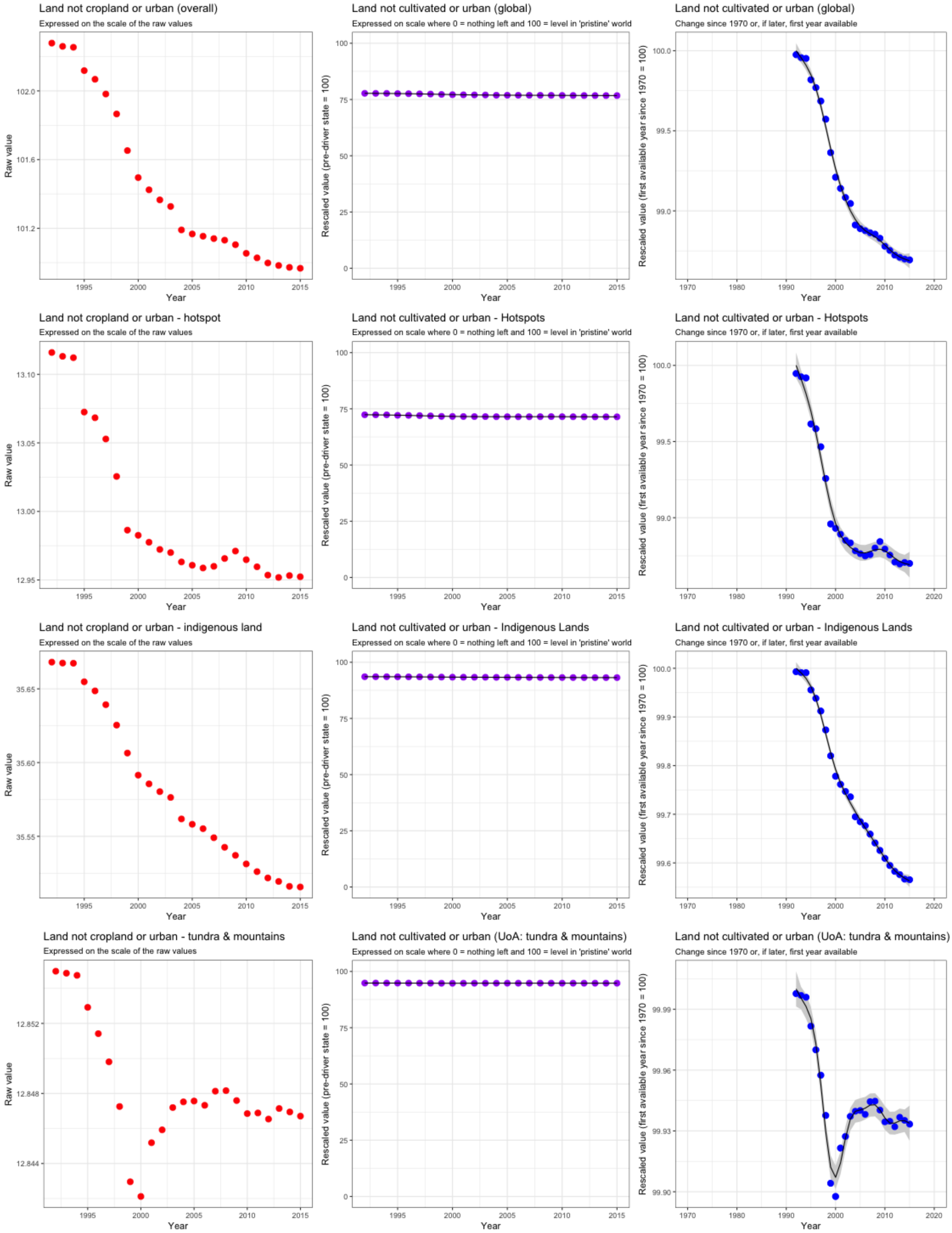
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Representative
This indicator is based upon global data sets representative of most terrestrial areas in the world.
Years covered: 1992-2015, annual time-steps

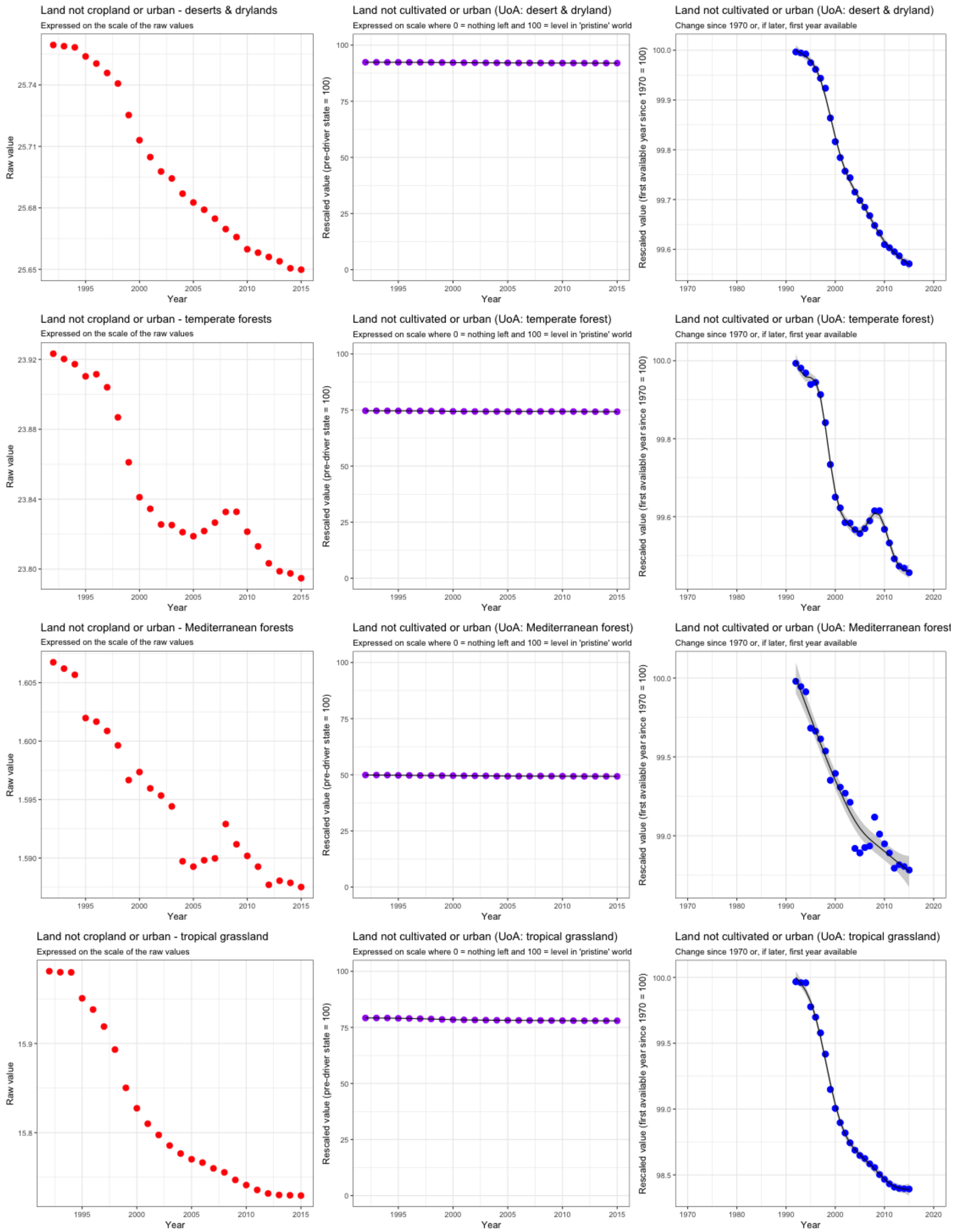
The fraction of land not cultivated or urban is decreasing slowly throughout the world but rates are variable between regions, with more rapid loss seen within Temperate Grasslands and Tropical Forests.

Overview

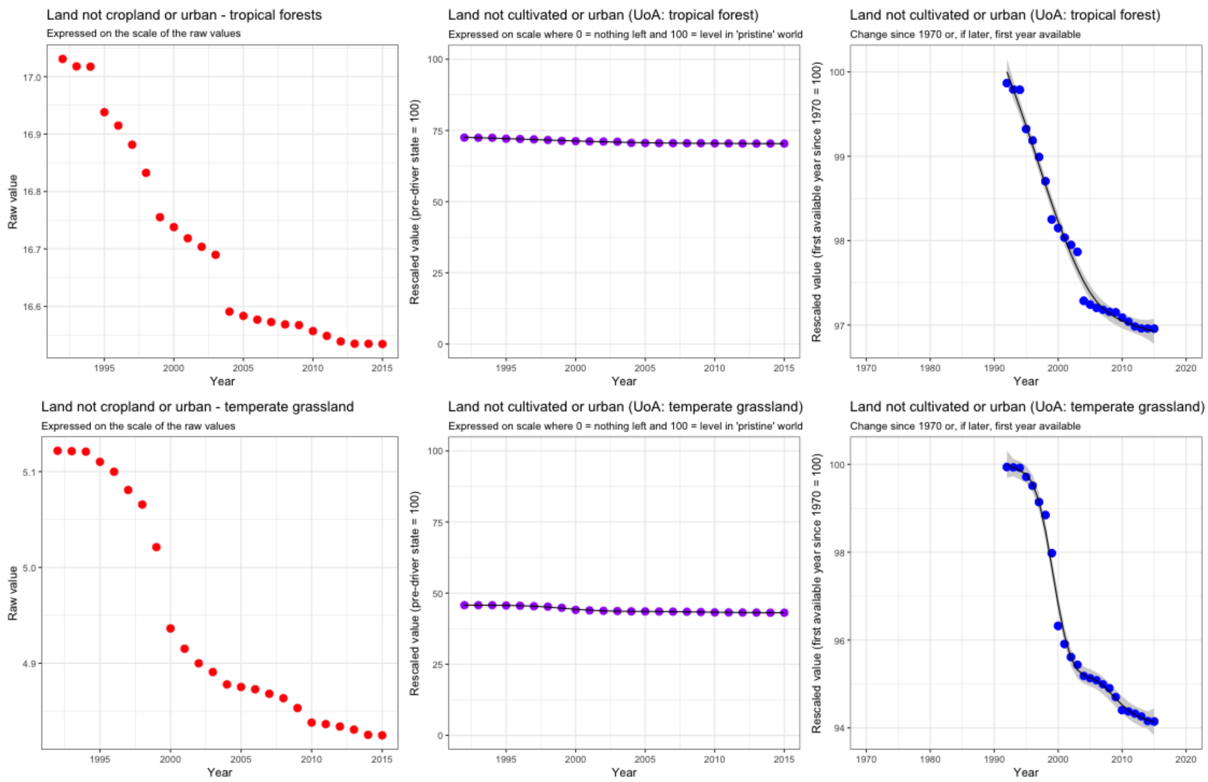
Land not cultivated or urban shows the remaining fraction of land that is not in either the cultivated or urban ‘anthromes’; not all of this land would be viewed as ‘natural’ (e.g., permanently grazed land). This indicator is provided at the global scale but is also calculated and plotted for each of the ‘natural’ terrestrial Natural Units of Analysis: Tundra & Mountains, Desert & Dryland, Temperate Forest, Mediterranean Forest, Tropical Grassland, Tropical Forest, and Temperate Grassland.

Status and trend





Land not cropland or urban - deserts & drylands
Expressed on the scale of the raw values
Raw value
Year
Land not cultivated or urban (UoA: desert & dryland)
Expressed on scale where 0 = nothing left and 100 = level in 'pristine' world
Rescaled value (pre-driver state = 100)
Year
Land not cultivated or urban (UoA: desert & dryland)
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
Year
Land not cropland or urban - temperate forests
Expressed on the scale of the raw values
Raw value
Year
Land not cultivated or urban (UoA: temperate forest)
Expressed on scale where 0 = nothing left and 100 = level in 'pristine' world
Rescaled value (pre-driver state = 100)
Year
Land not cultivated or urban (UoA: temperate forest)
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
Year
Land not cropland or urban - Mediterranean forests
Expressed on the scale of the raw values
Raw value
Year
Land not cultivated or urban (UoA: Mediterranean forest)
Expressed on scale where 0 = nothing left and 100 = level in 'pristine' world
Rescaled value (pre-driver state = 100)
Year
Land not cultivated or urban (UoA: Mediterranean forest
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
Year
Land not cropland or urban - tropical grassland
Expressed on the scale of the raw values
Raw value
Year
Land not cultivated or urban (UoA: tropical grassland)
Expressed on scale where 0 = nothing left and 100 = level in 'pristine' world
Rescaled value (pre-driver state = 100)
Year
Land not cultivated or urban (UoA: tropical grassland)
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
Year



Land not cultivated or urban: status and trend. Top row: A) Fraction of global land not cultivated or urban. B) Trendline for global rescaled data where 100% represents a pristine world. C) Trendline for rescaled data showing global change since 1992. Subsequent rows plot the same quantities for different subsets of land, as follows. Second row: hotspots of narrowly-distributed species. Third row: Indigenous lands. Fourth row: Arctic and mountain tundra. Fifth row: Deserts and xeric shrublands. Sixth row: Boreal and temperate Forest. Seventh row: Mediterranean forests, woodlands and scrub. Eighth row: Tropical and subtropical savannas and grasslands. Ninth row: Tropical & subtropical dry and humid forest. Tenth row: Temperate grasslands.

All units of analysis show reductions in the fraction of land not cultivated or urban since 1992 but higher rates of alteration are observed within Temperate Grasslands and Tropical Forests compared with other Units of Analysis. Temperate Grasslands also have the greatest fraction of alteration with over 55% of natural land lost to cultivation or urbanisation.

Sampling methodology and data selection

The land not cultivated or urban indicator is based upon land cover maps produced by the European Space Agency (ESA CCI LC version 2.0). The maps are derived from the Medium Resolution Imaging Spectrometer (MERIS), Advanced Very High Resolution Radiometer (AVHRR) and PROBA-V surface Reflectance at a 300m resolution. Areas defined as agricultural (i.e. raster class 10, 20, 20, and 40) or urban (i.e. raster class 190) were subtracted from the total terrestrial area for each unit of analysis. This dataset is derived from high resolution remote-sensed imagery which can accurately identify changes in land cover over time, producing a truly global map of change; however, it is difficult to obtain land use information from such data. For instance, the agricultural land use categories used to calculate the agricultural area include mosaics of natural and non-natural land as well as areas which may or may not be natural (for example the ESA category of *Tree or shrub cover*). The dataset also cannot distinguish between tree plantations and natural forest, nor can it distinguish between secondary vegetation and pristine. Note also that cultivated land does not include grazing land.

References

ESA, 2017, Land Cover CCI PRODUCT USER GUIDE VERSION 2.0. European Space Agency: Paris, France.

S 2.2.2.10 Leaf Area Index

Indicator status: Other indicator
EBV class: Ecosystem structure
Indicator reveals changes in the structural properties of vegetation
Indicator type: Representative
The indicator is produced using global satellite data
Years covered: 1982-2011, annual time-steps

On average, between 1982 and 2011 the leaf area index increased globally but with wide regional variation indicating widespread change to the structure of vegetation; the largest increases were in the middle and northern high latitudes.

Overview

Leaf area index is defined as half of the total one-sided leaf area per unit ground surface area (Chen and Black, 1992). It is an important structural property of vegetation, as processes such as evapotranspiration and gross photosynthesis are directly proportional to it (Fang and Liang, 2014). Vegetation is changing globally and this change can have hydrological, climatic and ecological impacts, among many others. This indicator examines global temporal variation in vegetation structure using satellite remote sensed data.

Status and trend

Leaf area index: status and trend. A) Leaf area index. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 1982.

From 1982 to 2011 there was an overall increase in leaf area index across the globe although year on year the trend was not always positive. The more pronounced annual fluctuations could be attributed to widespread weather patterns, such as the El Niño-Southern Oscillation events, as well as stochastic events such volcanic eruptions (Zhu et al. 2013). However, the globally aggregated number hides stark regional variations with the largest increases occurring in the middle and northern high latitudes (north of 30°N) (Liu et al. 2010).

Sampling methodology and data selection

A 30-year-long leaf area index dataset was estimated with an algorithm trained on Global Inventory Modeling and Mapping Studies (GIMMS) Normal Difference Vegetation Index (NDVI) based on NOAA AVHRR data and leaf area index products based on Terra Moderate Resolution Imaging Spectroradiometer (MODIS) for the years 2000-2009 (Zhu et al. 2013). All continents except Antarctica are included in the analysis. Global mean leaf area index was obtained by averaging all pixels with non-zero leaf area index.

References

Chen, J.M. and Black, T.A. 1992. Defining leaf area index for non-flat leaves. Plant, Cell and Environment, 15(4): 421–429.

Fang, H. and Liang, S. 2014. Leaf Area Index Models. Reference Module in Earth Systems and Environmental Sciences, Available at: https://www.sciencedirect.com/science/article/pii/B978012409548909076X. [Accessed: 11/10/2018].

Liu, S., Liu, R., & Liu, Y. (2010). Spatial and temporal variation of global LAI during 1981–2006. Journal of Geographical Sciences, 20(3), 323–332.

Zhu, Z., Bi, J., Pan, Y., Ganguly, S., Anav, A., Xu, L., Samanta, A., Piao, S., Nemani, R.R., and Myneni, R.B. 2013. Global data sets of vegetation leaf area index (LAI)3g and fraction of photosynthetically active radiation (FPAR)3g derived from Global Inventory Modeling and Mapping Studies (GIMMS) Normalised Difference Vegetation Index (NDVI3g) for the period 1981 to 2011. Remote Sensing 5(2): 927-948.

S 2.2.2.11 Mangrove forest area

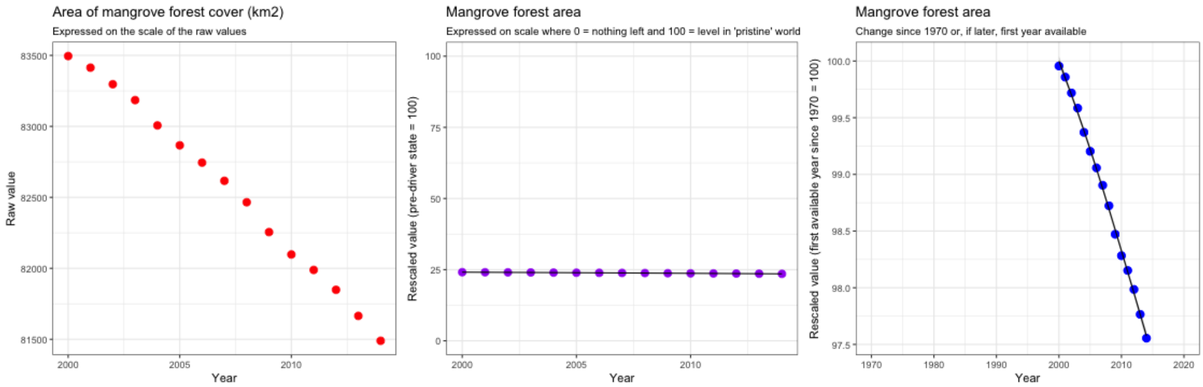
Indicator status: Other indicator
EBV class: Ecosystem structure
Indicator shows ecosystem extent and fragmentation
Indicator type: Representative/Sensitive
The indicator is drawn from global remote-sensed data that monitors a particularly vulnerable ecosystem
Years covered: 2000-2014, annual time steps

Deforestation and other pressures have steadily reduced the extent of mangrove forests since monitoring began 16 years ago.

Overview

Area of mangrove forest cover (km^2) provides a standardized spatial dataset that monitors mangrove cover globally at high spatiotemporal resolution. These data can be used to improve monitoring of mangrove carbon stocks and establish baseline local mangrove forest inventories required for payment for ecosystem service initiatives such as REDD+ or the voluntary carbon market. This indicator can also be used to drive the mangrove research agenda, particularly around monitoring of mangrove carbon stocks and the establishment of baseline local mangrove forest inventories required for payment for ecosystem service initiatives (Hamilton and Casey 2016). As data is derived from global remotely sensed products with high spatio-temporal granularity, data can be accurately compared across countries and regions. However, there is potential for errors of commission, where non-mangrove trees are incorrectly recorded as mangrove, and errors of omission, where mangrove trees exist but are not recorded. Mangrove trees less than 5m tall are not included in these data.

Status and trend



Mangrove forest area: status and trend. A) Area of mangrove forest cover. B) Trendline for rescaled data where 100% represents a pristine world, here taken to be the area of the mangrove biome (Olson et al. 2001). C) Trendline for rescaled data showing change from a 1970 baseline.

The area of mangrove forest cover has declined since monitoring began with rates of loss between 0.16% and 0.39% per year (Hamilton & Casey 2016). There are substantial regional differences, and Southeast Asia is of particular concern as it contains nearly half of the world's mangroves and is undergoing deforestation rates of between 3.58% and 8.08% per year (Hamilton & Casey 2016).

Sampling methodology and data selection

The Global Forest Change database, the Terrestrial Ecosystems of the World database and the Mangrove Forests of the World database were synthesized to extract mangrove forest cover at high spatial and temporal resolutions. The new database was then used to monitor mangrove cover at global and sub-global scales.

References

Hamilton, S.E. & Casey, D., 2016. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). Global Ecology and Biogeography doi: 10.1111/geb.12449.

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., Kassem, K. R. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51(11):933-938.

S 2.2.2.12 Natural habitat extent

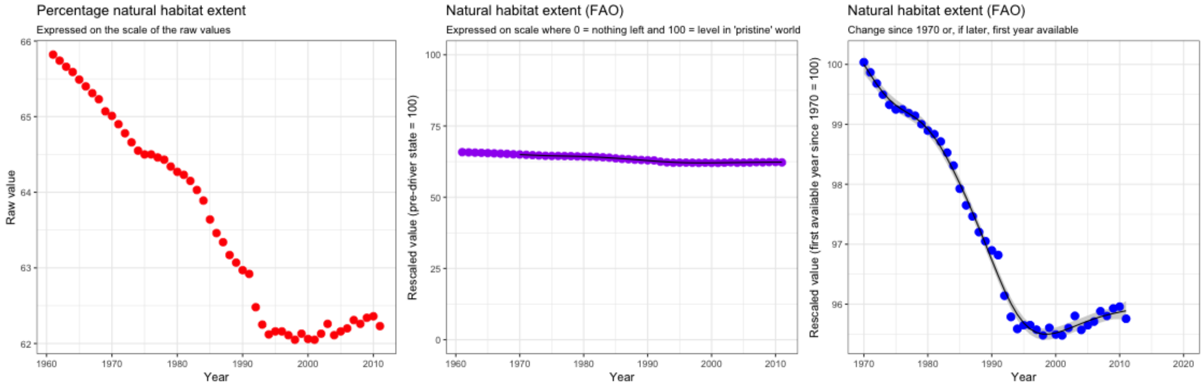
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation
Indicator type: Representative/Fundamental
This indicator uses global data on changing land use over time. Natural habitat is fundamental to other dimensions of nature and shapes the NCPs that can be delivered.
Years covered: 1961-2011, annual time steps

Approximately 3% of the world's terrestrial area has been converted from natural habitat to agriculture over the last 50 years but there is evidence that this conversion is slowing in recent years.

Overview

The conversion of natural habitats to agricultural and urban land is one of the most serious threats to biodiversity and with rising global demand for food through expanding global populations as well as an increase in per capita consumption, the loss of further natural habitat is likely to continue. Conversion of natural habitats to land for human use also puts pressure on intact habitats through fragmentation, eutrophication, alteration of water flows, and the introduction of alien species. This indicator measures the global extent of land which remains natural (i.e. the proportion of the land surface which is non-agricultural; though note that urban area is not accounted for in this indicator).This indicator is compiled using very detailed statistics collected over a long time period; however, the data is based upon the amount of natural habitat converted to agriculture only and will therefore underestimate the total loss of habitat due to other causes such as the construction of urban areas. Land which has been abandoned post-agricultural use is unlikely to have the same biodiversity value as pristine land, but this is not reflected by this indicator.

Status and trend



Natural habitat extent: status and trend. A) Percentage of terrestrial area containing natural habitat. B) Trendline for rescaled data where 100% represents a pristine world, c) Trendline for rescaled data showing change from a 1970 baseline.

The global extent of natural habitat has decreased by approximately 3% over the last 50 years. However, in the last two decades, the rate of natural habitat loss appears to be decreasing, and perhaps even increasing. This could be due to an intensification of agriculture allowing greater yield within smaller areas, but could also be due to reporting issues.

Sampling methodology and data selection

Data on the global extent of agricultural habitats was collected by the Food and Agricultural Organisation of the United Nations (FAO). Total natural habitat extent was calculated as the proportion of land which has not been converted to agricultural use. Note that this definition includes many land systems where human actions and management can strongly affect ecosystem structure and function and biodiversity, so is relatively permissive.

References

FAO, 2013. FAOSTAT Database. Food and Agriculture Organization of the United Nations (FAO). Available at http://www.fao.org/faostat/en/#data/EL

S 2.2.2.13 Percentage of live coral cover

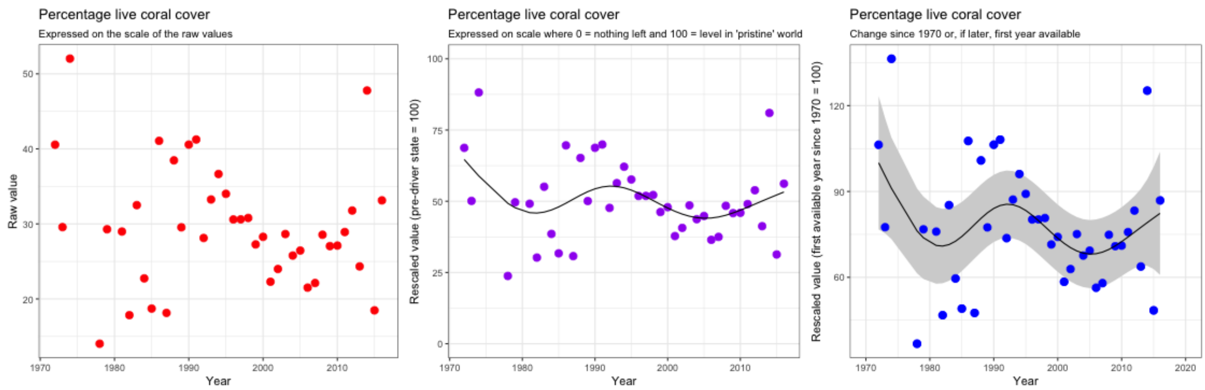
Indicator status: Other indicator
EBV class: Ecosystem structure
Live coral provides habitat for a diversity of marine organisms
Indicator type: Representative/Sensitive
Live corals lay down the reef and ensure maintenance of structure, so underpin the ecosystem. Coral reefs can grow only within a narrow environmental envelope (Kennedy et al. 2013) and are listed specifically as vulnerable ecosystems under Aichi Target 10.
Years covered: 1972-2016, annual time steps from 1981

This indicator reveals huge variation in the state of reefs, and also the slow, long-term decline in the level of live coral cover, such that average cover today is less than 25% of the reef surface and has declined at an average rate of 4% (i.e. 2% percentage points absolute cover) per decade.

Overview

The most widely-gathered metric of coral reef health is the percentage of living coral cover on the reef's surface. Aichi Target 10 specifically lists coral reefs as vulnerable ecosystems, and coral reef cover can be used to assess the state of global reefs, though there remains considerable variation among regions, and a strong influence of low and high-frequency stochastic events (e.g. the El Nino Southern Oscillation; ENSO).

Status and trend



Percentage of live coral cover: status and trend. A) Modelled global averages in coral cover. B) Trendline for rescaled data where 100% represents the coverage estimated for pre-industrial reefs (Eddy et al. 2018). C) Trendline for rescaled data showing change from a 1970 baseline.

Shallow coral reefs are naturally disturbed by tropical storms and pest outbreaks and the level of living coral has varied enormously for the nearly 50 years for which data are available. Typically, a reef will be damaged but then exhibit a period of recovery and any 'snapshot' of reef state will include both recovered and recently-damaged reefs. It is not surprising, therefore, that the average level of live coral cover sits well below 50% with considerable spread around it. However, taking the trend from the early 1970s to 2016, we see a chronic average decline in cover of 2% (absolute cover units) per decade. Despite this dramatic narrative, it is likely that this indicator is underestimating the decline of corals as it does not reflect the chronic morbidity effects that will reduce coral recovery potential. For example, in the Western Indian Ocean, coral reefs were impacted by bleaching events in 1998 and 2016, with 30% of reefs showing evidence of high or severe bleaching, but only 10% showing high or severe mortality (Obura et al., 2017). Yet bleaching can reduce the growth rate and fecundity of corals and contribute to long-term slowing down of reef recovery, thereby undermining ecosystem resilience (Ortiz et al. 2018). The coral cover indicator reveals great temporal variability due to climatic influences (e.g. ENSO), but considerable variation remains between regions. This variability may be in part due to variation in reef pressures, but the overarching response of coral reefs over the last decade is one of great regional variability in recovery potential. Although 75% of the world's reefs are under immediate threat from local impacts and increased sea temperatures (Burke et al., 2011), individual reef trajectories are hugely variable with a notable lack of resilience in the Caribbean. Indeed, the Caribbean shows far fewer signs of post-disturbance recovery than reefs of the Indo-Pacific (Roff and Mumby, 2012). While the most widely-used management tools, Marine Protected Areas (MPAs), are unable to mitigate climate-driven stress, global meta-analyses suggest that coral cover is more stable in MPAs than unprotected areas (Selig and Bruno, 2010) indicating that management may be an important tool in coral recovery, even in the Caribbean (Steneck et al. 2018).

Sampling methodology and data selection

This indicator collates datasets from more than 43 countries, representing more than 470 reefs and compassing 1509 records. Coral cover data were collated from published sources, most of which provided mean cover at the scale of individual reefs, although some presented national or even sub-regional averages. Inconsistent reporting of habitat type and depth prevented a clear assessment of the contribution of local habitat. Data from the Caribbean and Pacific were dominated by forereef habitats (95% and 78% respectively) whereas data from the Indian Ocean were dominated by shallow patch reefs (91%). A dynamic linear model was used to calculate yearly global averages.

In order to express coral cover relative to a pristine baseline, we used Eddy et al.'s (2018) estimate that pre-industrial reefs would have had an average live coral cover of 59%.

References

Burke, L., Reytar, K., Spalding, M. and Perry, A., 2011. Reefs at risk revisited.

Eddy, T. D., Cheung, W. W. L., & Bruno, J. F. (2018). Historical baselines of coral cover on tropical reefs as estimated by expert opinion. PeerJ, 6, e4308. doi:10.7717/peerj.4308

Kennedy, E. V., C. T. Perry, P. R. Halloran, R. Iglesias-Prieto, C. H. Schonberg, M. Wisshak, A. U. Form, J. P. Carricart-Ganivet, M. Fine, C. M. Eakin, and P. J. Mumby. 2013. Avoiding coral reef functional collapse requires local and global action. Current Biology 23:912-918.

Obura, D., Gudka, M., Rabi, F. A., Gian, S. B., Bijoux, J., Freed, S., Maharavo, J., Porter, S., Sola, E., Wickel, J., Yahya, S. and Ahamanda, S., 2017. Coral reef status report for the Western Indian Ocean. Global Coral Reef Monitoring Network (GCRMN)/International Coral Reef Initiative (ICRI). pp 144.

Ortiz, J. C., N. H. Wolff, K. R. N. Anthony, M. Devlin, S. Lewis, and P. J. Mumby. 2018. Impaired recovery of the Great Barrier Reef under cumulative stress. Science Advances 4:eaar6127.

Roff, G. and Mumby, P.J., 2012. Global disparity in the resilience of coral reefs. Trends in Ecology & Evolution, 27(7), pp.404-413.

Selig, E.R. and Bruno, J.F., 2010. A global analysis of the effectiveness of marine protected areas in preventing coral loss. PLoS One, 5(2), p.e9278.

Steneck, R. S., P. J. Mumby, C. MacDonald, D. B. Rasher, and G. Stoyle. 2018. Attenuating effects of ecosystem management on coral reefs. Science Advances 4:eaao5493.

S 2.2.2.14 Permanent surface water extent

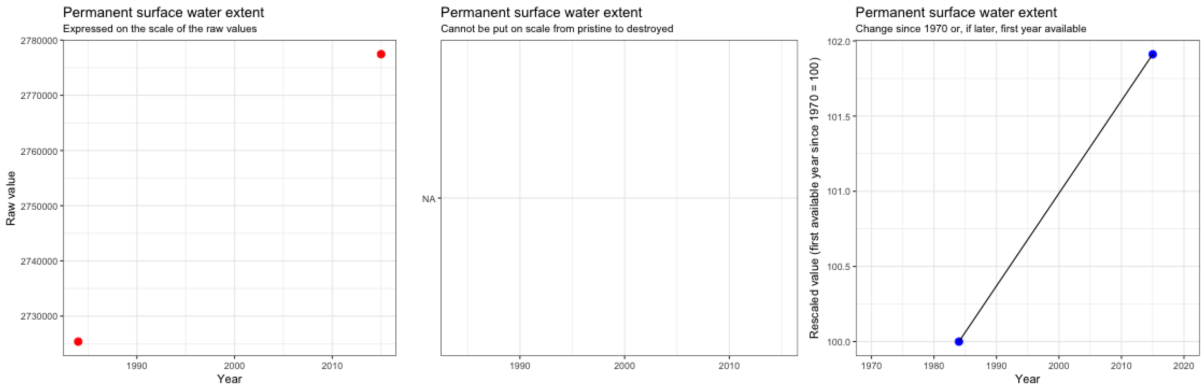
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Representative / Underpin NCP
This indicator is taken from a global dataset on the extent of surface water
Years covered: 1984-2015, single time step

Permanent surface water has increased since 1984, with a net gain of approximately 52,000 km^2.

Overview

Surface water is a naturally dynamic system with great seasonal fluctuations, rivers that change course and constantly restructuring coastlines. To this variability humans have added complexity by introducing artificial stability to some areas, through structures such as dams, reservoirs and canals, and removing stability in others through water extraction for agriculture and urban areas. Surface water is an essential resource for humans and nature alike and has great influence on climate, controlling weather patterns and energy levels. This indicator focuses on permanent surface water – where a surface has remained under water throughout the year as opposed to water that undergoes interannual fluctuations.

Status and trend



Permanent surface water extent: status and trend. A) Surface water change. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 1984.

Permanent surface water has increased since 1984, with a net gain of approximately 52 000 km^2 (Pekel et al. 2016). This represents a gain of approximately 2% over the last three decades. All continental regions apart from Oceania experienced a net increase in permanent surface water (Pekel et al. 2016). Loss of permanent surface water was concentrated in the Middle East and Central Asia, where 70% of the global loss in permanent water was localised. Losses were attributed to human actions, such as abstraction, damning and river diversion, as well as long term droughts. Gains were attributed to climate change as well as the production of reservoirs (Pekel et al. 2016).

Sampling methodology and data selection

The entire multi-temporal orthorectified Landsat 5, 7 and 8 archive was used to produce gridded permanent surface water extent maps for 1984 and 2015. Each 30m pixel was assessed as having permanent, seasonal or no surface water. Open water was considered to be any stretch of water larger than 30m x 30m and open to the sky, including freshwater and saline. Permanent surface water was designated if water is present for all twelve months within a year.

References

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, 418. doi:10.1038/nature20584; https://www.nature.com/articles/nature20584#supplementary-information

S 2.2.2.15 Remaining primary vegetation

Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Representative
This indicator uses global sources which are representative of terrestrial areas across the world.
Years covered: 850-2015, annual time-steps

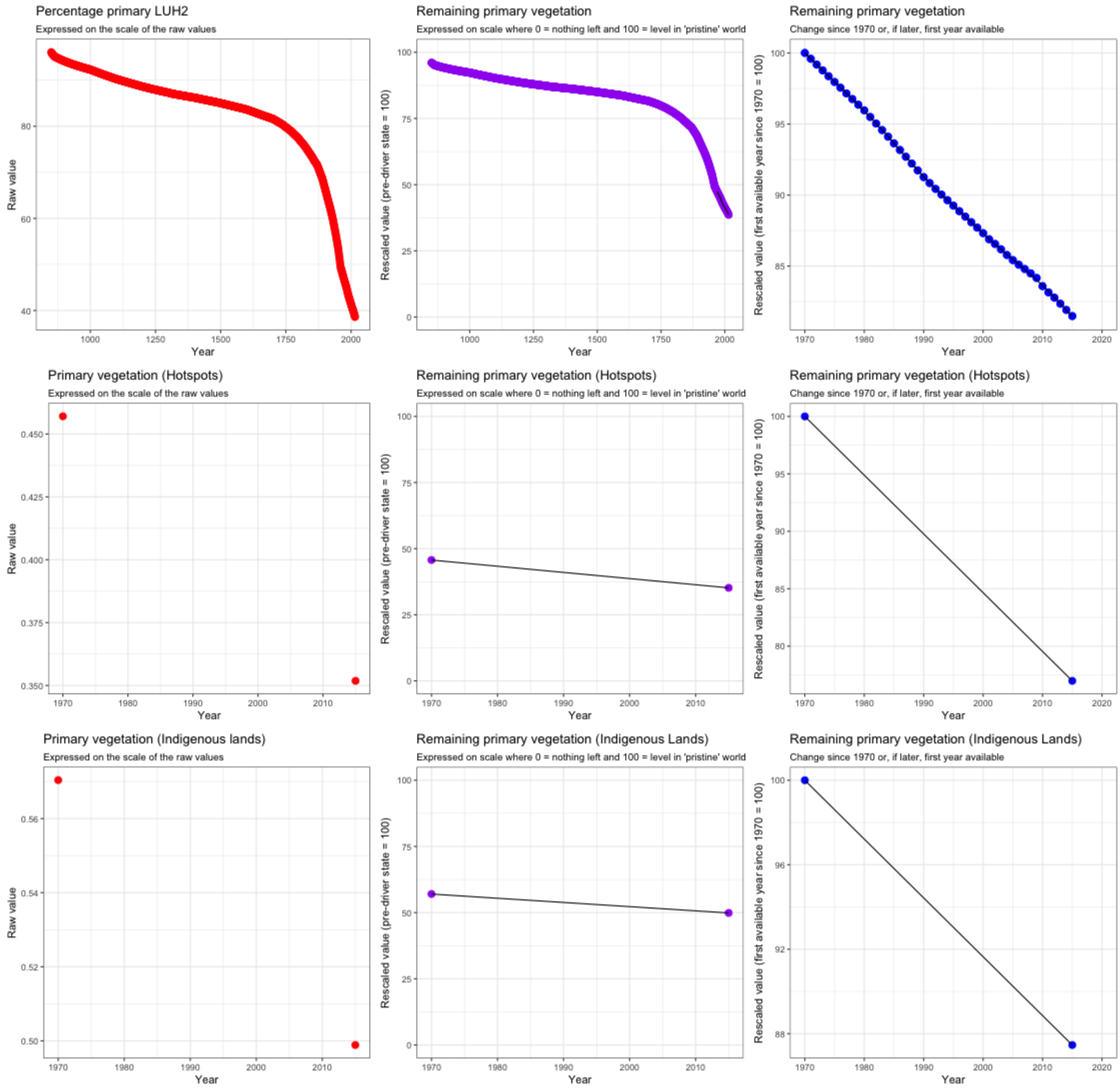
Humans have been removing primary vegetation for millennia, but this process accelerated around the start of the industrial revolution; around 40% of the world's primary vegetation was lost in the last 250 years and this loss is still continuing.

Overview

Primary vegetation provides critical habitat for specialist species and is the best adapted habitat for providing many of the ecosystem services on which we depend. Primary vegetation is natural vegetation that can be found in forested or non-forested biomes that has never been converted for human uses. This indicator is derived from the Land-Use Harmonization 2 (LUH2) global gridded land use maps developed for the

World Climate Research Program Coupled Model Intercomparison Project (CMIP6) (Hurtt et al. *in prep*).

Status and trend



Remaining primary vegetation: status and trend. Top row: A) Proportion of global land containing primary vegetation (850-2015). B) Trendline for rescaled data where 100% represents a pristine world. C) Trendline for rescaled data showing change since 1970. Second row: as top row, for hotspots of narrowly-distributed species. Third row: as top row, for Indigenous lands.

By 1970 over half of the global terrestrial primary vegetation has been removed with most loss occurring post-1750. In the years from 1970 to 2015 a further 20% of the primary vegetation remaining in 1970 was lost.

Sampling methodology and data selection

The Extent of Remaining Primary Vegetation indicator is based upon the LUH2 gridded global land use maps produced by advanced Earth System Models (ESM) which model the combined pressures of land use conversion and fossil fuel emissions on the carbon-climate system (Hurtt et al. *in prep*). The maps are gridded at quarter degree resolution. The pressure data is derived from the History Database of the Global Environment (HYDE) (Klein Goldewijk et al. 2011). Primary vegetation is defined as natural vegetation (either forest or non-forest) that has never been impacted by human activities (e.g. agriculture or wood harvesting) since the start of the time series (850). However, such areas may be indirectly impacted by humans, for instance, through hunting, pollution or the introduction of invasive alien species. Although these maps present a step forward in our understanding of how humans have altered the earth over the last thousand years, they still represent modelled estimates, and the uncertainty associated with the land use present within each particular grid cell increases as we step back in time through the series.

References

G. Hurtt, L. Chini, R. Sahajpal, S. Frolking, et al. “Harmonization of global land-use change and management for the period 850-2100”. Geoscientific Model Development (In prep). Data downloadable from http://luh.umd.edu/.

Klein Goldewijk, K., A. Beusen, M. de Vos and G. van Drecht (2011). The HYDE 3.1 spatially explicit database of human induced land use change over the past 12,000 years, Global Ecology and Biogeography 20(1): 73-86.DOI: 10.1111/j.1466-8238.2010.00587.x.

S 2.2.2.16 Seagrass meadow area

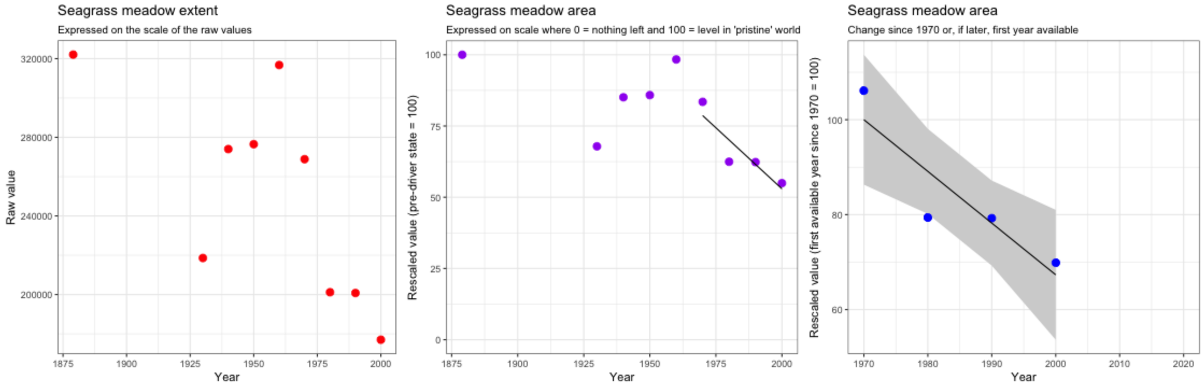
Indicator status: Other
EBV class: Ecosystem structure
Assesses extent of ecosystem
Indicator type: Representative / Sensitive
The indicator is based on global data pertaining to a vulnerable ecosystem
Years covered: 1879 – 2000, 10 year time-steps from 1930

The global extent of seagrass meadows has declined by 51,000km^2 since 1879.

Overview

Seagrass meadows are extremely productive areas upon which thousands of species of marine vertebrates and invertebrates are dependent. Humans also depend on seagrass meadows - these shallow, warm, coastal meadows provide accessible areas in which to harvest fish and other seafood, and also provide benefits to nature such as sediment stabilisation, nutrient filtration and cycling, and carbon sequestration. However, their accessible nature means that they are readily exploitable and at risk due to coastal development and pollution. In addition to such direct human pressures, they are also impacted by indirect pressures such as climate change, and overfishing causing detrimental feedbacks to the food web (Unsworth et al. 2014). This indicator utilises a comprehensive global dataset to assess the change in the extent of seagrass meadows over time.

Status and trend



Seagrass meadow area: status and trend. A) Seagrass meadow area (km^2). B) Data rescaled to show change from the area in 1879. C) Data rescaled to show trend since 1970.

Although results reveal fluctuations, all assessments show decline in comparison to the area in 1879, and, in recent years, assessments have consistently indicated that seagrass meadow extent is approximately two thirds the size that it was in 1879. When extrapolated to a global level, this equates to a loss of at least 51,000km^2 of seagrass meadow area from 1879 to 2006 (Waycott et al. 2009). The true number may be as much as 35 times higher as many areas of seagrass meadows remain unmapped (Waycott et al. 2009).

Sampling methodology and data selection

Study-level data was synthesised from 215 sites, comprising a total of 1128 observations across the globe (Waycott et al. 2009). Only studies with at least two estimates of area that spanned a time period of over two years were included in the assessment. Percentage rate of change and net change for each site was calculated and aggregated within decadal intervals from 1930. All measures pre-1930 were aggregated due to lack of data.

References

Unsworth, R. K. F., van Keulen, M., & Coles, R. G. (2014). Seagrass meadows in a globally changing environment. Marine Pollution Bulletin, 83(2), 383-386. doi:https://doi.org/10.1016/j.marpolbul.2014.02.026

Waycott, M., Duarte, C. M., Carruthers, T. J. B., Orth, R. J., Dennison, W. C., Olyarnik, S., . . . Williams, S. L. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences, 106(30), 12377.

S 2.2.2.17 Soil organic carbon (correlative model)

Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator tracks the health of ecosystems

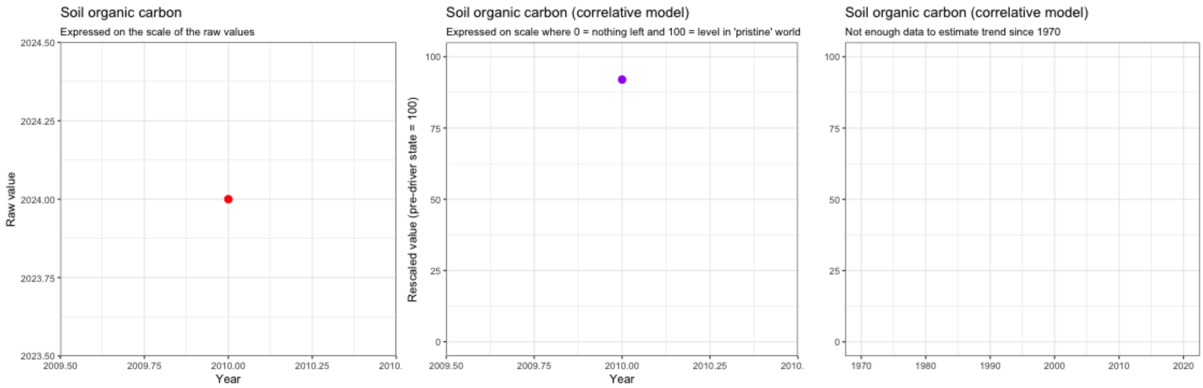
Indicator type: Representative
This indicator is based upon a globally representative dataset
Years covered: 2010

According to a correlative model, there has been an 8% drop in global soil organic carbon caused by conversion of pristine land to anthropogenic uses.

Overview

Humanity struggles to balance the requirements of food production with the maintenance of biodiversity and the minimisation of climate change and these challenges are all underpinned by the quality of our soils. Very little information is available on soil biodiversity at a global level, but this dataset helps to provide a snapshot as to how soil condition has been altered from a pristine system through conversion to anthropogenic land uses.

Status and trend



Soil organic carbon (correlative model): status and trend. A) Gigatonnes of soil organic carbon in 2010. B) Change in soil organic carbon from pristine (where 100% represents a pristine world, using the estimate from Van der Esch et al. 2017). C) No trendline data available.

The conversion of natural habitats to anthropogenic land uses has caused an 8% decline in the global quantity of soil organic carbon (Van der Esch et al. 2017).

Sampling methodology and data selection

The change in soil organic carbon was estimated following the S-World methodology (Stoorvogel et al. 2017). Gigatonnes of soil organic carbon was estimated for current and natural conditions within the top 50cm of topsoil. Correlative models were built to relate the Normalized Difference Vegetation Index (NDVI) to environmental conditions and soil properties of pre-selected natural areas around the world. This knowledge was then used to produce maps of NDVI for a pristine world which were compared with actual current-day NDVI maps. Landscape properties, detailed in the S-World methodology, were combined with spatially explicit data on land use intensity from GlobCov to produce maps of where soil organic carbon has been removed by conversion to anthropogenic land uses. Pristine and current levels of soil organic carbon were obtained from Van der Esch et al. (2017). A range of values of current soil organic carbon can be found in FAO (2017)

References

FAO 2017. Soil Organic Carbon: the hidden potential. Food and Agriculture Organization of the United Nations. Rome, Italy

Van der Esch, S., ten Brink, B., Stehfest, E., Bakkenes, M., Sewell, A., Bouwman, A., Meijer, J., Westhoek, H., van den Berg, M., 2017, Exploring future changes in land use and land condition and the impacts on food, water, climate change and biodiversity: Scenarios
for the Global Land Outlook. PBL Netherlands Environmental Assessment Agency, The Hague.

Stoorvogel, J.J., Bakkenes, M., ten Brink, B.J.E., Temme, A.J.A.M., 2017, To what extent did we change our soils? A global comparison of natural and current conditions. Land Degradation & Development, 28(7), 1982-1991.

S 2.2.2.18 Soil organic carbon (mechanistic models)

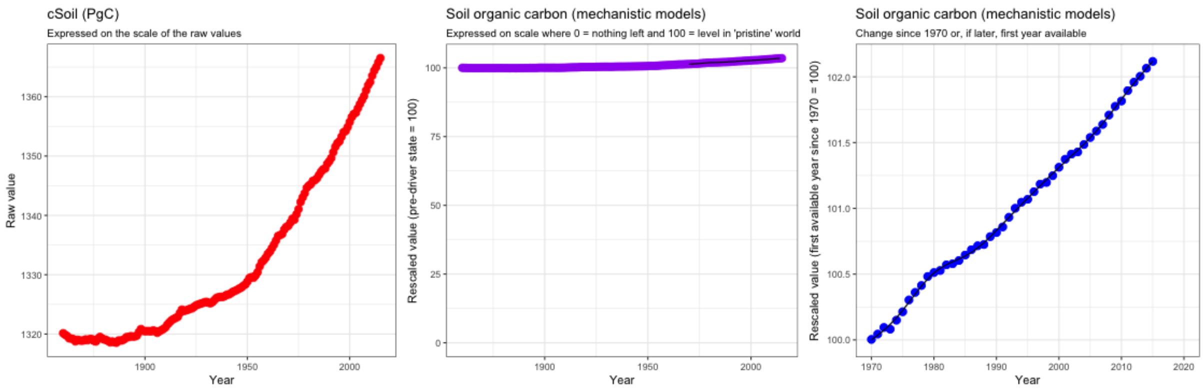
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Representative
This indicator is based upon globally representative data
Years covered: 1860-2015, annual time steps

According to mechanistic models, the global levels of soil organic carbon have increased since 1860.

Overview

Land use conversion alters soil environmental characteristics such as water retention, temperature, and fertility. Such changes impact the below-ground carbon cycle. This indicator tracks the uptake of carbon by living matter - a proxy of below-ground biomass.

Status and trend



Soil organic carbon (mechanistic models): status and trend. A) Total soil organic carbon (PgC). B) Trendline for rescaled data where 100% represents the value in

1860, the earliest date for which the models have been run. C) Trendline for rescaled data showing change since 1970.

Global levels of soil organic carbon have risen since 1860. The rate of change has increased, with an eight times greater gain in global soil organic carbon estimated from 1940 to 2015 as compared with the gain estimated from 1860 to 1940.

Sampling methodology and data selection

Soil organic carbon was estimated using the mean response values from two bookkeeping models: the BLUE (Bookkeeping of Land Use Emissions) model (Hansis et al. 2015) and the estimate published by Houghton and Nassikas (2017) (as described in LeQuere et al. 2018). Pristine (baseline) values were taken to be the estimated level pertaining to the start of the time series (here 1860).

References

Hansis, E., Davis, S. J., & Pongratz, J. (2015). Relevance of methodological choices for accounting of land use change carbon fluxes. Global Biogeochemical Cycles, 29(8), 1230-1246. doi:10.1002/2014GB004997

Houghton, R. A., & Nassikas, A. A. (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015. Global Biogeochemical Cycles, 31(3), 456-472. doi:10.1002/2016GB005546

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

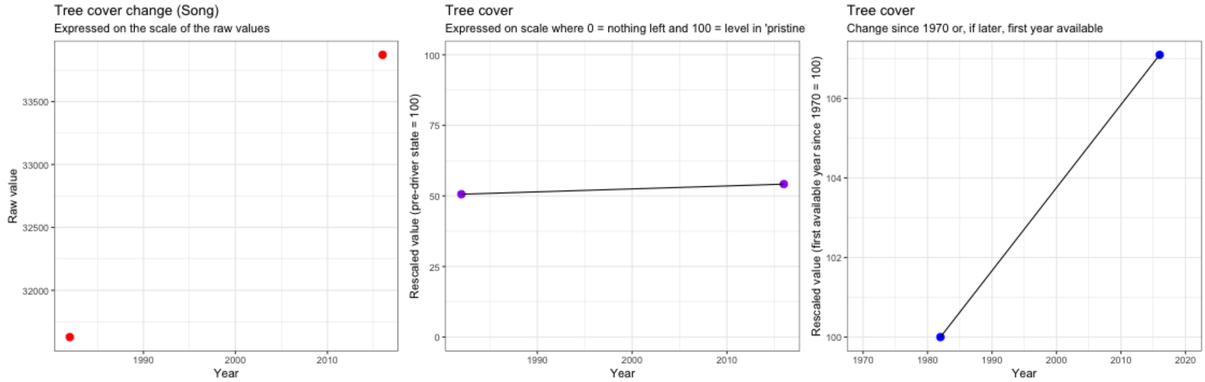
S 2.2.2.19 Tree cover

Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Representative
This indicator is based upon globally representative data
Years covered: 1982-2016, single time step

Tree cover increased by approximately 7% in the period 1982 to 2016.

Overview

Forests play an essential role in the earth's dynamics through regulation of biogeochemical cycles as well as providing habitat for much of our terrestrial biodiversity. Understanding how the global vegetation-climate interactions have changed over time is fundamental information for climate change models. Furthermore, long-term, high-resolution data of tree cover allows detailed understanding of where and how forests are being altered for human use and the likely impacts this is having on ecosystem service provision as well as terrestrial biodiversity.



Tree cover: status and trends. A) Tree cover change. B) Trendline for rescaled data where 100% represents the value when human civilisation began. C) Trendline for rescaled data showing change since 1982.

At a global scale, tree cover increased by 2.24 million km^2 from 1982 to 2016. This translates to an increase of approximately 7%. However, these global numbers hide stark regional differences, with tropical deforestation and agricultural expansion leading to a net tree cover loss in the tropics, and afforestation or reforestation due to climate impacts as well as agricultural intensification and urbanisation leading to a net increase in tree cover in temperate regions (Song et al. 2018). Changes in vegetation cover are attributed to both direct human activities (60%) as well as indirect impacts such as climate change (40%) (Song et al. 2018). At a continental scale, Asia gained the most tree cover with a net increase of 1.3 million km^2 and South America lost the most tree cover with a net loss of 479 000 km^2 (Song et al. 2018).

Sampling methodology and data selection

The dataset was compiled from multiple satellite sensors, including the Advanced Very High Resolution Radiometer (AVHRR), the Moderate Resolution Imaging Spectroradiometer, and the Landsat Enhanced Thematic Mapper Plus. Trees were assessed as vegetation over 5m in height. Data was compiled onto grids at 0.05^o x 0.05^o spatial resolution.

Crowther et al. (2015) estimate that the global number of trees has fallen by 45.8% since the dawn of human civilisation. On the assumption that tree number will be proportional to the area of tree cover, this figure is used to estimate a pristine value for forest cover, placing the Song et al. (2018) values into context.

References

Crowther, T. W., Glick, H. B., Covey, K. R., Bettigole, C., Maynard, D. S., Thomas, S. M., . . . Bradford, M. A. (2015). Mapping tree density at a global scale. Nature, 525, 201. Retrieved from https://doi.org/10.1038/nature14967. doi:10.1038/nature14967

Song, X.-P., Hansen, M. C., Stehman, S. V., Potapov, P. V., Tyukavina, A., Vermote, E. F., & Townshend, J. R. (2018). Global land change from 1982 to 2016. Nature, 560(7720), 639-643. doi:10.1038/s41586-018-0411-9

S 2.2.2.20 Vegetation biomass (mechanistic model)

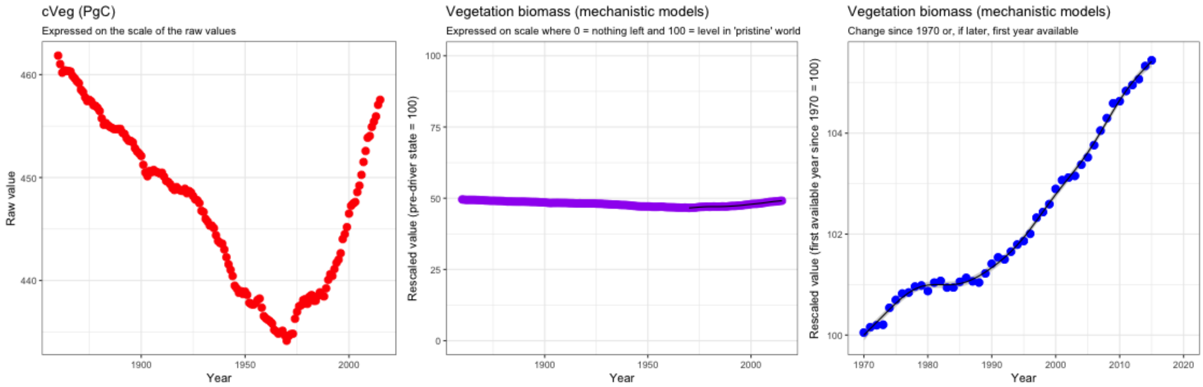
Indicator status: Other indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent and fragmentation.
Indicator type: Representative
This indicator is based upon globally representative data
Years covered: 1860-2015, annual time steps

Present global vegetation biomass is approximately half what would be expected within a pristine world.

Overview

Vegetation biomass tracks how land use change has altered carbon stocks stored in vegetation over time. The alteration, both interannual and long-term, in the availability of such stocks for uptake into food webs results in the transformation of species communities.

Status and trend



Vegetation biomass: status (from a synthesis comparing present-day vegetation with potential under current climate) and trend (from mechanistic models). A) Total terrestrial vegetation biomass (PgC). B) Trendline for rescaled data where 100% represents the potential vegetation biomass with today's climate. C) Trendline for rescaled data showing change since 1970.

Global vegetation biomass is approximately half its potential value. Broadly this has not changed since 1860, although a closer examination of the trendline reveals a decreasing trend until the 1970's followed by recovery in the last 40 years.

Sampling methodology and data selection

Vegetation biomass was calculated using the mean response values from two bookkeeping models: the BLUE (Bookkeeping of Land Use Emissions) model (Hansis et al. 2015) and the estimate published by Houghton and Nassikas (2017) (as described in LeQuere et al. 2018).

In order to express the recent values relative to those expected in a pristine world, we used Erb et al.'s (2017) estimate that present-day terrestrial vegetation biomass is

~49% of the level expected in a world with today's climate but no human land use. Erb et al.'s (2017) estimate was based on synthesising seven estimates of biomass stocks in present-day vegetation (with a mean of 450 PgC) with six estimates of biomass stocks of potential vegetation in current climate conditions (with a mean of 916 PgC). We therefore multiplied the most recent value in the time series by 916/450 to estimate an appropriate baseline (i.e., respecting differences among models).

References

Erb, K.-H., Kastner, T., Plutzar, C., Bais, A. L. S., Carvalhais, N., Fetzel, T., . . . Luyssaert, S. (2017). Unexpectedly large impact of forest management and grazing on global vegetation biomass. Nature, 553, 73. doi:10.1038/nature25138

Hansis, E., Davis, S. J., & Pongratz, J. (2015). Relevance of methodological choices for accounting of land use change carbon fluxes. Global Biogeochemical Cycles, 29(8), 1230-1246. doi:10.1002/2014GB004997

Houghton, R. A., & Nassikas, A. A. (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015. Global Biogeochemical Cycles, 31(3), 456-472. doi:10.1002/2016GB005546

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

S 2.2.2.21 Wetland Extent Trends index

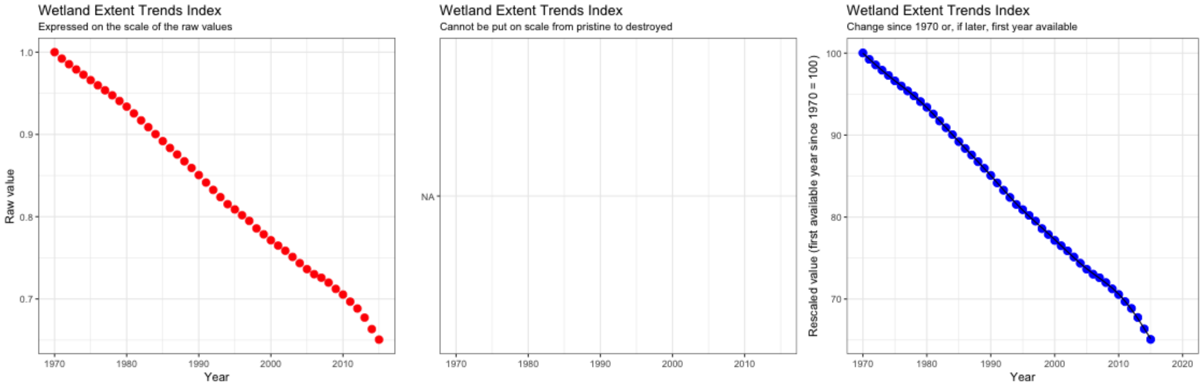
Indicator status: Highlighted indicator
EBV class: Ecosystem structure
This indicator reveals trends in ecosystem extent.
Indicator type: Representative/Sensitive
Wetland extent is fundamental, but it is also considered to be sensitive as aquatic ecosystems are known to be highly threatened systems, sensitive to small changes in water use, temperature, salinization or pollution. The indicator is also calculated using a method that makes it more sensitive to changes in the extent of small rather than large wetlands.
Years covered: 1970-2015, annual time steps

The Wetland Extent Trends Index has fallen by one third since 1970.

Overview

Studies to assess the status of wetlands suggest that these important habitats are declining in extent around the world. In order to track progress to Aichi Target 5, it is important that work is undertaken to estimate the global baseline rate of decline of wetland extent. The *Wetland Extent Trends (WET) index* estimates the average rate of change in wetland extent over the recent period of 1970 to 2015 using time-series data from published scientific literature and global wetland databases. As each time series refers to a change in area of a specific wetland, the index is calculated as change from a 1970 baseline of 1. The WET index enables the rate of loss of wetlands to be estimated, providing an indication of the status of wetlands globally. Data can be disaggregated from the global scale to six regions and into three types of wetland. Although the index accounts for over-representation and bias, there are data gaps from some regions of the world, and large areas of wetlands are not included e.g. Orinoco and Amazon basins due to lack of data. Wetland extent data is also unevenly distributed around the type of wetland; for instance, there are more extensive datasets for mangrove than alpine and tundra wetlands.

Status and trend



Wetland Extent Trends Index: status and trend. A) Wetland Extent Trends Index. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline showing change since 1970.

There has been a decline in the *Wetland Extent Trends (WET) index* of 35% between 1970 and 2015. This is an indication of how wetlands are faring across the globe but this decline is not even, for instance, marine and coastal wetlands are declining faster than inland wetlands and European and Latin American wetlands are declining faster than other areas (Dixon et al. 2016; Ramsar 2018).

Sampling methodology and data selection

The *Wetland Extent Index* uses a variation of the Living Planet Index (LPI) methodology to aggregate extent trend data from the wetland literature and global databases (Dixon *et al.* 2016). The Index calculates the average change in extent for each year compared to the preceding year, which are then chained together to make an index. The analysis is based on a database containing over 2,000 wetland extent time-series records gathered from a literature search and through personal communication with relevant experts with known data. The data is best thought of as a matrix with the possible 'wetland classes' of the data across the *x* axis and the possible 'locality' of the wetland down the *y* axis. The cells of the matrix contain the wetland change time-series data for each unique combination. The average trend in wetland extent was calculated for all wetlands in each cell of the matrix for which one or more time-series were available. The average trends for individual locality-wetland class combinations (matrix cells) were then aggregated by region, giving each cell equal weight. The regional aggregations were then themselves averaged to create the global Index. The *Wetland Extent Trends (WET) index* is weighted according to area estimates of wetland extent at the regional level, based on the Global Lakes and Wetlands Database (GLWD) (Lehner & Doll 2004).

References

Dixon, M.J.R., Loh, J., Davidson, N.C., Beltrame, C., Freeman, R., Walpole, M. (2016, with updated data) Tracking global change in ecosystem area: The Wetland Extent Trends index. Biological Conservation 193, 27–35.

Lehner, B. and Döll, P. (2004): Development and validation of a global database of lakes,
reservoirs and wetlands. Journal of Hydrology 296/1-4: 1-22.

Ramsar Convention on Wetlands. (2018). Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat.

S 2.2.3 Indicators of ecosystem function

S 2.2.3.1 Biological pump efficiency

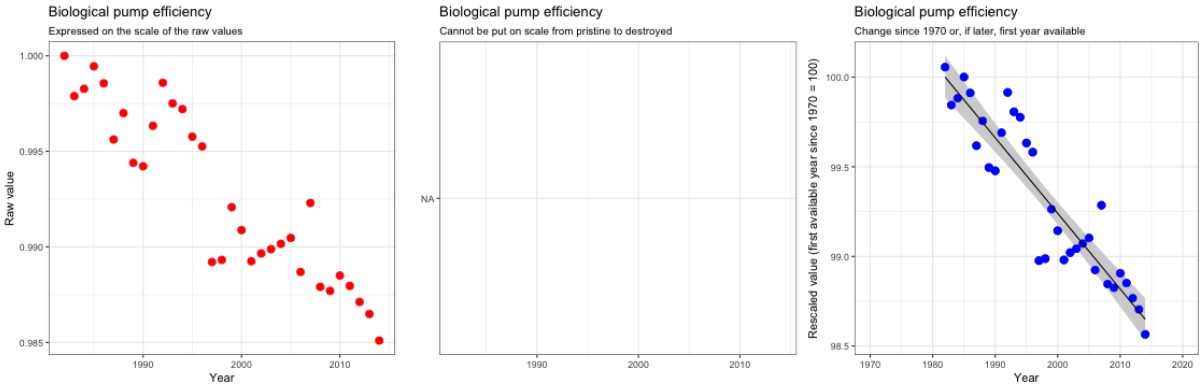
Indicator status: Other indicator
EBV class: Ecosystem function
Indicator reveals the efficiency of carbon sequestration
Indicator type: Representative
This indicator aims to be used at a global scale for all phytoplankton
Years covered: 1982 and 2014, annual time-steps

The oceanic biological pump has experienced a small drop in efficiency since 1982.

Overview

The oceanic biological pump, or the cycle of carbon fixation, sedimentation and remineralization, links the marine food webs with the global carbon cycle. Atmospheric CO_2 is synthesized by marine phytoplankton living in the surface waters. Such phytoplankton may be consumed by predators or they may die and sink to the ocean floor. Some carbon may be remineralised as the phytoplankton sinks, and this may eventually be taken up again as atmospheric carbon, or it may reach the ocean floor and be removed from the cycle (carbon sequestration). The amount of atmospheric CO_2 that is synthesized by marine phytoplankton is dependent upon sea surface temperatures but this relationship is complex as temperatures not only impact the activity of the phytoplankton, but also their life cycles, and the relative abundance of both the phytoplankton species and their consumers within the surface community (Edwards & Richardson 2004).

Status and trend



Biological pump efficiency: status and trend. A) Change in biological pump efficiency from 1982 to 2014. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available . C) Trendline showing change since 1982.

The results show a small drop in biological pump efficiency leading to decreased carbon sequestration, other things being equal. That the results show a small effect is unsurprising as the expected directional shifts due to anthropogenic climate change over the limited time span of the observations will be small compared to the natural variation and may be difficult to detect (Cael et al.2017). There are regional differences, with larger decreases observed in midlatitudes and the Arctic (Cael et al. 2017). Although the methodology is overly simplistic, capturing limited elements of a complex cycle, this indicator provides an indication that the efficiency of carbon sequestration in the oceans is decreasing. Such small changes may still have significant consequences to atmospheric CO_2 levels given the importance of the ocean in the global carbon cycle.

Sampling methodology and data selection

The biological pump efficiency is measured as the ratio of the carbon exported from the surface waters to the primary production within that layer. The efficiency is dependent upon phytoplankton growth, respiration, sinking, remineralization and other processes (Cael et al. 2017). These elements are impacted by temperature, primary production and community structure. As the influence of community structure cannot be assessed robustly, and there is a lack of scientific consensus on the global trends of primary productivity as well as their impact on biological pump efficiency, these elements are not considered in these estimates of efficiency. The data is produced by using known relationships between sea surface temperature and 1) the growth and photosynthetic ability of phototrophs and 2) the grazing ability of heterotrophs. The phototroph biomass minus the grazing gives the amount of biomass lost via sinking, and the fate of this biomass is then influenced by the sinking rate. Using process-based models it is then possible to calculate the influence of sea surface temperature on the ratio of the amount of carbon produced (biomass) versus the amount lost through sinking (i.e., on the biological pump efficiency). Pairing this knowledge with gridded sea surface temperature data (for a description see Cael et al. 2017) provides a global map of biological pump efficiency for each time period.

References

Cael, B.B., Bisson, K., Follows, M.J., 2017. How have recent temperature changes affected the efficiency of ocean biological carbon export? Limnology and Oceanography Letters, 2, 113-118.

Edwards, M., Richardson, A.J. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature, 430, 881-884.

S 2.2.3.2 Biomass turnover rate

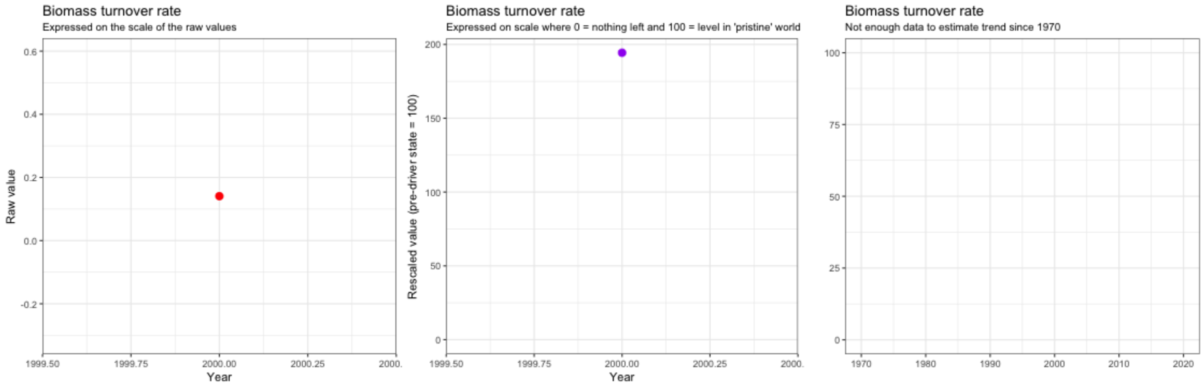
Indicator status: Other indicator
EBV class: Ecosystem function
Biomass turnover rate measures the ability of ecosystems to function
Indicator type: Representative
Biomass turnover rate is based upon globally representative data
Years covered: 2000

The conversion of pristine land to anthropogenic land uses has caused a near doubling in the biomass turnover rate.

Overview

The biomass turnover rate is crucial in determining the feedback between the terrestrial carbon cycle and the climate as well as impacting the availability of biomass within ecosystems. This indicator explores how land use has altered the biomass turnover rate through the alteration of plant growth, the replacement of long-lived perennial species with annual crops, and the removal of biomass stocks.

Status and trend



Biomass turnover rate: status. A) Biomass turnover rate estimated for 2000. B) Change in biomass turnover rate from a pristine system (where 100% represents a pristine world). C) No trendline data available.

The biomass turnover rate shows an increase from a pristine state of approximately 190% (Erb et al. 2016). This indicates that land use has had a significant impact on the rate of biomass turnover. These results may be complicated by anthropogenic impacts that both accelerate and decelerate the rate. For instance, land management may lead to both increased levels of NPP through fertilization and decreased levels of NPP through loss of soil carbon.

Sampling methodology and data selection

Potential vegetation is quantified as the amount of vegetative biomass available under current climate in a world with no land use. To assess the impacts of land use on biomass turnover rate, the ratio of biomass to net primary production for potential vegetation was compared to that of present-day (2000) conditions (Erb et al. 2016).

References

Erb, K.-H., Fetzel, T., Plutzar, C., Kastner, T., Lauk, C., Mayer, A., Niedertscheider, M., Korner, C., Haberl, H., 2016, Biomass turnover time in terrestrial ecosystems halved by land use, Nature Geoscience, 9, 674-678.

S 2.2.3.3. Evapotranspiration (model ensemble)

Indicator status: Other indicator
EBV class: Ecosystem function
Indicator provides information on plant transpiration
Indicator type: Representative

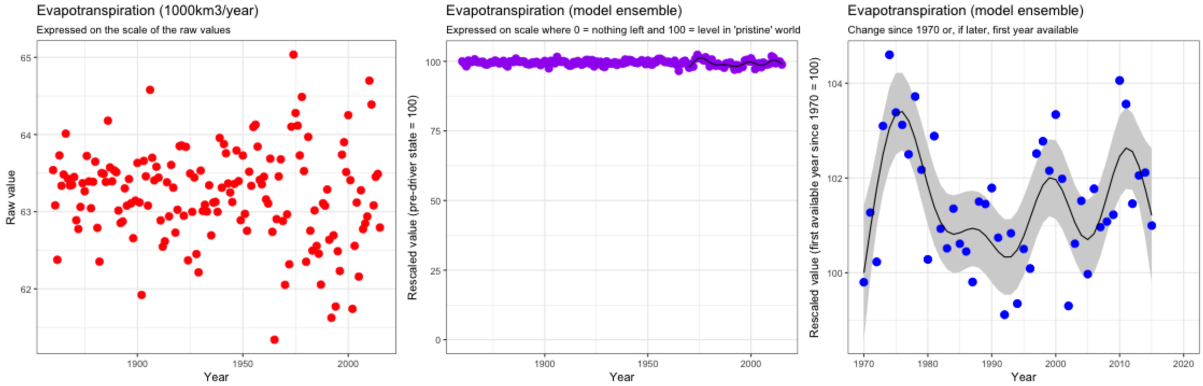
This indicator is based upon globally representative data
Years covered: 1860-2015, annual time steps

Levels of global evapotranspiration have fluctuated over the last 150 years, with the overall trend showing no divergence from the baseline.

Overview

Evapotranspiration measures the movement of water to the atmosphere from the land and sea including evaporation and transpiration by plants. Fluxes in evapotranspiration occur through changing climatic conditions but can also indicate changes to the plant community as transpiration rates are linked to the species present, their relative abundance, and the maturity of the plants. Evapotranspiration is dependent on levels of precipitation unless irrigation occurs.

Status and trend



Evapotranspiration: status and trend. A) Evapotranspiration (thousand km^3/year). B) Evapotranspiration rescaled to show deviation in trendline from a pristine world where the pristine baseline is assessed as the 1860 level (the first year for which data is calculated). C) Trendline for rescaled data showing change since 1970.

Levels of evapotranspiration have fluctuated in the last 150 years leading to no overall trend in the dataset. When recent data trends are examined, it appears that there is an overall positive trend in the dataset (with most values estimated as higher than the 1970 value) but this may be due to 1970 being an exceptionally low year – of the 156 years for which we have data, the bottom six years, in increasing order, are 1965, 1992, 2002, 1994, 1902 and 1970 and the top six years are 1975, 2011, 1978, 1906, 2010 and 1974.

Sampling methodology and data selection

The TRENDY version 6 outputs (Le Quéré et al. 2018) were used. The TRENDY v6 dataset is a collection of terrestrial carbon cycle model outputs. The models were run from 1860 to 2016 with observed temporal variations in atmospheric CO2 concentration (ice-core and direct observation), climate (global gridded climate data from CRU-NCEP), and land use (Hurtt LULCC data based on HYDE 3.2 data). In this assessment, model outputs with variable atmospheric CO2, climate and land use (S3 run) were used, although trendy v6 data covers other runs (S1-run: variable CO2, fixed climate and land use, and S2 run: variable CO2 and climate and fixed land use).

Among 14 participating models, eight model outputs (CABLE, CLM4.5, ISAM, JSBACH, JULES, LPJwsl, LPX, and VISIT) were used because of availability of outputs required in this assessment.

References

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

S 2.2.3.4 Marine net primary productivity (remote-sensing)

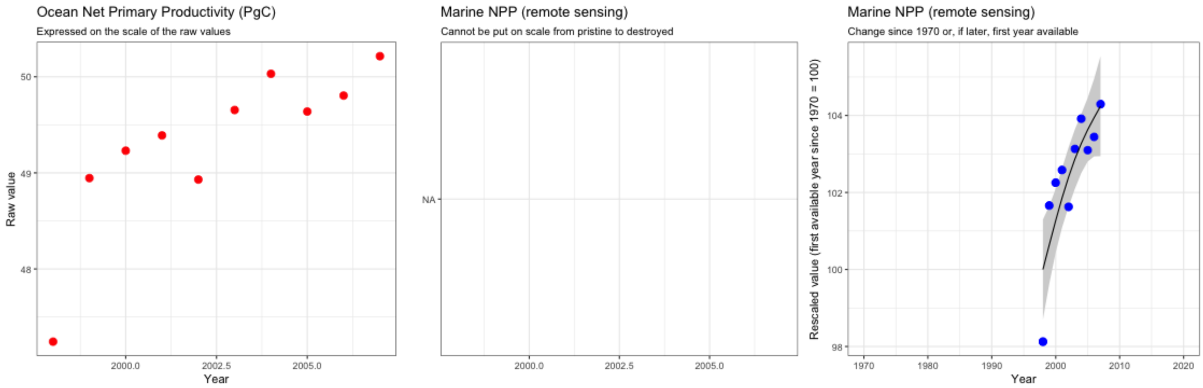
Indicator status: Other indicator
EBV class: Ecosystem function
Marine NPP measures the ability of ecosystems to function
Indicator type: Representative/Underpin NCP
This indicator is based upon globally representative data and indicates ecosystem service potential
Years covered: 1998-2007, annual time-steps

Due to changing climate the marine net primary productivity has increased since 1998 - this increase will result in a greater availability of marine phytoplankton biomass to support marine food webs but it is unlikely to counteract the detrimental impacts of climate change on marine biodiversity.

Overview

Oceans are a vital carbon sink, with recent estimates showing that one quarter of anthropogenic CO_2 emitted in the last 20 years was removed by oceanic processes (Le Quere et al. 2018). The majority of available carbon, more than one hundred million tonnes per day, is sequestered by marine phytoplankton who support (and contribute to) the vast array of biodiversity found in our oceans (Behrenfeld et al. 2006). This indicator reveals the trend in the productivity of the ocean - an indirect measure of the quantity of marine phytoplankton biomass available to the oceanic food webs as well as a guide as to how climate change is impacting marine systems.

Status and trend



Marine NPP: status and trends. A) Total marine net primary production (PgC). B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 1998.

Global marine NPP has increased since 1998, with an increase of approximately 3 PgC per year in 2007 compared to 1998. This represents an approximate increase of 6% per year since 1998. The trendline has remained relatively constant in the last decade apart from a large decline in NPP observed in 1998 that was likely due to the impacts of the El Nino Southern Oscillation (ENSO) event experienced at that time. There are regional differences, for instance, tropical seas have tended to experience increased NPP and temperate seas have tended to experience decreased NPP (Behrenfeld et al. 2006). Although NPP has increased in some regions, for many marine species the detrimental impacts of climate change, such as alterations to food webs and acidification, are likely to offset any positive impacts from increased productivity.

Sampling methodology and data selection

Marine NPP is measured following the methodology outlined in Behrenfeld & Falkowski (1997). Satellite-based measures of chlorophyll concentration, together with data on sea-surface temperature and irradiance, are used to produce modelled estimates of global marine primary productivity.

References

Behnrenfeld, M.J., Falkowski, P.G., 1997, Photosynthetic rates derived from satellite-based chlorophyll concentration, Limnology & Oceanography, 42:1, 1-20.

Behrenfeld, M.J., O'Malley, R.T., Siegel, D.A.,McClain, C.R., Sarmiento, J.L., Feldman, G.C., Milligan, A.J., Falkowski, P.G., Letelier, R.M., Boss, E.S., 2006, Climate-driven trends in contemporary ocean productivity, Nature 444, 752-755.

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

S 2.2.3.5. NPP remaining in terrestrial ecosystems

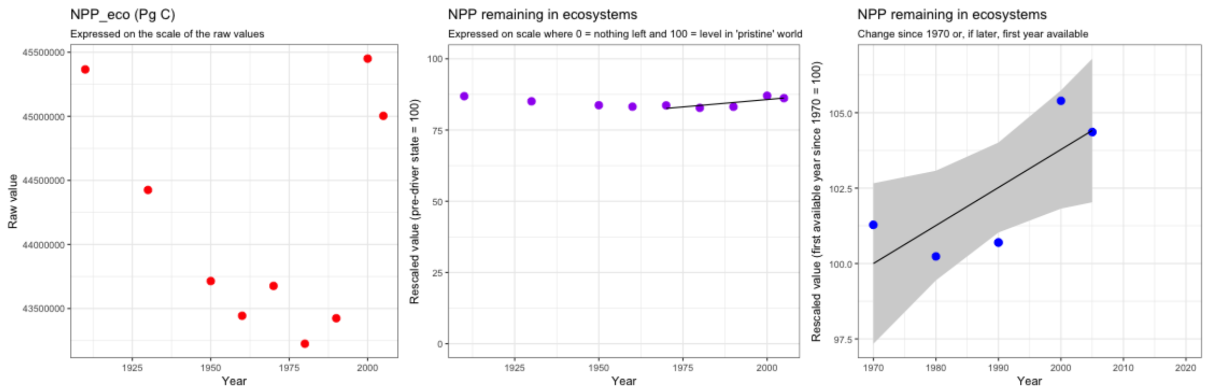
Indicator status: Other indicator
EBV class: Ecosystem function
NPP remaining in ecosystems measures the ability of ecosystems to function
Indicator type: Representative
This indicator is based upon globally representative data
Years covered: 1910-2005, variable time-steps but decadal from 1950-2000

The net primary productivity remaining in terrestrial ecosystems is now at 1910 levels, but data from these years alone would not capture the change in this indicator over time - over the last 100 years net primary productivity has fallen and recovered due to the contrasting pressures of the extra resource required to support our growing *population balanced with the increasing ability of ecosystems to produce NPP due to the CO_2 fertilization effect.*

Overview

Net primary productivity (NPP) remaining in terrestrial ecosystems reflects the balance between NPP and human appropriation of it, and estimates the amount of NPP that remains in the ecosystems to underpin the trophic web. This may be used to indicate progress against Aichi Target 4 by revealing the measure of impact that human consumption has on natural resources. Net primary production (NPP) is the net amount of biomass produced each year by plants and may therefore be used to provide an indication of trophic energy flows in ecosystems. Net primary productivity remaining in ecosystems (Pg C*)* measures to what extent land conversion and biomass harvest alter the availability of NPP (biomass) in ecosystems. It is a prominent measure of the "scale" of human activities compared to natural processes (*i.e.* of the "physical size of the economy relative to the containing ecosystem"). As human harvest of biomass is a major component of this indicator, it is also closely related to socio-economic metabolism as measured by material flow accounts. This indicator relates to land-use change, one of the most important drivers of terrestrial biodiversity loss, although the direct relationship between the removal of NPP and biodiversity remains unclear.

Status and trend



NPP remaining in terrestrial ecosystems: status and trend. A) Total net primary productivity remaining in terrestrial ecosystems (PgC). B) Trendline for rescaled data where 100% represents a pristine world. C) Trendline for rescaled data showing change since 1970.

The potential biomass production has increased considerably over the last century due to the CO_2 fertilization effect (Krausmann et al. 2013); however, this gain in potential NPP has not resulted in a gain in the amount of NPP remaining in ecosystems to an increase in consumption driven by an increasing global population. The net primary productivity available in ecosystems estimated for 2005 was approximately equal to that estimated for 1910.

Sampling methodology and data selection

Krausmann et al. (2013) calculated net primary productivity remaining in ecosystems by subtracting the biomass of harvested crops from the potential biomass production. The potential biomass production is estimated per grid cell through the LPJmL global vegetation model using atmospheric CO_2 concentration, climate and soil type (Sitch et al. 2003). The harvested biomass comprises used elements, such as crops, roundwood removal, as well as biomass harvested by livestock, and unused elements, such as biomass killed during harvest which is not part of the crop (for instance, roots), biomass removed during management of public areas, and biomass destroyed by human-induced fires. The crop and roundwood data were taken from national-scale FAO agricultural databases. However, the patchy coverage of the FAO data, especially towards the start of the time series, resulted in regional summaries being extrapolated from the countries in each region where data was available using per capita values and population numbers.

The baseline value used here is the global potential terrestrial NPP (not just that remaining after human use) estimated for 1910. This is higher than the NPP value estimated for 1860 by the TRENDY ensemble of models (Le Quere et al. 2018), perhaps because land-use change had already reduced NPP by 1860 (Krausmann et al. 2013). Using the ensemble 1860 value as a baseline would suggest that the NPP remaining in ecosystems is around 95% of the baseline level, even higher than the 86% reported here. Using high and low estimates of current HANPP (from Krausman et al. 2013) leads to a range of 83-91% of the baseline.

References

Krausmann, F, Erb, K-H, Gingrich, S, Haberl, H, Bondeau, A,Gaube, V, Lauk, C, Plutzar, C, Searchinger, T.D., 2013, Global human appropriation of net primary production doubled in the 20th century, PNAS, 110:25, 10324-10329.

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

Sitch S et al. (2003) Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Global Change Biol 9:161-185.

S 2.2.3.6. Oceanic carbon sequestration

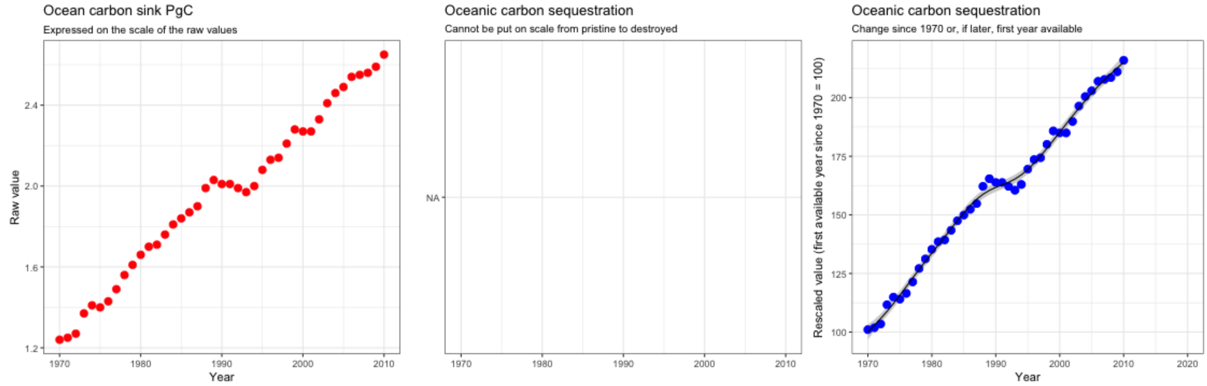
Indicator status: Other indicator
EBV class: Ecosystem function
Indicator reveals the efficiency of carbon sequestration
Indicator type: Representative/Underpin NCP
This indicator is based upon globally representative data and indicates ecosystem service potential
Years covered: 1970-2010, annual time steps

Oceanic carbon sequestration has doubled since 1970.

Overview

When atmospheric carbon dioxide is dissolved into surface waters the carbon may be taken up by living creatures through photosynthesis or through incorporation into animal shells as calcium carbonate, or it may remain as dissolved inorganic carbon, a major contributor to oceanic acidification. As living creatures die and fall to the ocean floor, any material that is not taken up by scavengers and detritivores will result in the long-term sequestration of carbon into the ocean sediment. In the past decade it is estimated that the ocean has provided a sink for about one quarter of the carbon released through anthropogenic sources (Le Quere et al. 2018).

Status and trend



Oceanic carbon sequestration: status and trend. A) Oceanic carbon sequestration (PgC). B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available .C) Trendline for rescaled data showing change since 1970.

Oceanic carbon sequestration has more than doubled since 1970, leading to an increase in the amount of carbon matter locked in the ocean sediment. Carbon sequestration is influenced by temperature as well as the amount of atmospheric carbon available, and carbon sequestration does not occur evenly across the globe, with waters in northern latitudes absorbing greater carbon than those of tropical or southern latitudes (Le Quere et al. 2018).

Sampling methodology and data selection

Oceanic carbon sequestration is estimated using an ensemble of global ocean biogeochemistry models (GOBMs) constrained by observations (Le Quere et al. 2018). GOBMs were selected to represent the physical, chemical, and biological processes that control ocean carbon sequestration. Eight GOBMs were used to estimate oceanic carbon sequestration over time (CCSM-BEC CSIRO, NorESM-OC, MITgcm-REcoM2, MPIOM-HAMOCC, NEMO-PISCES (CNRM), NEMOPISCES (IPSL), and NEMOPlankTOM5). All GOBMs fall within 90% confidence of the range assessed through observed data (Le Quere et al. 2018). Human-induced changes to oceanic nutrient supply were not included within models, leading to an underestimate of carbon sequestration (Le Quere et al. 2018).

References

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

S 2.2.3.7 Terrestrial carbon sequestration (model ensemble)

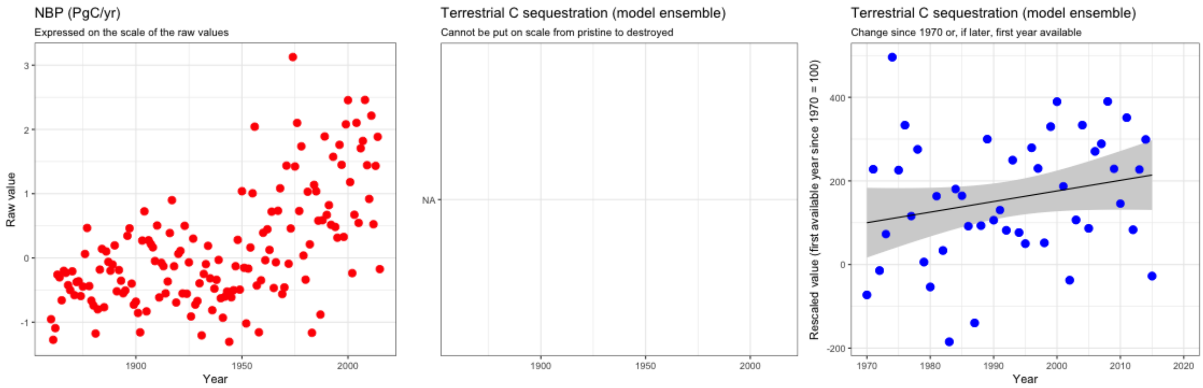
Indicator status: Other indicator
EBV class: Ecosystem function
Indicator reveals the efficiency of carbon sequestration
Indicator type: Representative/Underpin NCP
This indicator is based upon globally representative data and indicates ecosystem service potential
Years covered: 1860-2015, annual time steps

Despite annual fluctuations in terrestrial carbon sequestration, there is an indication that sequestration has increased in the last 150 years.

Overview

Terrestrial carbon sequestration quantifies the store of carbon that is accumulated in vegetative biomass over a year. Terrestrial carbon sequestration occurs when carbon is locked into perennial plant biomass and thereby removed from the global carbon cycle until the plant is consumed or destroyed by fire. Annual plants, plants consumed by herbivores and crops harvested on an annual basis will not contribute to terrestrial carbon sequestration, so if terrestrial carbon sequestration does not increase at the same rate as net primary productivity this may be an indication that agriculture (crops or pasture) may be influencing levels of sequestration.

Status and trend



Terrestrial carbon sequestration: status and trend. A) Terrestrial carbon sequestration per year (PgC). B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 1970.

Although terrestrial carbon sequestration shows annual fluctuations, the data reveals a trend towards an increase in sequestration over time. The rate of gain is lower than that observed for terrestrial NPP, thereby indicating that the annual removal of biomass (through consumption, harvesting or fire) has increased over time.

Sampling methodology and data selection

The TRENDY version 6 outputs (Le Quéré et al. 2018) were used. The TRENDY v6 dataset is a collection of terrestrial carbon cycle model outputs. The models were run from 1860 to 2016 with observed temporal variations in atmospheric CO2 concentration (ice-core and direct observation), climate (global gridded climate data from CRU-NCEP), and land use (Hurtt LULCC data based on HYDE 3.2 data). In this assessment, model outputs with variable atmospheric CO2, climate and land use (S3 run) were used, although TRENDY v6 data covers other runs (S1-run: variable CO2, fixed climate and land use, and S2 run: variable CO2 and climate and fixed land use). Among 14 participating models, eight model outputs (CABLE, CLM4.5, ISAM, JSBACH, JULES, LPJwsl, LPX, and VISIT) were used because of availability of outputs required in this assessment.

References

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

S 2.2.3.8 Terrestrial NPP (model ensemble)

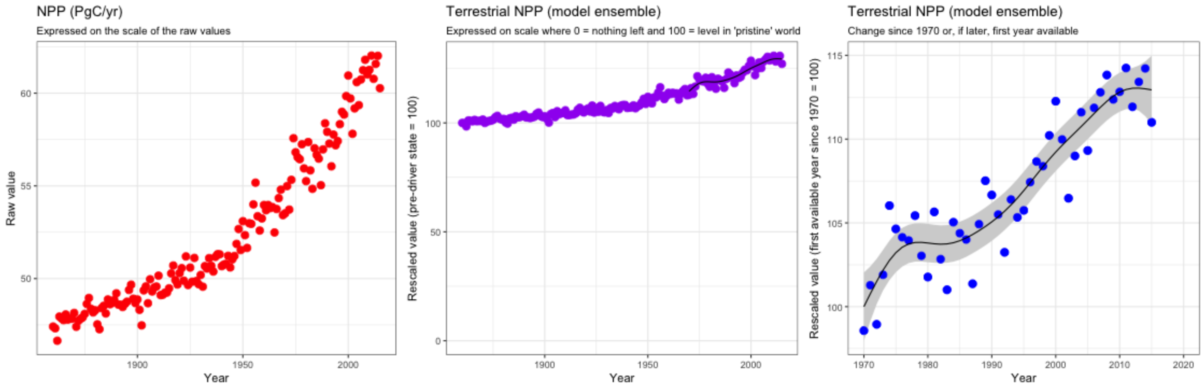
Indicator status: Other indicator
EBV class: Ecosystem function
Indicator reveals the efficiency of carbon sequestration
Indicator type: Representative/Fundamental
This indicator is based upon globally representative data and NPP is fundamental to the structure and function of ecosystems
Years covered: 1860-2015, annual time steps

Terrestrial NPP has increased by approximately 27% in the last 150 years, according to an ensemble of mechanistic models

Overview

Terrestrial net primary production (NPP) describes the total amount of carbon taken up in vegetative biomass production and therefore provides an indication of trends in the global productivity of plants. NPP levels are determined by both natural and anthropogenic mechanisms including temperature, solar radiation, precipitation, atmospheric CO_2, fertilization and the introduction of crops.

Status and trend



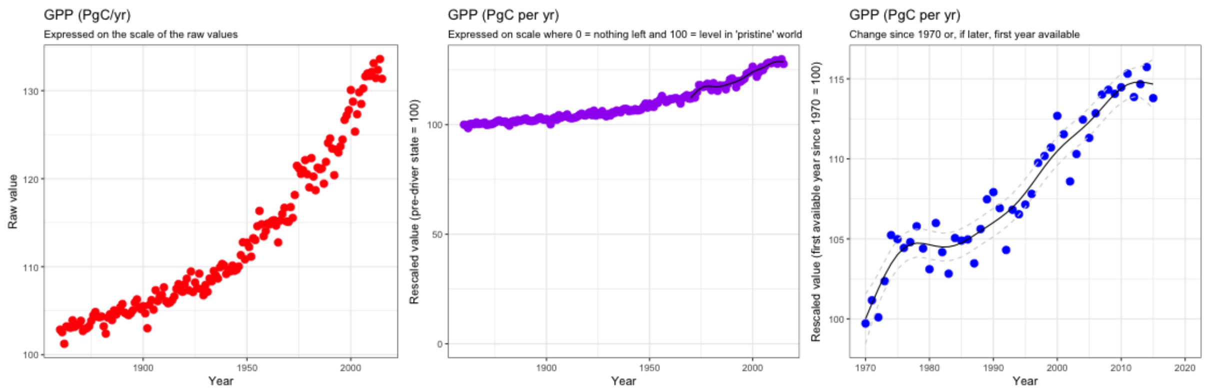
Terrestrial NPP (model ensemble): status and trend. A) Terrestrial net primary production (NPP, in PgC/yr). B) Terrestrial NPP rescaled to show deviation in trendline from an 1860 baseline (the first year for which data is calculated). C) Trendline for rescaled data showing change since 1970.

Approximately 12 Pg more carbon per year is sequestered into vegetative biomass than was 150 years ago. This represents an increase of about 27%. The rate of change in terrestrial NPP is increasing; for instance, NPP increased by ~ 6% from 1860 to 1910 and by ~15% from 1965 to 2015. Increases in NPP may be driven by increasing global average temperatures, increased atmospheric CO_2 availability, and the regrowth of forests in areas abandoned from agriculture due to urbanisation and agricultural intensification. Decreases in NPP may be driven by the replacement of forests by herbaceous crops.

Sampling methodology and data selection

The TRENDY version 6 outputs (Le Quéré et al. 2018) were used. The TRENDY v6 dataset is a collection of terrestrial carbon cycle model outputs. The models were run from 1860 to 2016 with observed temporal variations in atmospheric CO2 concentration (ice-core and direct observation), climate (global gridded climate data from CRU-NCEP), and land use (Hurtt LULCC data based on HYDE 3.2 data). In this assessment, model outputs with variable atmospheric CO2, climate and land use (S3 run) were used, although TRENDY v6 data covers other runs (S1-run: variable CO2, fixed climate and land use, and S2 run: variable CO2 and climate and fixed land use). Among 14 participating models, eight model outputs (CABLE, CLM4.5, ISAM, JSBACH, JULES, LPJwsl, LPX, and VISIT) were used because of availability of outputs required in this assessment.

Terrestrial gross primary production (GPP), also estimated by these models, shows extremely similar status and trends, as expected given it is a component of NPP (the difference between GPP and NPP is the amount of respiration done by the primary producers). We therefore do not report it separately in the synthesis, but include the status and trend figures here for completeness.



Terrestrial gross primary production (GPP): status and trend. A) Terrestrial GPP (PgC/yr). B) Terrestrial GPP rescaled to show deviation in trendline from a pristine world where the pristine baseline is assessed as the 1860 level (the first year for which data is calculated). C) Trendline for rescaled data showing change since 1970.

References

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2018) Global Carbon Budget 2017, Earth Syst. Sci. Data, 10, 405-448, https://doi.org/10.5194/essd-10-405-2018, 2018.

S 2.2.3.9 Terrestrial NPP (remote-sensing)

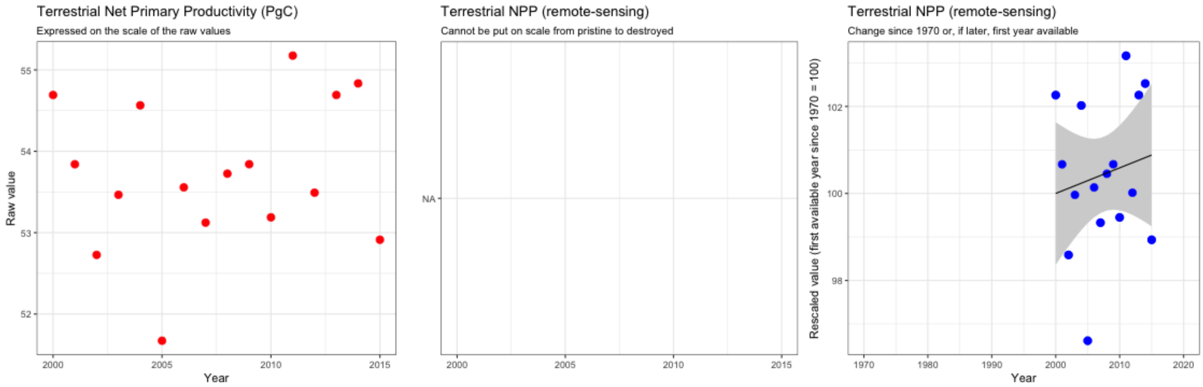
Indicator status: Other indicator
EBV class: Ecosystem function
Terrestrial NPP measures the ability of ecosystems to function
Indicator type: Representative/Underpin NCP
This indicator is based upon globally representative data and indicates ecosystem service potential
Years covered: 2000-2015, annual time-steps

The global pattern of trends in terrestrial NPP seen from remote-sensing is complex and shows annual and regional variation caused by the contrasting pressures of changing temperatures and precipitation levels.

Overview

Terrestrial net primary production (NPP) quantifies the amount of biomass produced by terrestrial plants. This indicator is sensitive to atmospheric carbon availability as well as temperature, solar radiation and rainfall and may therefore provide an indication of how climate change is influencing the energy available (as vegetative biomass) to terrestrial food webs. This indicator also provides a measure of the potential yields available to agriculture without management which is of relevance when considering the sustainability of management practices.

Status and trend



Terrestrial NPP (remote-sensing): status and trend. A) Total terrestrial net primary production (PgC). B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline for rescaled data showing change since 2000.

Comparison of 2015 levels to those of 2000 shows an overall decline in terrestrial NPP of 0.55 petagrams of carbon but there has been considerable interannual variability and the trendline for all data points has a positive slope (Figure C). Increases in terrestrial NPP can be explained by increases in temperature, and the declines can be attributed to changing precipitation patterns causing widespread droughts, especially across the Southern Hemisphere. This disparity of the change in the climate between the Northern and Southern Hemispheres has resulted in an increase in NPP across the Northern Hemisphere and a decrease in NPP across the Southern Hemisphere. However, the majority of the variation in the global NPP is explained by changes in the tropical rainforests, with the Amazon rainforest alone observed to explain 66% of global NPP variations (Zhao and Running 2010). Such variation is likely to have detrimental impacts on the food webs of these biodiverse areas - biodiversity that is already under strain from pressures such as land conversion and fragmentation.

Sampling methodology and data selection

Spatially explicit terrestrial NPP is produced through the combination of vegetation distribution maps with climate data (Zhao & Running 2010). The Moderate Resolution Imaging Spectroradiometer (MODIS) database provides data on the photosynthetic activity of each grid cell (the fraction of photosynthetically active radiation, FPAR) as well as the aerial plant cover of each grid cell (leaf area index, LAI). Climate data was extracted from data provided by the National Center for Environmental Prediction (NCEP) (Kanamisu et al. 2002). Soil moisture was assessed using the Palmer Drought Severity Index (Dai et al. 2004). Data is updated annually and released publicly through: http://www.ntsg.umt.edu/project/modis/mod17.php.

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Kanamitsu, M. et al., 2002, NCEP–DOE AMIP-II reanalysis (R-2). Bull. Am. Meteorol. Soc. 83, 1631

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S 2.2.4 Indicators of community composition – local scale

S 2.2.4.1 Biodiversity Intactness Index (overall)

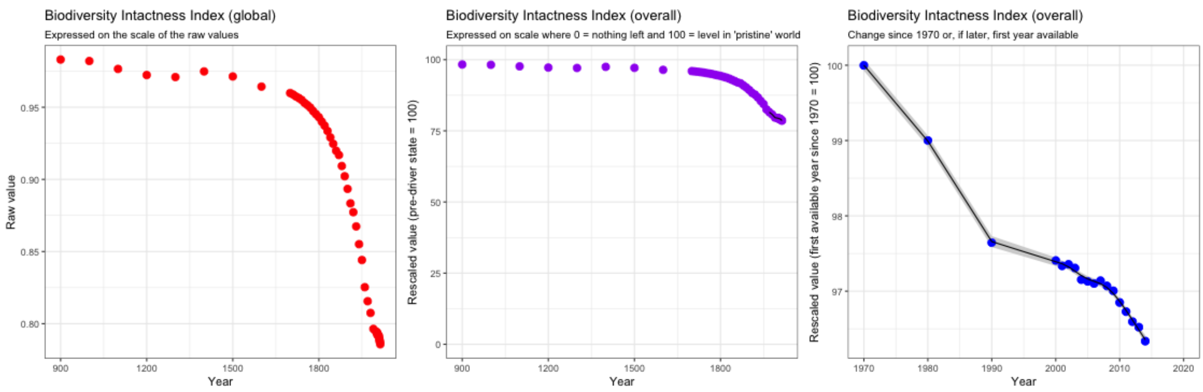
Indicator status: Core indicator
EBV class: Community composition
This indicator provides information on the relative change in abundance of native species as compared to a pristine system
Indicator type: Representative
This indicator is based upon globally and taxonomically representative data.
Years covered: 900-2014, 10 year time-steps from 1700

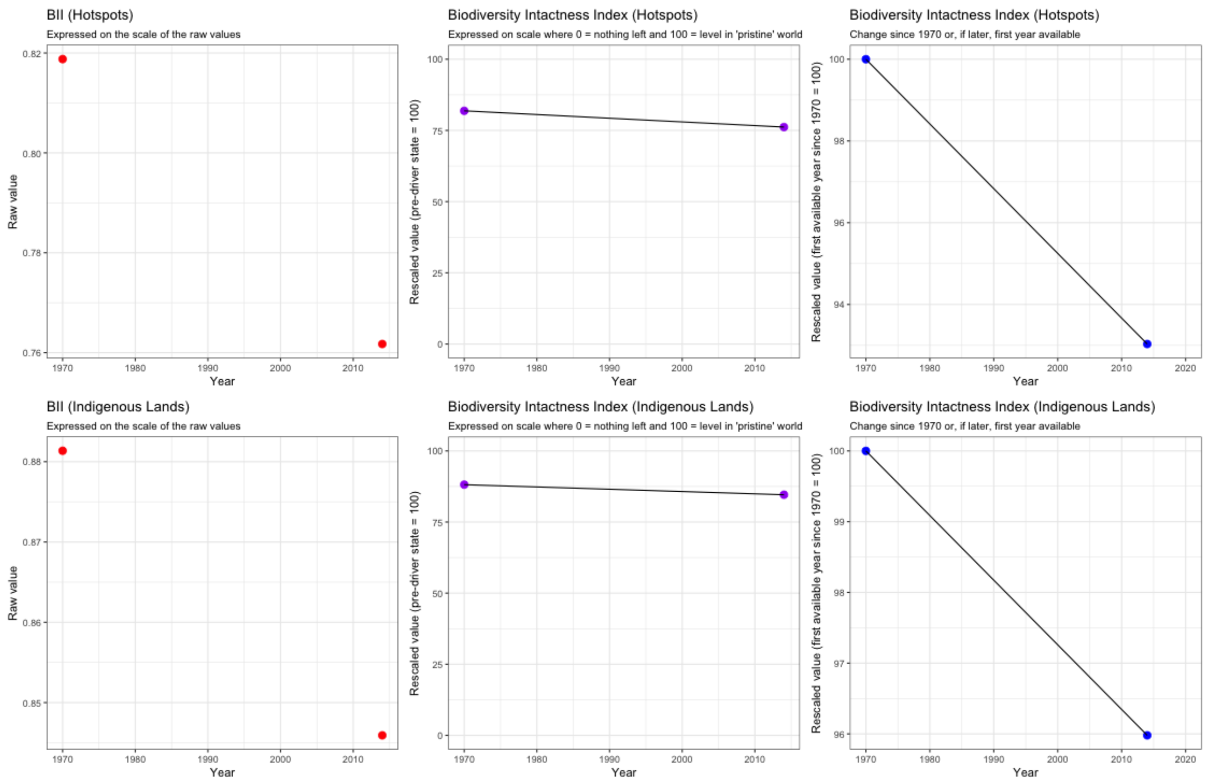
Local biodiversity intactness has, on average, decreased across the world's terrestrial ecosystems by at least 20%.

Overview

The conversion of pristine land for agriculture and urbanisation has dramatic consequences to native biodiversity and ecosystem services. Such pressures are amplified when land is used intensively or when other pressures are introduced within the landscape such as the presence of roads or human settlements. Anthropogenic pressures change the composition of species communities at local scales through pressures causing declines in abundance of certain sensitive species, as well as increases of other, often widespread, species. The provision of NCP within a defined area is determined by the abundance of the relevant species within that area. The Biodiversity Intactness Index (BII) provides an indication of where NCP may be threatened due to the decline in the abundances of native species across a wide range of taxonomic groups.

Status and trend





Biodiversity Intactness Index (BII) overall: status and trend. Top row: A) Change in global mean BII since 900CE. B) Trend in global mean BII on a scale from 0 to 100%, where 100% represents a world with no human pressures. C) Trend in global mean BII since 1970. Second row: As top row, but estimates are for land within the hotspots of narrowly-distributed species and are for 1970 and 2015. Third row: As top row, but estimates are for Indigenous lands and are for 1970 and 2015.

The average level of BII has decreased since 900 with a sharp decline in intactness observed post-1700. Such loss is likely to have consequences to the functioning of ecosystems and the essential services that they provide (Newbold *et al.* 2016; Scholes & Biggs 2005). However, there are some indications that the rate of loss of intactness is slowing, with the rate of loss observed from 1990-2010 nearly a third that observed from 1970-1990. The average level of local biodiversity intactness is lower in areas considered hotspots of narrowly-distributed species and higher in Indigenous lands.

Sampling methodology and data selection

The PREDICTS framework estimates how site-level community abundance and abundance-based compositional similarity respond to land use and related pressures (Newbold et al. 2015). Biodiversity data is obtained from the PREDICTS database, a geographically and taxonomically representative database amalgamated from primary literature to explore how anthropogenic pressures have influenced local biodiversity (Hudson et al. 2017). Models are then combined with time series data on land use, land use intensity, and human population density to produce gridded maps of biodiversity change over time; note that effects of other pressures having a different spatial pattern from these (e.g., climate change) will be missed. Gridded annual land use and human population density maps were taken from Hurtt et al. (*in prep*). Combining maps of abundance with compositional similarity provides estimates of the Biodiversity Intactness Index (BII), first proposed by Scholes & Biggs (2005) and first implemented within the PREDICTS framework by Newbold et al. (2016). Annual global averages are calculated from grid cell results weighted by net primary productivity, to reflect the greater ecological importance of productive rather than unproductive regions. The data used here come from Hill et al. (2018), who provide full methodological details.

S 2.2.4.1.1. Subset: Tropical Forest BII

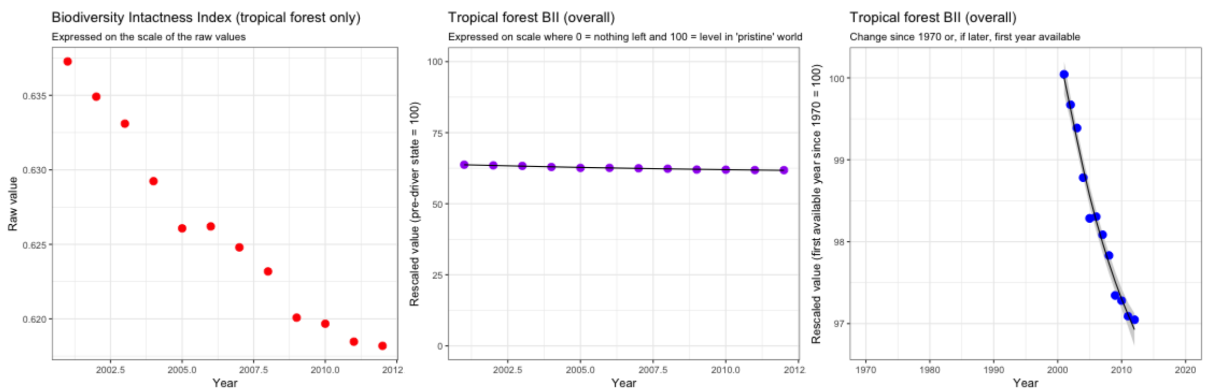
Indicator status: Core indicator
EBV class: Community composition
This indicator provides information on the relative change in abundance of native species as compared to a pristine system
Indicator type: Representative
This indicator is based upon globally and taxonomically representative data
Years covered: 2001-2012, annual time-steps

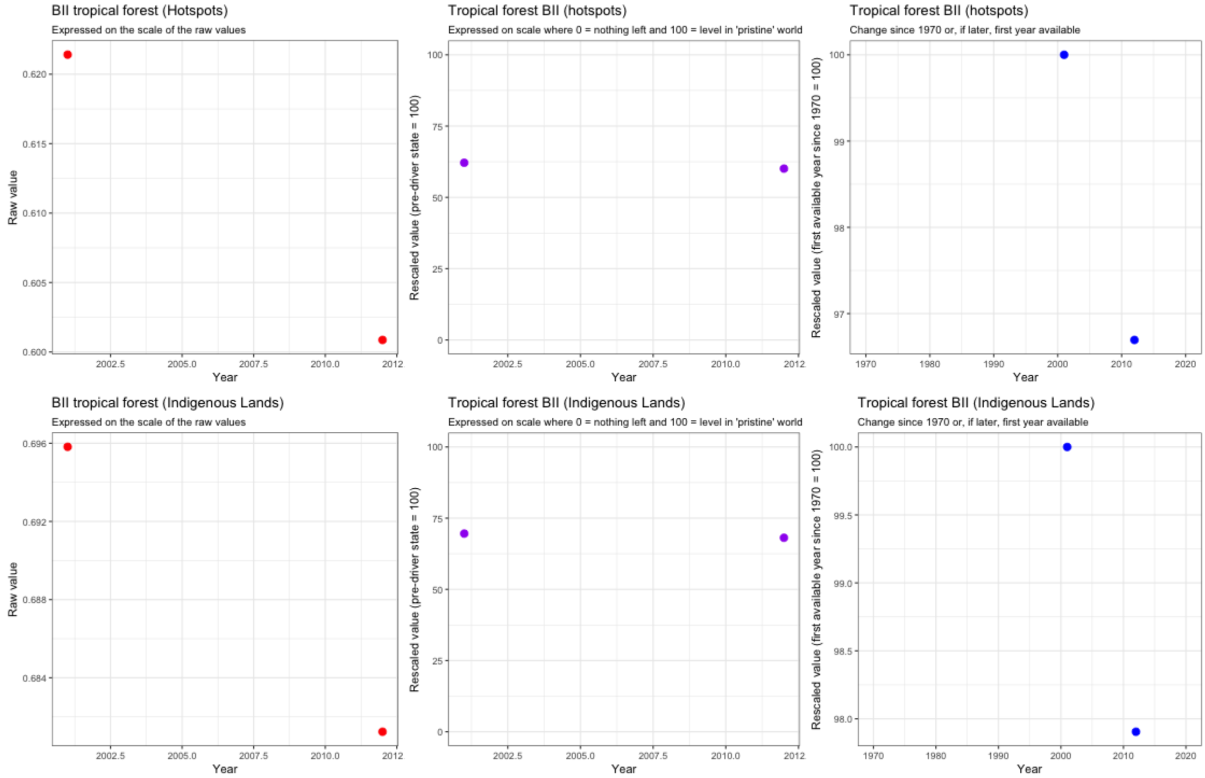
Anthropogenic pressures have resulted in the loss of nearly 40% of terrestrial biodiversity intactness on average in tropical and subtropical forest biomes.

Overview

The conversion of pristine land for agriculture and urbanisation has dramatic consequences to native biodiversity and ecosystem services. Such pressures are amplified when land is used intensively or when other pressures are introduced within the landscape such as the presence of roads or human settlements. Anthropogenic pressures change the composition of species communities at local scales through pressures causing declines in abundance of certain sensitive species, as well as increases of other, often widespread, species. The provision of ecosystem services within a defined area is determined by the abundance of the relevant species within that area. The Biodiversity Intactness Index (BII) provides an indication of where ecosystem services may be threatened due to the decline in the abundances of native species. This indicator focuses on tropical and subtropical forest biomes – regions where high levels of biodiversity have intersected with often high levels of deforestation in recent years.

Status and trend





Tropical forest Biodiversity Intactness Index (BII): status and trend. Top row: A) Global mean change in BII in tropical and subtropical forest biomes. B) Trend in tropical forest BII where 100% represents a pristine world. C) Trend in tropical forest BII since 1970. Second row: as top row, but for the intersection between tropical and subtropical forest biomes and the hotspots of narrowly-distributed species. Third row: as top row, but for the intersection between these biomes and Indigenous lands.

Tropical and subtropical forest BII has been severely degraded, with nearly 40% of local intactness, on average, lost due to anthropogenic pressures. This dramatic result highlights the increased pressure faced by tropical and subtropical ecosystems in particular as the average local intactness here is estimated to be much lower than the global average. The average level of local biodiversity intactness within tropical forests is still rapidly decreasing with approximately 3% of intactness lost from 2001 to 2012.

Sampling methodology and data selection

The PREDICTS framework estimates how site-level community abundance and abundance-based compositional similarity respond to land use and related pressures (Newbold et al. 2015). Biodiversity data is obtained from the PREDICTS database, a geographically and taxonomically representative database amalgamated from primary literature to explore how anthropogenic pressures have influenced local biodiversity (Hudson et al. 2017). Models are then combined with time series data on land use, land use intensity, the density of roads, and human population density to produce maps of biodiversity change over time. Annual land use maps for tropical forests were produced using methods outlined by Hoskins et al. (2016). For sources of other pressure variables see Newbold et al. (2016). Combining maps of abundance with compositional similarity provides estimates of the Biodiversity Intactness Index (BII), first proposed by Scholes & Biggs (2005) and first implemented in the PREDICTS framework by Newbold et al. (2016). This indicator comes from De Palma et al. (2018), who have improved on the compositional similarity modelling approach used by Newbold et al. (2016).

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Scholes, R.J., Biggs, R., 2005, A biodiversity intactness index, Nature, 434, 45-49.

S 2.2.4.2. Local species richness (BioTime)

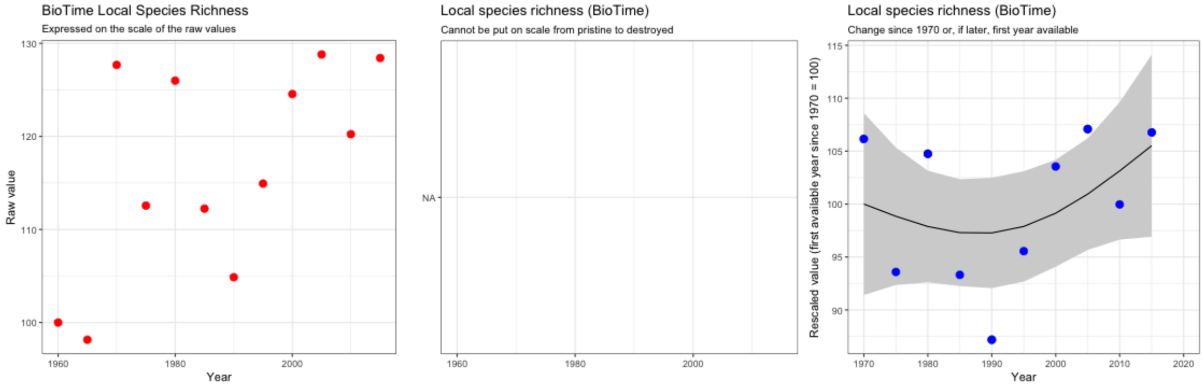
Indicator status: Highlighted indicator
EBV class: Community composition
This indicator provides data on the change in number of species within a community
Indicator type: Representative
This indicator is based upon the BioTime dataset - a global dataset containing a wide variety of taxonomic groups.
Years covered: 1960-2015, 5 year time-steps

Local species richness has, on average, increased by about 5% since 1960, but the increase is not statistically significant.

Overview

The extent to which biodiversity change in local assemblages contributes to global biodiversity loss is poorly understood. This indicator includes time series from nearly 8.8 million species abundance records from biomes across Earth to assess how species richness within assemblages is changing through time. The indicator identifies quantified patterns of temporal diversity, measured as change in local diversity. The geographical distribution of study locations is global, and includes marine, freshwater, and terrestrial biomes, extending from the polar regions to the tropics in both hemispheres.

Status and trend



Local species richness (BioTime): status and trend. A) Change in local species richness. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trend in local species richness since 1970.

Local species richness has increased since 1960 with a slight, but not statistically significant, gain of 5% estimated between 1960 and present-day. This suggests that, whilst global biodiversity may be declining, local richness may be increasing. Although results are variable, only one time period (1965) reveals a negative trend. This pattern may be explained through species invasions and biotic homogenization; however, data comes from a mix of impacted and unimpacted sites.

Sampling methodology and data selection

Data are extracted from the BioTime database, a global database consisting of nearly 8.8 million species abundance records from assemblages consistently sampled for a minimum of 2 years. The database encompasses 550 000 sites across marine, freshwater and terrestrial realms with records pertaining to plant, invertebrate and vertebrate species. Although BioTIME contains records dating from 1874 here sampling data are restricted to post-1960. Rarefied species richness per study is calculated to account for variation in sampling effort. Within each study, species richness for all sampling years is expressed as a proportion of the first year sampled (t_0=100%). Years are binned into five-year intervals and local species richness per interval is estimated using a mixed-effects modelling structure with the natural logarithm of species richness predicted by interval and study-level random effects included.

References

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S 2.2.4.3. Local species richness (PREDICTS)

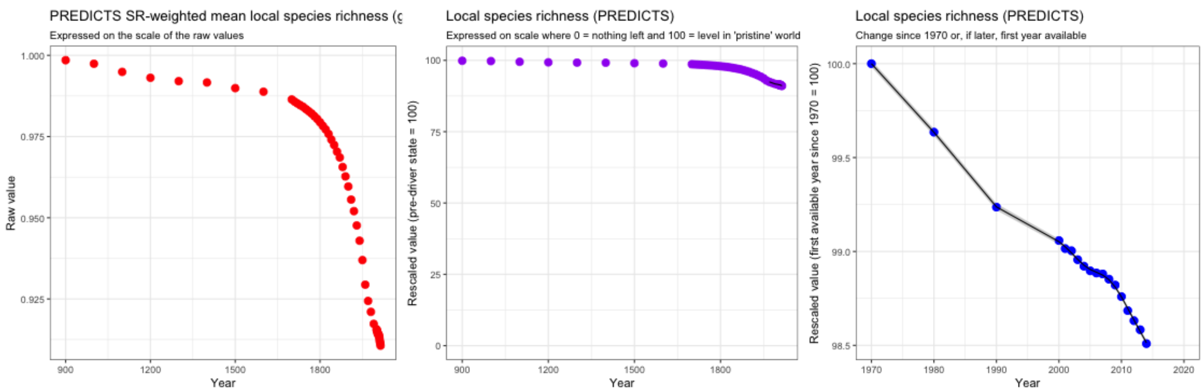
Indicator status: Other indicator
EBV class: Community composition
This indicator provides information on the change in average local species richness over time
Indicator type: Representative
This indicator is based upon globally and taxonomically representative data.
Years covered: 900-2014, 10-year time steps from 1700, annual since 2000.

On average, species richness is about 9% lower in local terrestrial communities than before human impacts began.

Overview

Local species richness trends are modelled using data from the PREDICTS database - a geographically and taxonomically representative database amalgamated from primary literature to explore how anthropogenic pressures have influenced local biodiversity (Hudson et al. 2017). Local species richness explores how community-level species richness is influenced by human pressures such as land use change, land use intensity and human density. Models are projected onto historical maps of pressures (Hurtt *et al. in prep*) to produce trendlines of local species richness from 900 to 2014.

Status and trend



Local species richness (PREDICTS): status and trend. A) Estimated average change in local species richness. B) Trend in local species richness where 100% represents a pristine world. C) Trend in local species richness since 1970.

Local species richness is estimated to have fallen by about 9%, on average, in the world's terrestrial communities. About 90% of this loss has occurred since 1700. Declines still continue: since 1970, local terrestrial communities have on average lost 1.5% of the species they had in 1970.

Sampling methodology and data selection

The PREDICTS framework estimates how site-level species richness responds to land use and related pressures (Newbold et al. 2015). Biodiversity data is obtained from the PREDICTS database, a geographically and taxonomically representative database amalgamated from primary literature to explore how anthropogenic pressures have influenced local biodiversity (Hudson et al. 2017). Models are then combined with time series data on land use, land use intensity, and human population density to produce gridded maps of biodiversity change over time. Gridded annual land use and human population density maps were taken from Hurtt et al. (*in prep*). Annual global averages are calculated from grid cell results weighted by vertebrate species richness (IUCN data). The data used here come from Hill et al. (2018), who provide full methodological details.

References

Hill, S. L. L., et al. (2018) Worldwide impacts of past and projected future land-use change on local species richness and the Biodiversity Intactness Index. bioRxiv. doi: https://doi.org/10.1101/311787.

Hurtt, G., L. Chini, R. Sahajpal, S. Frolking, et al. "Harmonization of global land-use change and management for the period 850-2100". Geoscientific Model Development (In prep).

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Newbold, T.N., Hudson, L.N., Arnell, A.P., Contu, S., De Palma, A., Ferrier, S., … Purvis, A., 2016, Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment, Science, 353 (6296), 288-291.

S 2.2.4.4. Mean Species Abundance index

Indicator status: Highlighted indicator
EBV class: Community composition
This indicator provides information on the relative change in the mean abundance of species within a community
Indicator type: Representative
The index is compiled from global data encompassing a wide variety of taxonomic groups

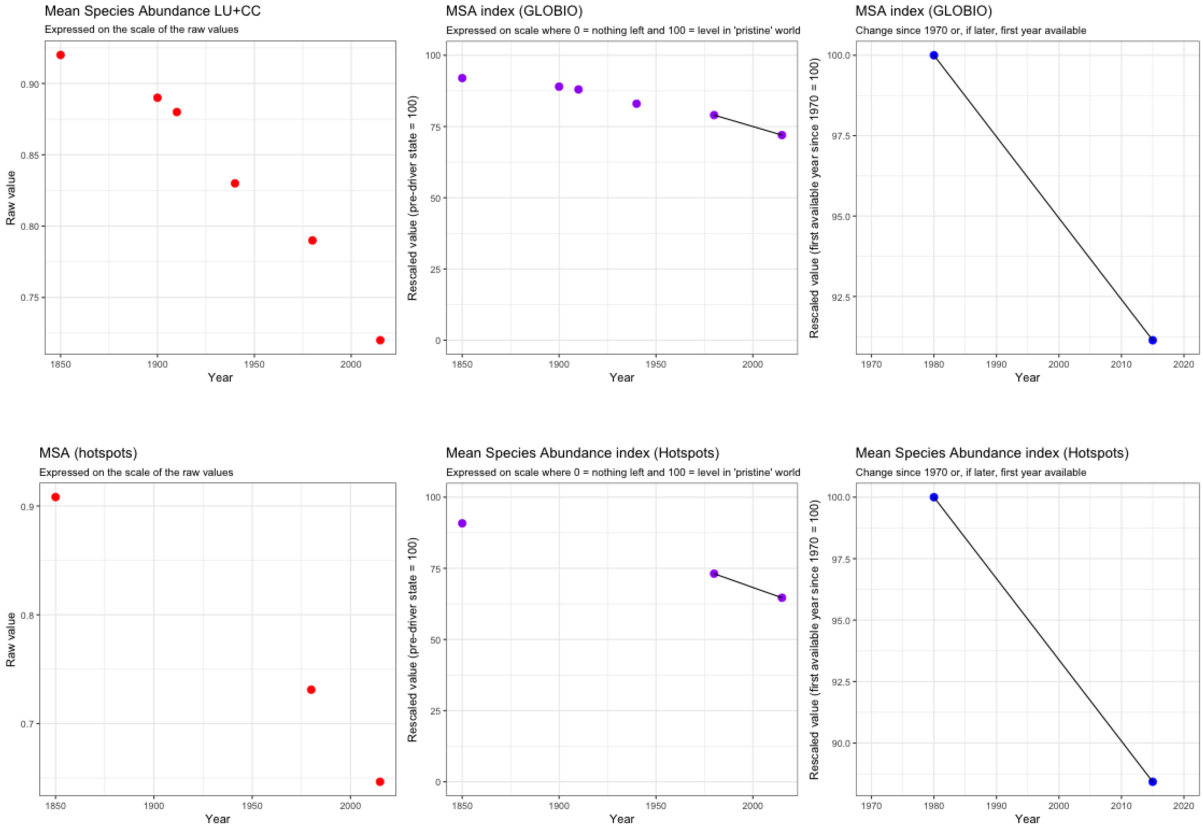
Years covered: 1850-2015, variable time-steps

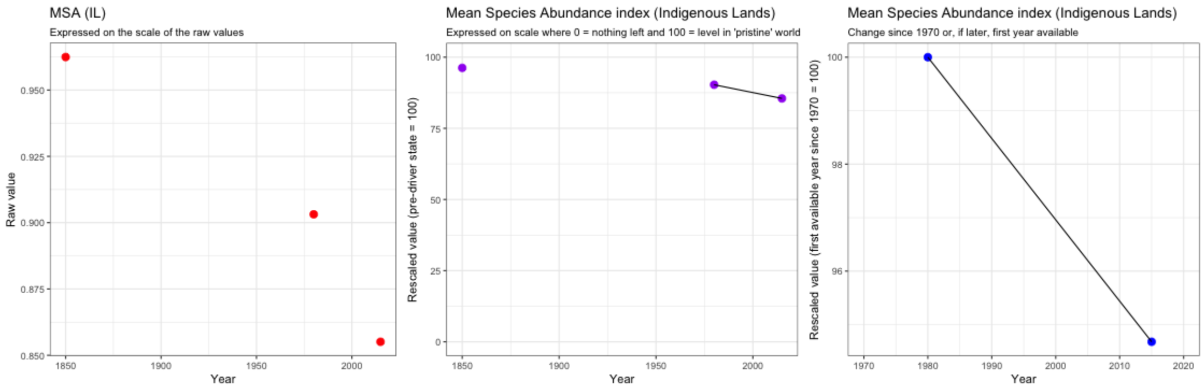
Human impacts have caused dramatic changes to native biodiversity with a loss of approximately one quarter, on average, of Mean Species Abundance across the globe.

Overview

Homogenisation results when human actions directly or indirectly cause certain, often specialised, species to decline, while other, often opportunistic and widespread, species proliferate across regions that previously would have been ecologically distinct. This process may lead to extinctions on a local or global scale; but, prior to this, the relative abundances of species within their native communities will change. The Mean Species Abundance (MSA) index measures the impacts of multiple anthropogenic pressures on the abundance of original species, measured relative to their abundance in the original state of the ecosystem. As such it is an indicator of biodiversity intactness that is particularly sensitive to change (as increases in abundance are not accounted for and abundance-focused indices will detect change prior to species richness indices).

Status and trend





Mean Species Abundance index: status and trend. Top row: A) Global average Mean Species Abundance. B) Trend in Mean Species Abundance where 100% represents a pristine world. C) Trendline showing % change in mean species abundance since 1980. Second row: As top row, but for land within the hotspots of narrowly-distributed species. Third row: as for top row, but for Indigenous lands only.

Human impacts have caused dramatic changes to native biodiversity with a loss of approximately one quarter, on average, of MSA across the globe. Loss of MSA is greater within hotspots and lower within Indigenous lands. Over the last four decades the rate of loss within Indigenous lands is approximately half of that within hotspots.

Sampling methodology and data selection

MSA is defined as the average of the abundances of originally occurring species relative to their abundances in the original, pristine or mature state as the basis (Alkemade et al. 2009; Schipper et al. 2016). The model is based on a set of correlative relationships between biodiversity (MSA) on the one hand and anthropogenic pressures on the other. The biodiversity data is obtained from the literature and pressure variables are obtained from the IMAGE model (Stehfest et al. 2014) and from global pressures layers. Land use maps were downscaled as described in Kim et al. (2018). The GLOBIO model uses climate change, nitrogen deposition and land use change (obtained from the IMAGE model) and proximity to roads (data obtained from the GRIP 4 dataset (Meijer et al. 2018)) to calculate change in MSA; however, the data shown here focuses solely on the impacts to biodiversity caused by land use change and climate change.

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Schipper AM, Bakkenes M, Meijer JR, Alkemade R, Huijbregts MAJ (2016) The GLOBIO model. A technical description of version 3.5. PBL publication 2369, The Hague, PBL Netherlands Environmental Assessment Agency. http://www.pbl.nl/node/62870

Stehfest, E., van Vuuren, D., Kram, T., Bouwman, L., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., den Elzen, M., Janse, J., Lucas, P., van Minnen, J., Müller, C., Prins, A. (2014) Integrated Assessment of Global Environmental Change with IMAGE 3.0 - Model description and policy applications. The Hague, PBL Netherlands Environmental Assessment Agency.

S 2.2.5 Indicators of community composition – regional scale

S 2.2.5.1 Bird species per grid cell (cSAR)

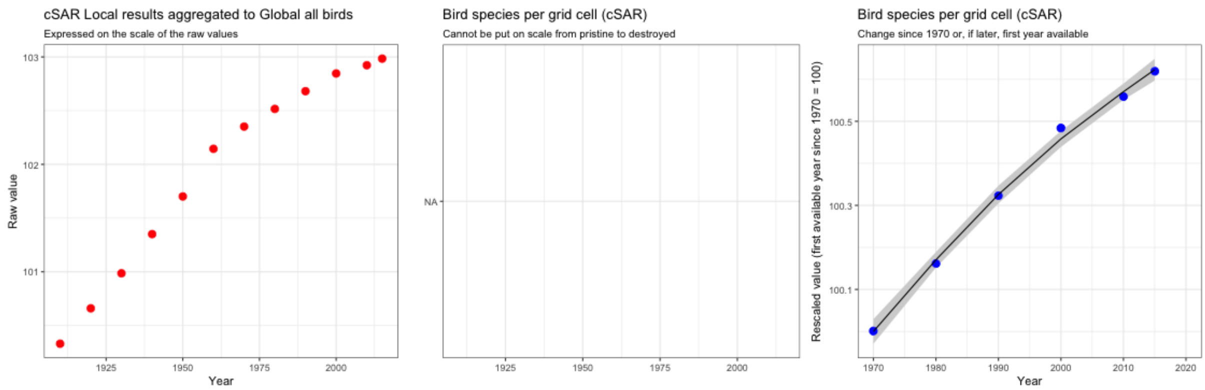
Indicator status: Other indicator
EBV class: Community composition
The indicator measures changes in species richness.
Indicator type: Representative
The indicator uses data from a broad range of bird species.
Years covered: 1900-2015, 10 year time steps

Estimated average bird species richness within 0.25º grid cells has increased steadily since 1900.

Overview

Mean bird species per grid cell assesses the response of biodiversity to land use change using countryside species-area relationship models (Pereira & Daily, 2006). It accounts for the persistence of species in human-modified habitats and for the differential use of habitats by different species groups. The model assesses how species richness changes (i.e., species richness trend) across specified land uses at different time steps.

Status and trend



Bird species per grid cell: status and trend. A) Percentage change in mean species richness of birds per 0.25º grid cell. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trend in mean bird species richness per grid cell since 1970.

On average, species richness has increased since 1900 at the grid-cell scale, with an increase of approximately 3% estimated over this time. The trendline increased steeply to 1960 but the rate of change has slowed in recent years. This increase is in contrast to the trendline observed for specialist birds (see below) indicating that the increase is likely caused by the spread of generalist bird species into novel regions.

Sampling methodology and data selection

For each cell, the countryside SAR utilises a modified form of the species area relationship to assess bird species richness (Kim et al. 2018). The calculation centers around the habitats present within a region of interest. For each habitat type, the affinity of a functional group of birds is assessed and multiplied by the area cover of the habitat extracted from land use maps. The values for all habitats are summed and this value then replaces the Area value within the traditional SAR formula with the parameters *c* and *z* dependent on the taxonomic group and sampling scheme respectively. Habitat preferences and species range maps are extracted from the Birdlife database. The relative affinity of each group to modified habitat compared with pristine habitat is modelled using the PREDICTS database. The comparison of the resulting richness across two time steps gives the expected proportional change caused by the change in habitat. The change is then multiplied by the number of bird species found within the sampling unit (here 0.25^{o} grid cell) according to BirdLife range maps. The result estimates the mean proportion of species in the sampling unit that are expected to be lost or gained over the time step.

2.2.5.1.1. Subset: Forest-specialist bird species per grid cell (cSAR)

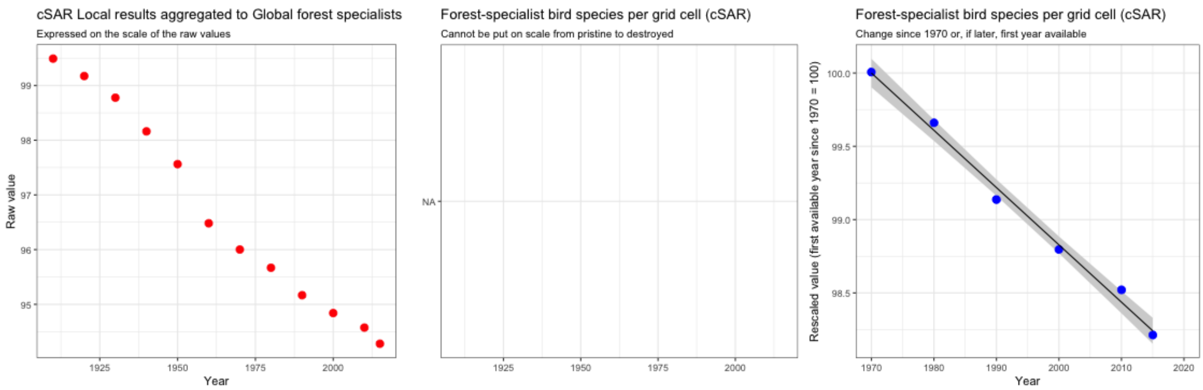
Indicator status: Other indicator
EBV class: Community composition
The indicator measures changes in species richness.
Indicator type: Representative/Sensitive
The indicator uses data from a broad range of specialist bird species.
Years covered: 1900-2015, 10 year time steps

The species richness of forest specialist birds has, on average, steadily decreased since 1900 at the scale of 0.25^{o} grid cells.

Overview

Mean forest-specialist bird species per grid cell assesses the response of forest specialists to land use change using countryside species-area relationship models (Pereira & Daily, 2006). It accounts for the persistence of species in human-modified habitats and for the differential use of habitats by different species. The model assesses how species richness changes (i.e. species richness trend) across specified land uses at different time steps.

Status and trend



Forest-specialist bird species per grid cell: status and trend. A) Percentage change in mean species richness of birds per 0.25º grid cell. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trend in mean species richness per grid cell since 1970.

Forest specialist bird diversity has, on average, decreased by about 6% since 1900. This decrease is in contrast to the trend observed when all bird species (specialists and generalists) are considered (see above). Rate of change has been steady apart from a dramatic decline in diversity that occurred between 1950 and 1960.

Sampling methodology and data selection

For each cell, the countryside SAR utilises a modified form of the species area relationship to assess bird species richness as described above. Bird species are subset to those who are characterised as forest specialists using information provided by the Birdlife database.

References

Kim, H., Rosa, I. M. D., Alkemade, R., Leadley, P., Hurtt, G., Popp, A., . . . Pereira, H. M. (2018). A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios. *bioRxiv*. doi: https://doi.org/10.1101/300632

Pereira, H.M. & Daily, G.C. (2006). Modelling biodiversity dynamics in countryside landscapes. Ecology, 87, 1877-1885.

S 2.2.5.2 Cumulative number of alien species

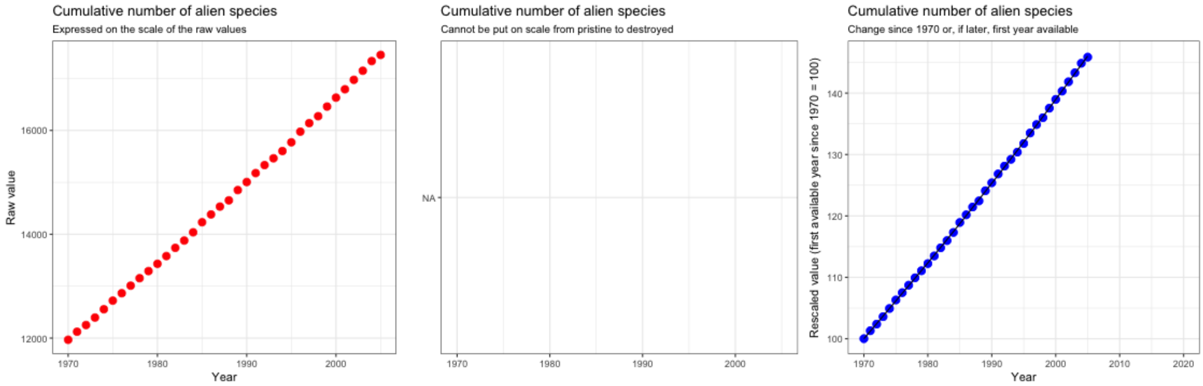
Indicator status: Other indicator
EBV class: Community composition
This indicator tracks the total number of invasive alien species worldwide that have been introduced into species communities
Indicator type: Representative
This indicator is based upon a globally representative dataset containing information regarding a variety of taxonomic groups
Years covered: 1970-2005, annual time-steps

Nearly 5700 novel alien species have become established since 1970.

Overview

Alien species are species that have been deliberately or unintentionally introduced by humans outside their native ranges. Alien species introductions can lead to local extinctions of native species, global biotic homogenization, and implications to ecosystem functioning. The disturbance caused by alien species is likely to be correlated to the abundance of the introduced species as well as the sensitivity of the native species.

Status and trend



Cumulative number of alien species: status and trend. A) Cumulative number of alien species. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline expressed as percentage of the cumulative number of alien species in 1970.

The cumulative number of alien species has risen steadily since 1970, with an increase of approximately 50% in 35 years.

Sampling methodology and data selection

The dataset is compiled of regional first records of alien species that are now established in multiple regions worldwide (Seebens et al. 2017). The dataset includes 45,813 records of 16,926 species from 282 regions. Data was compiled from primary literature as well as online databases. Data was restricted to 2005 to avoid biases due to lags in reporting.

References

Seebens, H., et al. 2017. No saturation in the accumulation of alien species worldwide. Nature Communications. 14435.

S 2.2.5.3. Cumulative introduced invasive aliens

Indicator status: Highlighted indicator
EBV class: Community composition

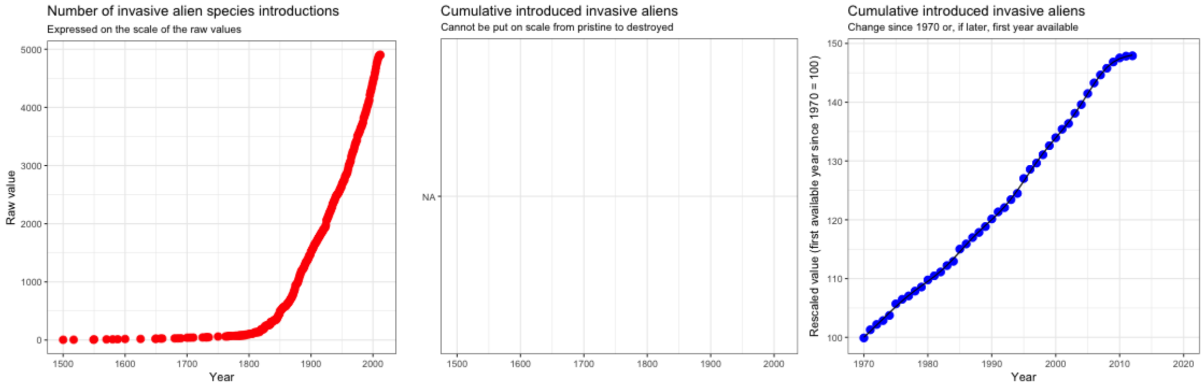
This indicator tracks the number of invasive alien species that have been introduced into species communities
Indicator type: Representative
This indicator encompasses 3914 species including plants, invertebrates, and vertebrates
Years covered: 1500-2012, annual time-steps from 1822

Invasive alien species introductions have dramatically increased over the last two centuries due to huge changes in international trade and infrastructure; the slowdown seen in the rate in the last decade may be due to our recent efforts to prevent such introductions, or may be due to reporting lags.

Overview

An "alien species" in this instance refers to a species, subspecies or lower taxon introduced outside its natural past or present distribution; it includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce. "Invasive alien species" is used to mean an alien species whose introduction, establishment and spread threatens biological diversity. This indicator tracks the number of invasive and potentially invasive alien species that have been introduced (and have often become established) in 21 countries over the last 500 years.

Status and trend



Cumulative introduced invasive aliens: status and trend. A) Cumulative number of invasive alien species introductions. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline plotting the cumulative number of introduced invasive aliens as a percentage of the number in 1970.

The number of invasive alien species introductions has significantly increased over the last 500 years, with a dramatic increase in rate after 1800. The increasing introduction rates of invasive alien species may cause higher establishment rates and are related to increasing international trade and human density. To date, there is an encouraging rise in the adoption of national and international conventions and agreements, regulations and codes of conduct to prevent introduction, establishment, and spread of invasive alien species. There is some indication that these measures are having an impact in that the rate of introductions appears to have decreased in the last decade; however, this may be due to reporting lags. This indicator is drawn from a large dataset with

4903 introduction records and over 500 years of data collection. However, only 21 countries are represented in the dataset (9 islands and 12 countries located on continents), with notable gaps in data from continental Africa, continental Asia and Australia. There is also taxonomic bias - while all taxonomic groups were considered, the majority of the records are plants (>60%), invertebrates, fish, mammals, and birds.

Sampling methodology and data selection

Data were considered from 21 countries that had at least 30 records of species introduction with published year of introduction resulting in the inclusion of 4,903 introduction records from 3,914 invasive alien species. Countries include 9 islands and 12 countries located on continents.

References

IUCN SSC Invasive Species Specialist Group

Pagad et al. 2015 IUCN SSC Invasive Species Specialist Group: invasive alien species information management supporting practitioners, policy makers and decision takers. Management of Biological Invasions (2015) Volume 6, Issue 2: 127–135 http://dx.doi.org/10.3391/mbi.2015.6.2.03

S 2.2.5.4 Functional intactness (Madingley)

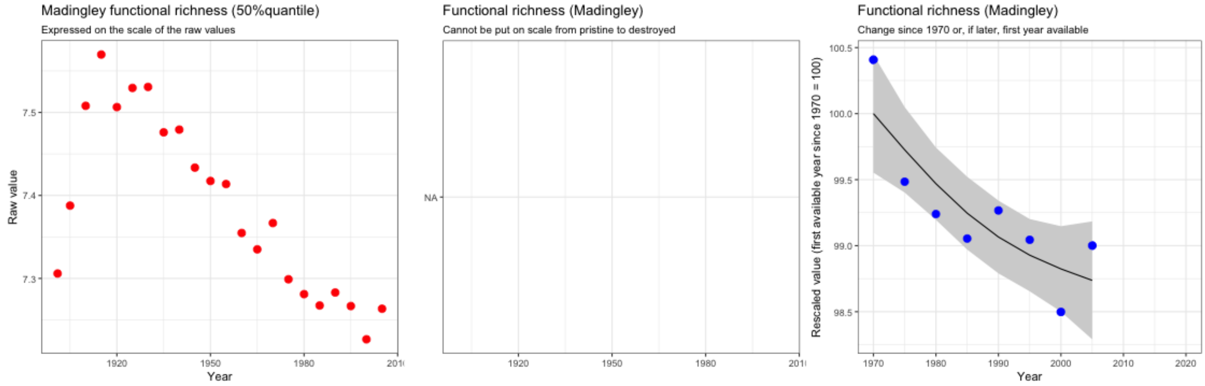
Indicator status: Other indicator
EBV class: Community composition
Measures changes in the functional dynamism of a community
Indicator type: Representative
The indicator is derived from a globally-representative general ecosystem model
Years covered: 1901-2005, 5 year time steps

Functional intactness has slightly but steadily decreased in the last century with an overall decline of 0.6%.

Overview

The functional richness of a community describes how much of the functional trait space is occupied by organisms, and has been shown to be a strong predictor of ecosystem functioning (e.g. Gagic et al., 2015). Functional intactness measures how much of the original functional trait space occupied by a reference community is then occupied by a community at a particular time. Anthropogenic pressures can cause a decline in how much of the trait space is filled, especially when such pressures are selective in their removal (as is likely as specific traits may render species more sensitive to pressures or more desirable for human harvesting), and the fitness of a community may therefore decline due to inefficient exploitation of resources or lack of adaptive capacity. This indicator measures functionally intactness relative to the reference community of 1901.

Status and trend



Functional intactness (Madingley): status and trend. A) Change over time. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline showing change since 1970.

Functional intactness has steadily decreased in the last century with an overall decline of 0.6%. Declines in functional intactness can indicate the trait space of the community has declined or has moved relative to the reference case. Taken in conjunction with the indicator on Functional Richness, which shows declining functional richness, it is likely that the trait space of the community is shrinking. The implication of this is that levels of ecosystem function will also decline, although predicting the magnitude of change in function is challenging.

Sampling methodology and data selection

The Madingley model is a process-based model that describes ecosystem structure and function within marine and terrestrial realms. Most organisms are included within the flexible modelling framework, allowing exploration of the impacts of the environment, human pressures and species interactions on scales from local cohorts to global biodiversity as well as across time (Harfoot et al. 2014). The data described here was modelled using land use inputs from the LUH2 harmonised land use dataset and climate variables from the IPSL model outputs from 1951 to 2099 at 0.5-degree resolution (McSweeney and Jones, 2016). Climate for the period 1901 to 1951 was generated from randomly sampling the climate of the years 1951 to 1960.

References

Gagic, V., Bartomeus, I., Jonsson, T., Taylor, A., Winqvist, C., Fischer, C., Slade, E.M., Steffan-Dewenter, I., Emmerson, M., Potts, S.G. and Tscharntke, T., 2015. Functional identity and diversity of animals predict ecosystem functioning better than species-based indices. Proceedings of the Royal Society of London B: Biological Sciences, 282(1801), p.20142620.

Harfoot, M. B. J., Newbold, T., Tittensor, D. P., Emmott, S., Hutton, J., Lyutsarev, V., . . . Purves, D. W. (2014). Emergent Global Patterns of Ecosystem Structure and Function from a Mechanistic General Ecosystem Model. *PLOS Biology, 12*(4), e1001841. doi:10.1371/journal.pbio.1001841

Kim, H., Rosa, I. M. D., Alkemade, R., Leadley, P., Hurtt, G., Popp, A., . . . Pereira, H. M. (2018). A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios. *bioRxiv*. doi: https://doi.org/10.1101/300632

McSweeney, C. F., & Jones, R. G. (2016). How representative is the spread of climate projections from the 5 CMIP5 GCMs used in ISI-MIP? Climate Services, 1, 24-29. doi:https://doi.org/10.1016/j.cliser.2016.02.001

S 2.2.5.5 Species richness per grid cell (AIM)

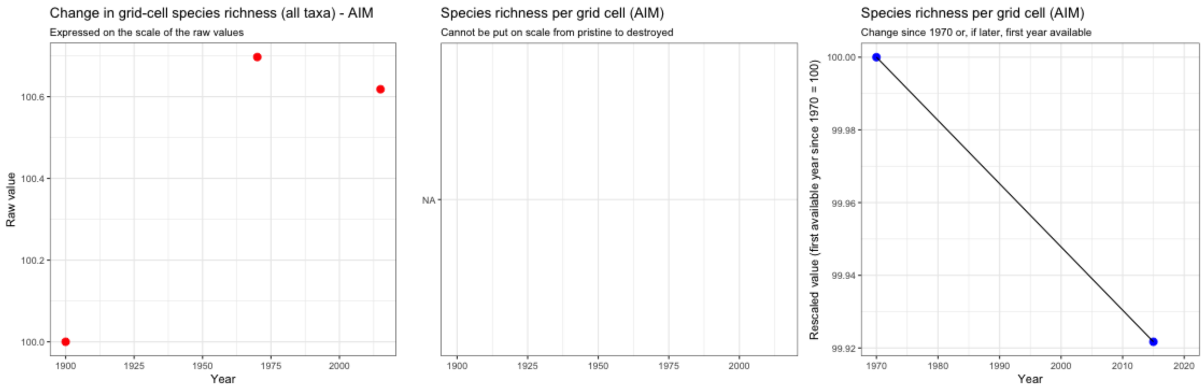
Indicator status: Other indicator
EBV class: Community composition
Indicator reveals changes to local species richness
Indicator type: Representative
Indicator is drawn from data representing over 9000 species from a range of taxonomic groups
Years covered: 1900, 1970 and 2015

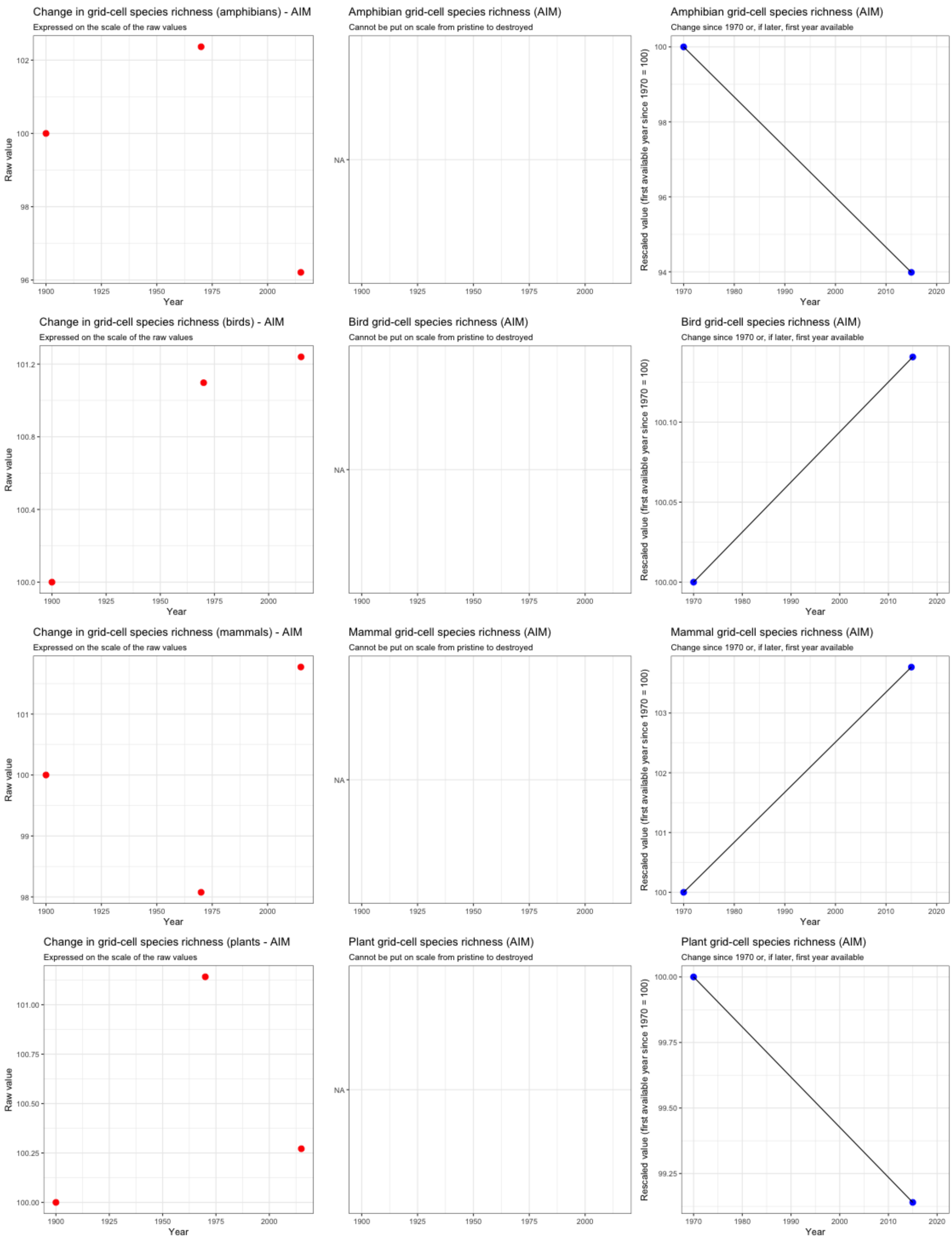
At the spatial scale of 0.5^o grid cells, average species richness of birds, amphibians, reptiles, mammals and vascular plants is inferred to have increased slightly since 1900.

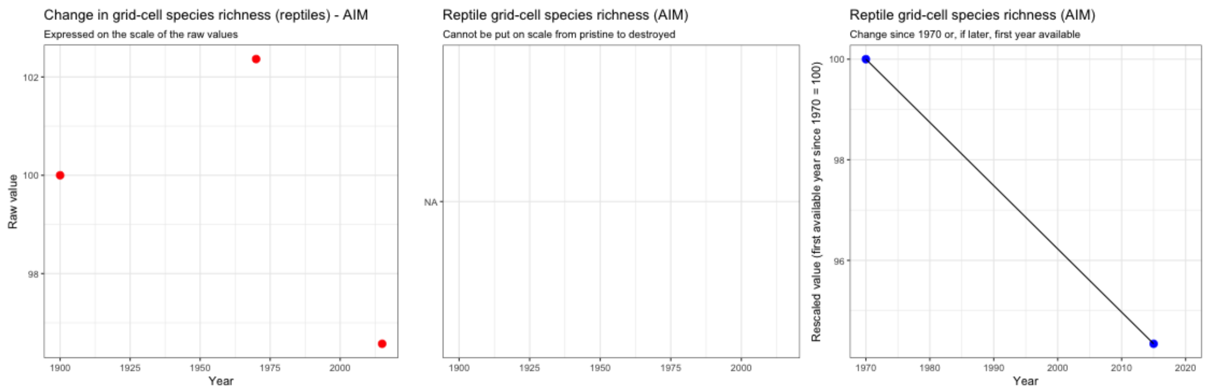
Overview

This indicator evaluates the change in species ranges associated with both land use change and climate. The dataset draws upon the land use allocations and environmental outputs of the Asian-Pacific Integrated Model/Computable General Equilibrium (AIM/CGE) integrated assessment model (Hasegawa et al. 2017). This highly flexible modelling approach allows the examination of pressure/response relationships in the past, present and future including the analysis and disaggregation of biodiversity responses to land use and climate.

Status and trend




Change in grid-cell species richness (amphibians) - AIM
Expressed on the scale of the raw values
Raw value
102
100
98
96
1900 1925 1950 1975 2000
Year
Amphibian grid-cell species richness (AIM)
Cannot be put on scale from pristine to destroyed
NA
1900 1925 1950 1975 2000
Amphibian grid-cell species richness (AIM)
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
100
98
96
94
1970 1980 1990 2000 2010 2020
Year
Change in grid-cell species richness (birds) - AIM
Expressed on the scale of the raw values
Raw value
101.2
100.8
100.4
100.0
1900 1925 1950 1975 2000
Year
Bird grid-cell species richness (AIM)
Cannot be put on scale from pristine to destroyed
NA
1900 1925 1950 1975 2000
Bird grid-cell species richness (AIM)
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
100.10
100.05
100.00
1970 1980 1990 2000 2010 2020
Year
Change in grid-cell species richness (mammals) - AIM
Expressed on the scale of the raw values
Raw value
101
100
99
98
1900 1925 1950 1975 2000
Year
Mammal grid-cell species richness (AIM)
Cannot be put on scale from pristine to destroyed
NA
1900 1925 1950 1975 2000
Mammal grid-cell species richness (AIM)
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
103
102
101
100
1970 1980 1990 2000 2010 2020
Year
Change in grid-cell species richness (plants - AIM
Expressed on the scale of the raw values
Raw value
101.00
100.75
100.50
100.25
100.00
1900 1925 1950 1975 2000
Year
Plant grid-cell species richness (AIM)
Cannot be put on scale from pristine to destroyed
NA
1900 1925 1950 1975 2000
Plant grid-cell species richness (AIM)
Change since 1970 or, if later, first year available
Rescaled value (first available year since 1970 = 100)
100.00
99.75
99.50
99.25
1970 1980 1990 2000 2010 2020
Year



Species richness per grid cell: status and trend. Top row: A) Change in average species richness per 0.5° grid cell. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline showing change since 1970. Second row: As top row, but for amphibians only. Third row: As top row, but for birds only. Fourth row: As top row, but for mammals only. Fifth row: As top row, but for plants only. Sixth row: As top row, but for reptiles only.

The model estimates that average grid-cell species richness will reach 100.6% by 2015 which corresponds to an increase of 0.6% from 1900. However, these numbers are likely to overestimate species richness as dispersal between grid cells of suitable habitat is assumed to be instantaneous and unlimited whereas in reality species are likely to encounter barriers to dispersal resulting in a greater decline of their range than is estimated.

Sampling methodology and data selection

The AIM-biodiversity model incorporates the distribution data of 9,025 species assessed by IUCN Red List (http://www.iucnredlist.org/) in five major taxonomic groups: vascular plants, amphibians, reptiles, birds, and mammals. Species distribution models were undertaken to quantify the extent of suitable habitat in the present-day (2005) for each species using distribution data from the Global Biodiversity Information Facility (GBIF; www.gbif.org), climate data from the WorldClim database (www.worldclim.org) and landuse data (output from the AIM/CGE model; Hasegawa et al. 2017). Models were processed using the Maxent (Phillips et al. 2006) software. The potential distribution area for each species corresponds to regions where suitable habitat and IUCN-derived ranges overlap. Dispersal is assumed to be unlimited and instantaneous. The model includes many widespread species adapted to human disturbance, and might be underrepresenting the impact on rare species with narrow distribution due to data restriction. Species numbers are counted within each 0.5° grid cell at each time period, and averaged globally to give the indicator value.

References

Hasegawa T, Fujimori S, Ito A, Takahashi K, Masui T (2017) Global land-use allocation model linked to an integrated assessment model. Science of The Total Environment 580:787-796.

IUCN Red list of Threatened Species (http://www.iucnredlist.org/, accessed on Oct. 2016)

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190: 231-259.

S 2.2.6 Indicators of species population – species persistence

S 2.2.6.1 Biodiversity Habitat Index (species persistence)

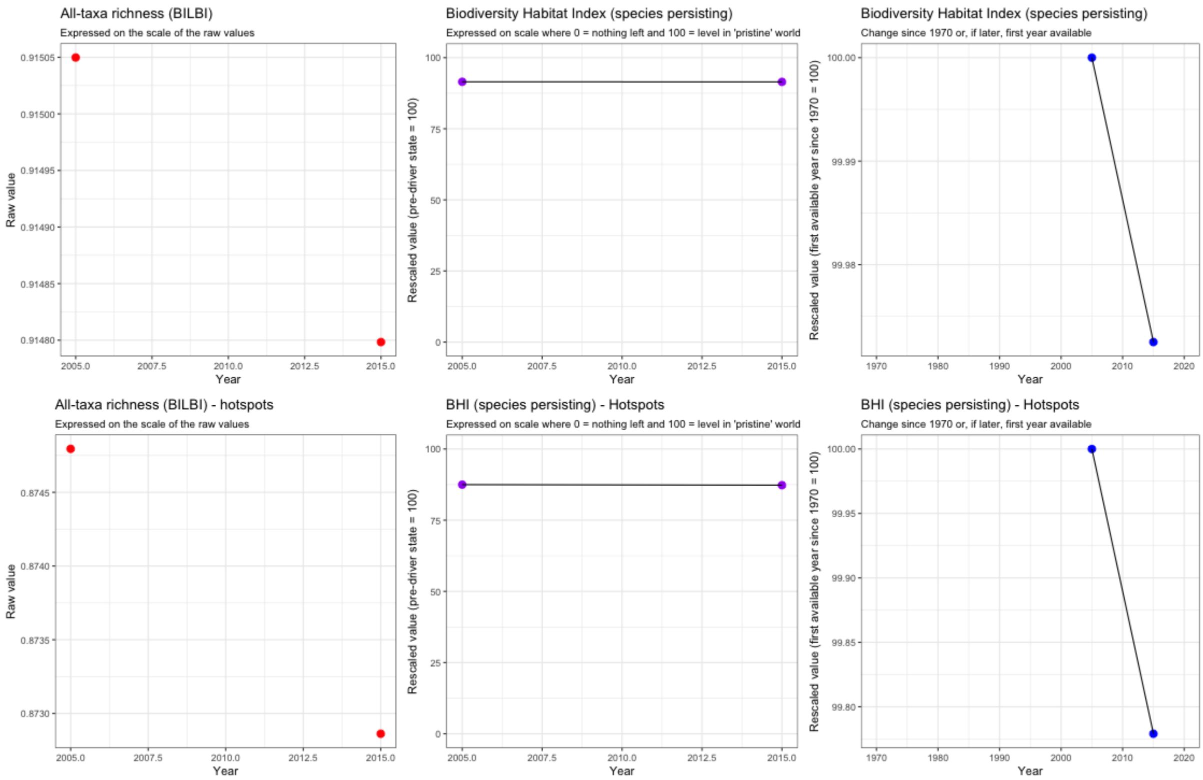
Indicator status: Core indicator
EBV class: Species populations
Measures relative persistence of differing assemblages of species
Indicator type: Representative
Indicator uses global data sources
Years covered: 2000-2015, single time step

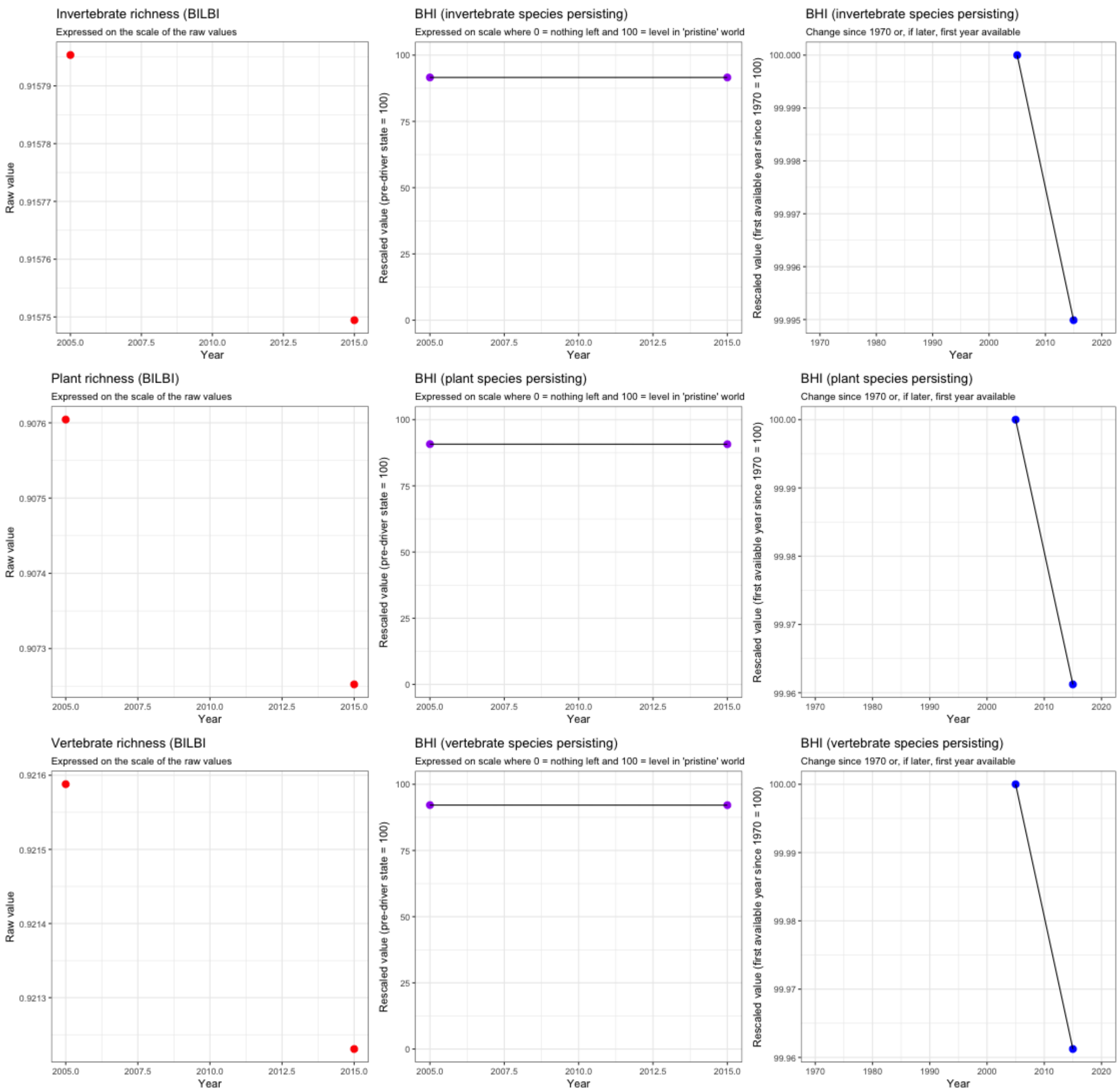
The continuing decline in terrestrial habitat integrity captured by the Biodiversity Habitat Index (as reported in the Ecosystem Structure section) implies that the global 'carrying capacity' for terrestrial species is continuing to decline.

Overview

The Biodiversity Habitat Index has been developed to provide data on global progress towards the reduction of habitat loss with relevance to Target 5 of the Aichi Targets. The species persistence aspect of the index estimates the impacts of habitat loss and degradation on the number of plant, invertebrate and vertebrate species that the habitat can continue to support indefinitely (i.e., at equilibrium), through the linkage of high resolution remotely-sensed datasets and ecological models including the species-area relationship.

Status and trend





Biodiversity Habitat Index (species persistence): status and trend. Top row: A) Modelled index data. B) Trendline for rescaled data where 100% represents a pristine world. C) Trendline for rescaled data showing change from 2005. Second row: As top row, but for all species within the hotspots of narrowly-distributed species. Third row: As top row, but for invertebrate species only. Fourth row: As top row, but for plant species only. Fifth row: As top for, but for vertebrate species only.

The number of species that terrestrial ecosystems can support at equilibrium declined between 2005 and 2015 due to habitat loss and degradation. The rate of decline is approximately equivalent for all taxonomic groups assessed. Extinction will not have been immediate; rather, the decline means that species will have been added to the extinction debt.

Sampling methodology and data selection

The indicator estimates habitat retention through the combination of fine-scale gridded data on the similarity in species composition of habitats and a habitat condition score assessed through tree cover data (Hansen et al. 2013). For each cell in the grid an estimate is derived of the proportion of habitat remaining across all cells that are ecologically similar to this cell of interest, using the technique of Allnutt et al. (2008). Ecological similarity between cells is predicted as a function of abiotic environmental surfaces (describing climate, terrain, and soils) scaled using generalised dissimilarity modelling (Ferrier et al. 2007) to reflect observed patterns of spatial turnover in species composition, based on best-available occurrence records for plants, vertebrates and invertebrates globally (Hoskins et al. 2018). This results in a map of beta diversity detailing the proportion of habitat remaining for environments supporting relatively distinct assemblages of species. To calculate the persistence of species, the species area relationship is applied to the derived habitat maps (https://www.bipindicators.net/indicators/biodiversity-habitat-index).

References

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Ferrier, S., Manion, G., Elith, J., and Richardson, K., 2007. Using generalised dissimilarity modelling to analyse and predict patterns of beta-diversity in regional biodiversity assessment. Diversity and Distributions, 13, pp.252-264.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. Science, 342(6160), pp.850-853. Data available online from http://earthenginepartners.appspot.com/science-2013-global-forest.

Hoskins, A. J., et al. (2018) Supporting global biodiversity assessment through high-resolution macroecological modelling: Methodological underpinnings of the BILBI framework. bioRxiv.

S 2.2.6.2 Global bird species richness change (cSAR)

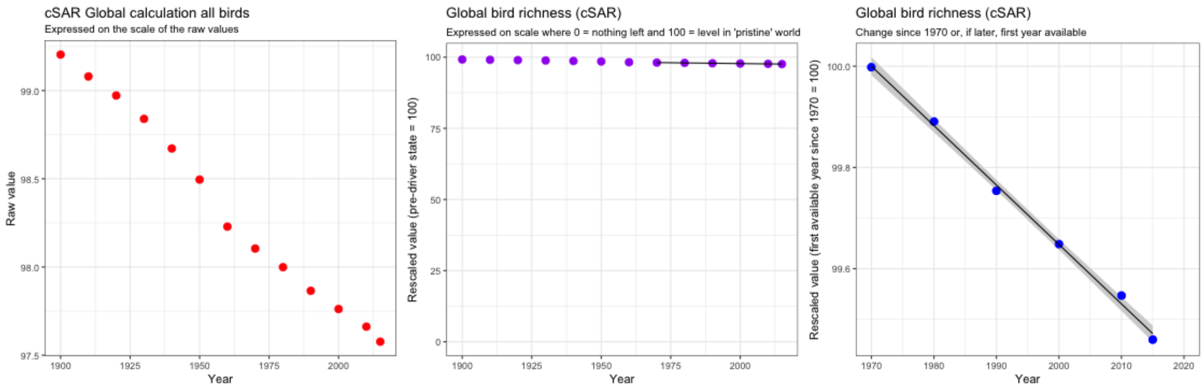
Indicator status: Other indicator
EBV class: Species populations
Assesses changes to global species richness
Indicator type: Representative/Fundamental
The methodology can be applied to a wide range of species or taxa, but is focussed only on birds due to data availability.
Years covered: 1900-2015, decadal time-steps

Between 1% and 2% of bird species have either become globally extinct or have been added to the extinction debt since 1900.

Overview

Global bird species richness (cSAR) models the response of biodiversity to land use change (Pereira & Daily, 2006; Martins & Pereira 2017). It accounts for the persistence of species in human-modified habitats and for the differential use of habitats by different species groups. Through the application of time-series pressure maps, change in equilibrium species richness over time can be calculated.

Status and trend



Global bird species richness: status and trend. A) Change in equilibrium bird species richness over time. B) Trend displayed on a scale where 100% represents a pre-industrial baseline. C) Trendline of change since 1970.

The indicator has steadily decreased since 1900, with the latest result (2015) estimating a reduction in equilibrial species richness at the global level of -1.6% since then. The rate of change of loss and the current state relative to pre-impact baseline are broadly comparable to other indicators of recorded species extinctions for mammals and birds (Global mammal and bird species remaining) and estimated extinction debt for plants (Global plant species remaining (BILBI)). This validates the different methodologies used to calculate these indicators and indicates that different taxonomic groups are exhibiting similar responses to anthropogenic pressures.

Sampling methodology and data selection

Bird species are grouped by habitat preferences using BirdLife data. The relative affinity of the group to modified habitat compared to pristine habitat is modelled using the PREDICTS dataset. For each species group, the area of each habitat type is extracted from land use maps and multiplied by the relevant habitat affinity and the results are summed for all habitats. This result is then used within a traditional species area relationship calculation with the constant relative to the species group and the exponential relative to the sampling scheme. The total number of bird species is given by the sum of species of each species group. The comparison of the resulting richness across two time steps gives the expected proportional change caused by the change in habitat. This change is then multiplied by the number of bird species found within the sampling unit (here global) according to BirdLife range maps. The result estimates the proportion of species within the sampling unit that are expected to be lost or gained over the time step.

S 2.2.6.2.1 Subset: Global forest-specialist bird richness (cSAR)

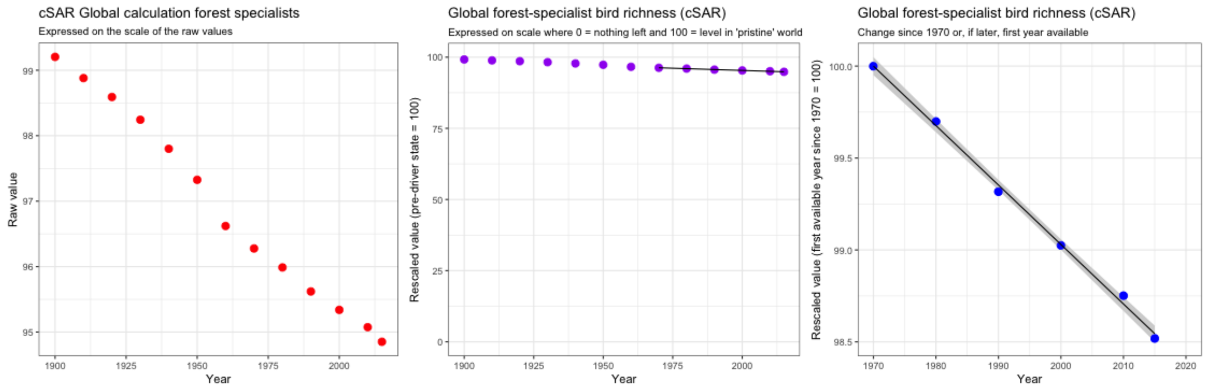
Indicator status: Other indicator
EBV class: Species populations
Assesses changes to global species richness
Indicator type: Representative/Fundamental/Sensitive
The methodology can be applied to a wide range of species and taxa, but is focussed only on birds due to data availability and only on forest specialists as they are expected to be particularly impacted.
Years covered: 1900-2015, decadal time-steps

The global decline of equilibrial forest-specialist bird species richness is occurring at approximately double the rate of that of bird species overall.

Overview

Global forest-specialist bird species richness (cSAR) models the response of avian forest specialists to land use change (Pereira & Daily, 2006; Martins & Pereira 2017). It accounts for the persistence of species in human-modified habitats and for the differential use of habitats by different species groups. Through the application of time series pressure maps, change in species richness over time can be calculated.

Status and trend



Global forest-specialist bird richness: status and trend. A) Change in equilibrium forest-specialist bird species richness over time. B) Trend displayed on a scale where 100% represents a pre-industrial baseline. C) Trend since 1970.

Global forest-specialists show greater overall losses, and exhibit a faster rate of loss, than the when all birds are considered. The indicators use the same methodology but the latter includes all bird species for which we have sufficient data. Forest-specialist birds would be expected to decline at a greater rate than generalist species as they are likely to be more sensitive to anthropogenic land use change because they are less able to utilise converted habitats.

Sampling methodology and data selection

Bird species are subset to those who are characterised as forest specialists by BirdLife. The relative affinity of the group to modified habitat compared to pristine habitat is modelled using the PREDICTS dataset. For each species group, the area of each habitat type is extracted from land use maps and multiplied by the relevant habitat affinity and the results are summed for all habitats. This result is then used within a traditional species area relationship calculation with the constant relative to the species group and the exponential relative to the sampling scheme. The total number of bird species is given by the sum of species of each species group. The comparison of the resulting richness across two time steps gives the expected proportional change caused by the change in habitat. This change is then multiplied by the number of forest specialist bird species found within the sampling unit (here global) according to BirdLife range maps. The result estimates the proportion of species within the sampling unit that are expected to be lost or gained over the time step at a global level.

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S 2.2.6.3. Global mammal and bird species remaining

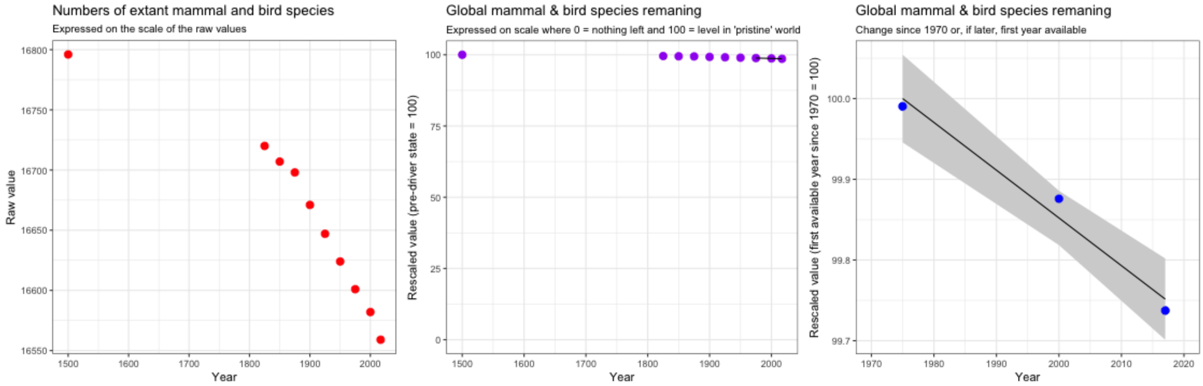
Indicator status: Highlighted indicator
EBV class: Species populations
The data is based upon changes in population and range size of species
Indicator type: Fundamental/Representative
This indicator covers a broad range of species from two well-studied taxonomic groups
Years covered: 1500-2017, 25 year time-steps from 1825

The number of extant mammal and bird species has declined since 1500, with an estimated 237 extinctions occurring in this time; and the rate of extinction has been accelerating over this time.

Overview

This indicator combines data from three datasets to reveal how the number of extant bird and mammal species have changed over time in the period after the industrial revolution, and compares this to the number that were present at 1500 AD, prior to widespread anthropogenic modification of the earth (though note that many anthropogenic extinctions precede this data: see Section 2.2.5.1). It is difficult to assess global extinction rates with certainty, especially when we are dealing with historical records; therefore this indicator focuses on taxonomic groups for which the data are most complete – birds and mammals.

Status and trend



Global mammal and bird species remaining: status and trend. A) Change over time. B) Trend displayed on a scale where 100% represents a pristine world. C) Trendline of change since 1975.

The number of mammal and bird species has declined since 1500, with an estimated 237 extinctions occurring in this time. The proportion of species that remain is high (98.6%), and the rate of change is low (-0.1%); however, the indicator focuses on an extreme situation.

Sampling methodology and data selection

The number of species present in 1500 was obtained from Cellabos et al. (2015) and the number of species present in 2017 was obtained from IUCN (2017). The number of species extinctions over time was obtained from the IUCN Red List database. Bird data was obtained from BirdLife International (2014) and mammal data from IUCN (2014). The data is provided in 25-year intervals from 1800-1825 to 1975-2000. Birds or mammal species that were categorised as ‘Extinct’ (birds and mammals) or ‘Possibly Extinct’ (birds only) in the Red List are included in this dataset. This data revealed that 46 mammal species and 92 bird species went extinct in this time period. It is likely that the number of extinctions is underestimated due to reporting lags and lack of absence data.

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S 2.2.6.4 Red List Index (overall)

Indicator status: Core indicator
EBV class: Species populations

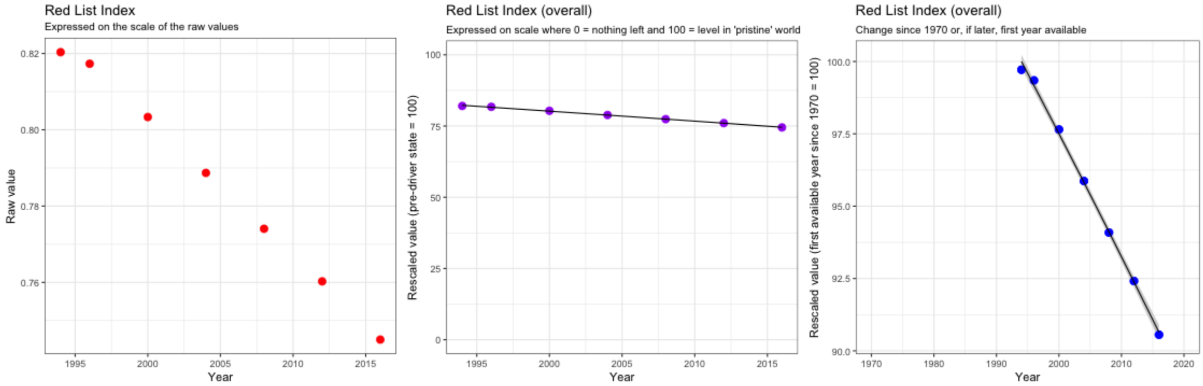
Monitors change in extinction risk based upon population and range size, structure and trends
Indicator type: Representative
Indicator compiles data pertaining to thousands of species worldwide.
Years covered: 1994-2016, yearly time-steps

The Red List Index for birds, mammals amphibians, corals and cycads has declined by approximately 10% in the last two decades, indicating that the average survival probability of thousands of species worldwide has decreased.

Overview

Species are the most intuitive unit of biodiversity, one which resonates with the public and about which we have a relatively good understanding. The IUCN Red List is a well-established and respected system for classifying species by their relative risk of extinction and has been widely recognised as an important component of the suite of indicators needed to track progress towards the 2020 Aichi Targets. The *Red List Index (RLI)* shows changes in the overall extinction risk of sets of species over time, and relates to the rate at which species move through IUCN Red List categories towards or away from extinction. Tracking the net movement of species through the Red List categories provides a useful metric of changing biodiversity status over timescales of decades, though it has limited temporal sensitivity because of the periodic nature of repeat assessments of the same species. The *Red List Index* can be disaggregated to show trends for species in different biogeographic ecosystems, political units, ecosystems, habitats, taxonomic groups, species relevant to different international agreements and treaties and to show trends driven by particular drivers such as invasive alien species or fisheries.

Status and trend



Red List Index (overall): status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1994.

A *Red List Index* value of 1.0 equates to all species being categorized as Least Concern, and hence that none are expected to go extinct in the near future. A *Red List Index* value of zero indicates that all species have gone extinct. A downwards trend in the graph line (i.e. decreasing *Red List Index* values) means that the expected rate of species extinctions is increasing, i.e. that the rate of biodiversity loss is increasing.

Red List Index values can be broadly equated to the proportion of the value it would show in a pristine world; it slightly underestimates that value because a small number of species are threatened with extinction solely by geological threats (mostly volcanoes) without any human component.

Sampling methodology and data selection

The Red List Index was initially designed and tested using data on all bird species from 1988–2004 (Butchart *et al.* 2004) and then extended to amphibians (Butchart *et al.* 2005), mammals, corals (Butchart *et al.* 2010), and cycads (in 2016). Additional taxonomic groups will be added over the next few years. The methodology was revised and improved in 2007 (Butchart et al. 2007). Red List Index trends can be calculated for any set of species that has been assessed at least twice for the IUCN Red List. For the set of species considered, trends are based on information from all non-Data Deficient species worldwide. The taxonomic coverage of the *Red List Index* is limited to birds, mammals, amphibians, corals and cycads; however, additional taxonomic groups (e.g., reptiles, and some fish, invertebrate and additional plant groups) are expected to be added over the coming decade. A sampled approach to Red Listing has been developed (Baillie *et al*. 2008) to assess the relative extinction risk particularly speciose and poorly known groups.

A method for calculating an aggregated *Red List Index* based on the data for multiple taxonomic groups was developed and published (Butchart *et al.* 2010). More specifically, Red List Indices have also been published showing the negative impacts of invasive species (McGeoch *et al.* 2010), and the positive impacts of conservation action (Hoffmann *et al.* 2010) and protected areas (Butchart *et al.* 2012). A *Red List Index* to show the impact of a single conservation institution was published by Young *et al.* (2014). The spatial distribution of the *Red List Index* was mapped by Rodrigues *et al.* (2014). A *Red List Index* for pollinators was published by Regan *et al.* (2015) and for wild relatives of farmed and domesticated species by McGowan et al. (2018).

S 2.2.6.4.1. Subset: Red List Index (species used in food and medicine)

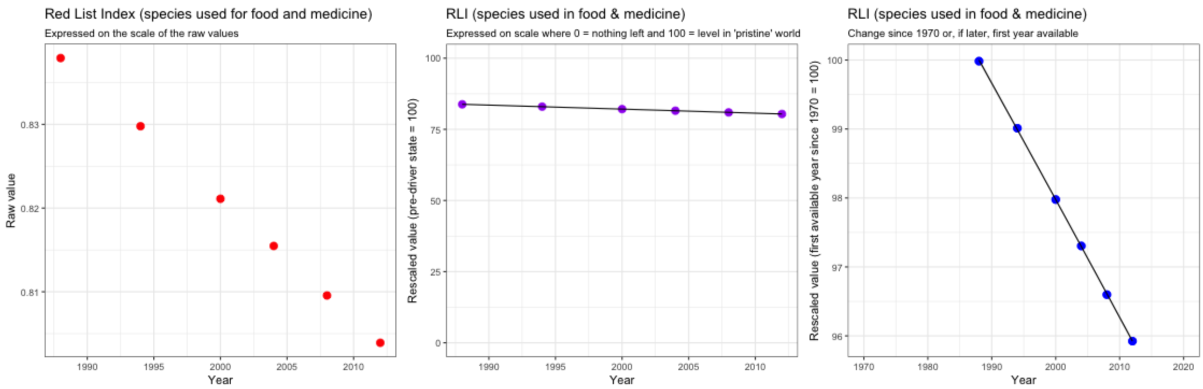
Indicator status: Core indicator
EBV class: Species populations
Monitors change in extinction risk based upon population and range size, structure and trends
Indicator type: Underpin NCP
Species are selected as they are edible or have health benefits
Years covered: 1988-2012, 6 year time-steps prior to 2000, and 4 year time-steps after

The expected rate of extinctions bird, mammal and amphibian species used in food and medicine has been steadily increasing over the past two decades.

Overview

Biodiversity provides many different ecosystem services to people, at local to global scales. This version of the Red List Index is based only on data for birds, mammals and amphibians that are known to be used by people for food or medicine. It shows changes in the aggregate extinction risk of these species over time. The decline in the index indicates that these species are moving ever faster towards extinction owing to a combination of unsustainable use and other pressures, such as habitat loss driven by unsustainable agriculture, logging and commercial and residential development. The Red List Index is based on data from the large majority of species worldwide for each group considered, and hence is less geographically biased than many comparable indicators; however, the Red List index does contain taxonomic bias being based on birds, amphibians and mammals at present with other taxonomic groups (e.g. reptiles, and some plant and invertebrate groups) expected to be added over the coming decade.

Status and trend



Red List Index (species used in food and medicine): status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1988.

The *Red List Index (species used for food and medicine)* is in decline, an increasing extinction risk for these species. However, the Red List Index is only moderately sensitive, owing to the breadth of Red List categories (Butchart *et al.* 2004, Butchart *et al.* 2005).

Sampling methodology and data selection

Methodology as described above (see *Red List Index (overall)*) with data subset to species used in food and medicine as identified using data collated by TRAFFIC.

S 2.2.6.4.2 Subset: Red List Index (forest specialists)

Indicator status: Core indicator
EBV class: Species populations
Monitors change in extinction risk based upon population and range size, structure and trends
Indicator type: Sensitive

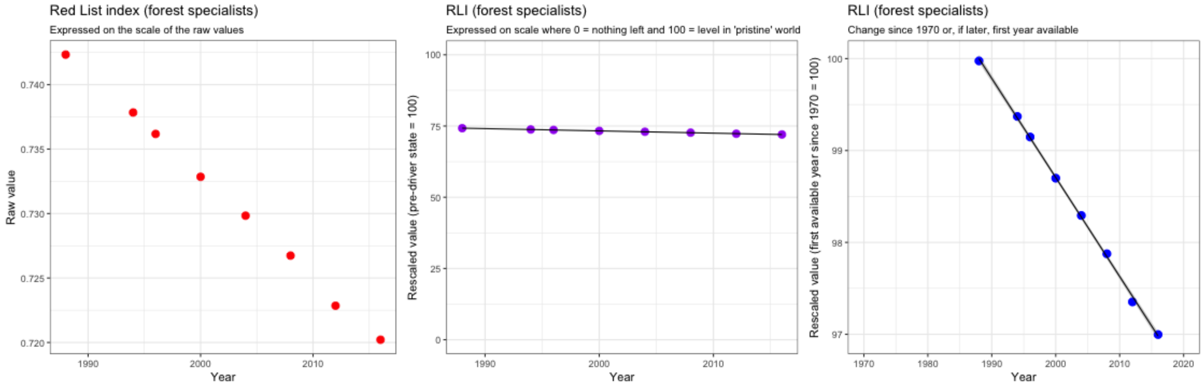
Indicator targets specialised species that are less likely to be able to adapt to anthropogenic pressures
Years covered: 1988-2016, annual time-steps

The survival probability of forest specialist bird, mammals, amphibians and cycads has steadily decreased over the past two decades.

Overview

Forest habitat is in decline throughout the world due to anthropogenic pressures such as timber harvesting, replacement of forest with agriculture, fragmentation and the introduction of invasive species. This indicator monitors the extinction risk of species that depend upon forest habitats. Although only recently developed, it is relevant in particular to Aichi Target 5 and SDG indicator 15.2. A similar approach could also be applied to some other habitats in future.

Status and trend



Red List Index (forest specialists): status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1988.

The *Red List Index (forest specialists)* has steadily declined over recent decades, losing nearly a quarter of the index value since 1970.

Sampling methodology and data selection

This is an indicator of aggregate extinction risk for species dependent on forests (birds, mammals, amphibians and cycads) derived by disaggregation of the Red List Index based on coding of 'Forest' importance for each species in the IUCN Habitats Classification Scheme (http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3) is classified as of 'major' importance (Butchart *et al.* 2004 PLoS Biology). Extinction risk was calculated as described above (see *Red List Index (overall)*).

S 2.2.6.4.3. Subset: Red List Index (pollinators)

Indicator status: Core indicator
EBV class: Species populations

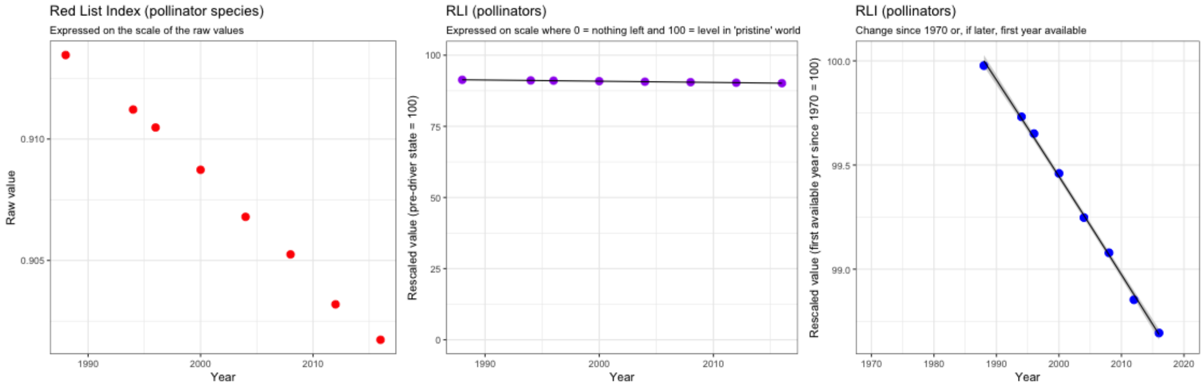
Monitors change in extinction risk based upon population and range size, structure and trends
Indicator type: Underpin NCP
This indicator targets species which provide pollination services
Years covered: 1988-2016, 4-year time-steps from 1996

Extinction risk for pollinating species of birds and mammals has increased steadily over the last two decades.

Overview

Biodiversity provides many different ecosystem services at local to global scales. Most services are difficult to link to individual species but pollination is an exception, with multiple studies showing that exclusion of particular groups of pollinator species leads to reduction in crop productivity and value. The Red List Index can be disaggregated to show trends in survival probability for subsets of species that are known to be pollinators. It is based on data from the IUCN Red List – the number of species in each Red List category of extinction risk, and the number moving categories between assessments owing to genuine improvement or deterioration in status for bird and mammal pollinators. Note that the index does not include insect pollinators, who are responsible for the bulk of animal pollination of crop and wild species.

Status and trend



Red List Index (pollinators): status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1988.

The *Red List Index (pollinator species)* among birds (e.g. sunbirds and New World warblers) and mammals (e.g. some bats and rodents) shows declining trends, indicating these species are moving faster towards extinction. However, overall they are less threatened than non-pollinator species (for which the Red List Index has lower values), perhaps reflecting the fact that average body size is larger among non-pollinators, and that large-bodied species tend to be more threatened.

Mammals and birds form only a minority of all pollinators, but extinction risk data for the invertebrate pollinators are currently not available (though an assessment for bumblebees is currently in preparation). It is likely, however, that they too are in decline. Aichi Target 14 calls for “ecosystems that provide essential services” to be "restored and safeguarded". The decline in the *Red List Index (pollinator species)* implies that ecosystems supporting them are not currently being adequately safeguarded.

Sampling methodology and data selection

This indicator was first published by Regan *et al.* (2015). Methodology was as described above (see *Red List Index (overall)*) but with the RLI database subset to pollinating species using information obtained through literature search.

S 2.2.6.4.4. Subset: Red List Index (internationally traded species)

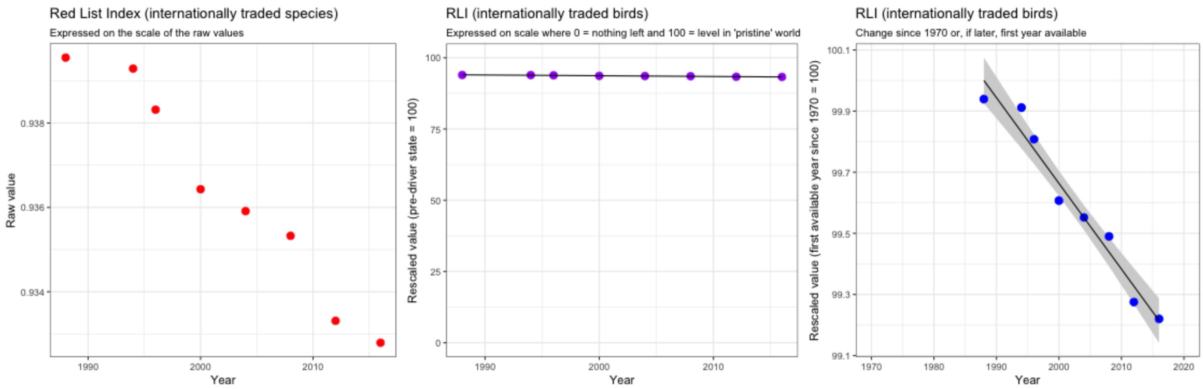
Indicator status: Core indicator
EBV class: Species populations
Monitors change in extinction risk based upon population and range size, structure and trends
Indicator type: Underpin NCP
Targets species of economic value
Years covered: 1988-2016, 4 year time-steps from 2000 and six year time-steps prior to 2000

The expected rate of extinctions of internationally traded species has increased slowly since 1988.

Overview

The Red List Index (internationally traded species) is a disaggregation of RLI data for birds in international trade. It complements two other disaggregated Red List Indices: RLI (trends driven by utilisation) and RLI (species used for food and medicine), but shows trends driven by all factors.

Status and trend



Red List Index (internationally traded species): status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1988.

The *Red List Index (internationally traded species)* has steadily decreased since 1988; however, the magnitude of change is small.

Sampling methodology and data selection

Bird species included in this assessment are known to be internationally traded, otherwise methodology follows that outlined above (see *Red List Index (overall)*).

S 2.2.6.4.5. Subset: Red List Index (wild relatives)

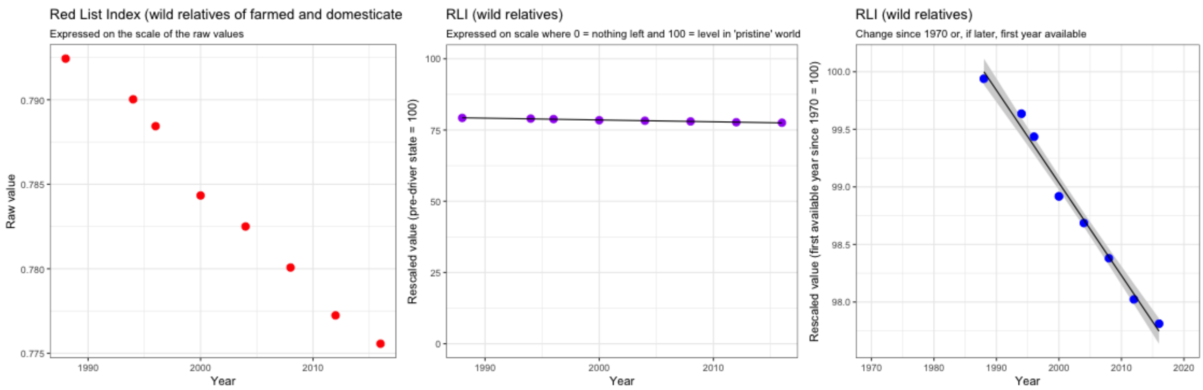
Indicator status: Core indicator
EBV class: Species populations
Monitors change in extinction risk based on population, range size, structure and trends
Indicator type: Underpin NCP
Indicator targets species which are likely to be valuable for agriculture
Years covered: 1988-2016, 4 year time-steps from 1996

The survival probability of wild relatives of farmed and domesticated mammals and birds has decreased by 2% since 1988.

Overview

The *Red List Index (wild relatives)* is a disaggregation of RLI data for birds and mammals that are wild relatives of domesticated species. The species targeted by this indicator are of interest as they may provide alternatives to currently farmed and domesticated species or contain genetic diversity that is important for future food security. Such alternatives may prove valuable due to current farming practices propagating a limited genetic pool of farming stock. These species may also have traits which could allow a more sustainable harvest as the increased genetic diversity may provide greater adaptability and less reliance on human intervention. The indicator is directly relevant to Aichi Biodiversity Target 13 “by 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.”

Status and trend



Red List Index (wild relatives): status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1988.

The *Red List Index (wild relatives of farmed and domesticated species)* exhibits a small but steady decline since 1988. This represents a deteriorating status of wild relatives of farmed and domesticated species on the IUCN Red List. If the trend of decline continues this could lead to extinctions of species that may have economic or social value.

Sampling methodology and data selection

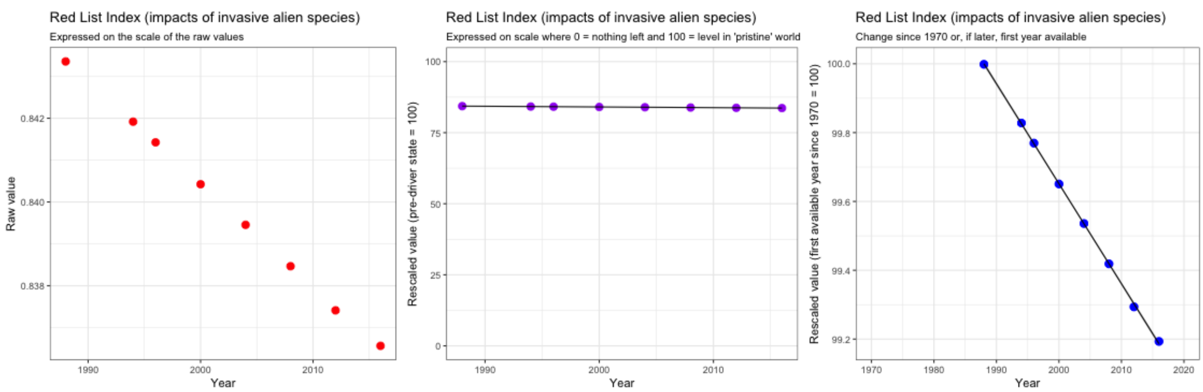
Species were considered as farmed or domesticated species if they were referred to as a source of food in the State of the World's Animal Genetic Resources for Food and Agriculture (FAO, 2007, 2015). For all vertebrate farmed or domesticated species, a single wild progenitor species was identified through taxonomy and nomenclature. For crop species, all wild species within the same genus were considered to be relatives as well as any species for which there was documented evidence that hybridisation was possible (McGowan et al. 2018).

S 2.2.6.4.6. Driver-specific Red List Indices

The following Red List Indices focus on specific species within the Red List database that are known to be impacted by specific anthropogenic pressures. While it is not informative to compare these subsets to the overall Red List Index as, due to the methodology, the subsets will always show a less steep decline, a comparison between the subsets will reveal the relative importance of the drivers in terms of their contribution towards increasing the likelihood of species extinctions. The Indices have been shown in the order of their relative impact going from the most important driver of extinction risk to the least. These indices are not included in the synthesis presented in Section 2.2.5, but were considered in the attribution synthesis of 2.2.6.

Subset: Red List Index (impacts of invasive alien species)

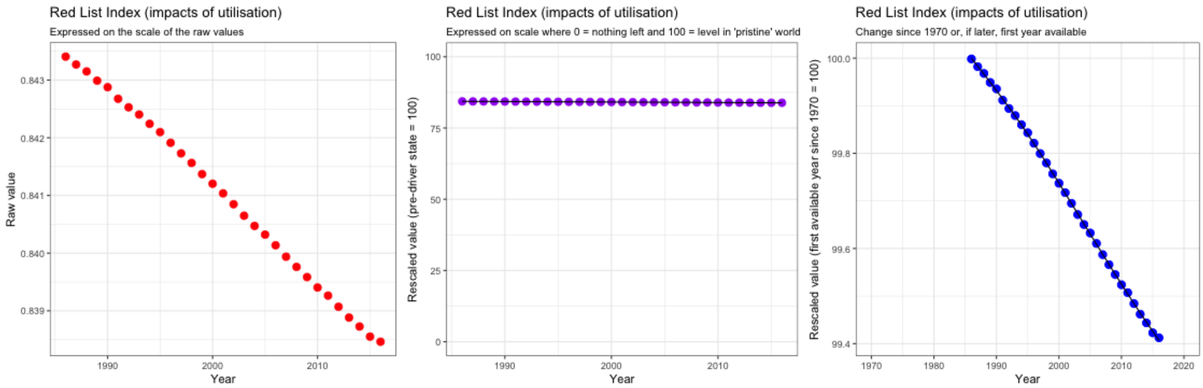
Globalisation has facilitated the spread of invasive alien species across most of the globe leading to decreased abundance and diversity of native species and changes to the functioning of the ecosystem (Vila et al. 2011). The Red List Index (impacts of invasive alien species) indicator shows trends in the status of birds, mammals and amphibians worldwide, driven only by the negative impacts of invasive alien species or the positive impacts of their control. Trends driven by other factors are filtered out.



Red List Index for impacts of invasive alien species on bird, mammal and amphibian species: status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1988.

Subset: Red List Index (impacts of utilisation)

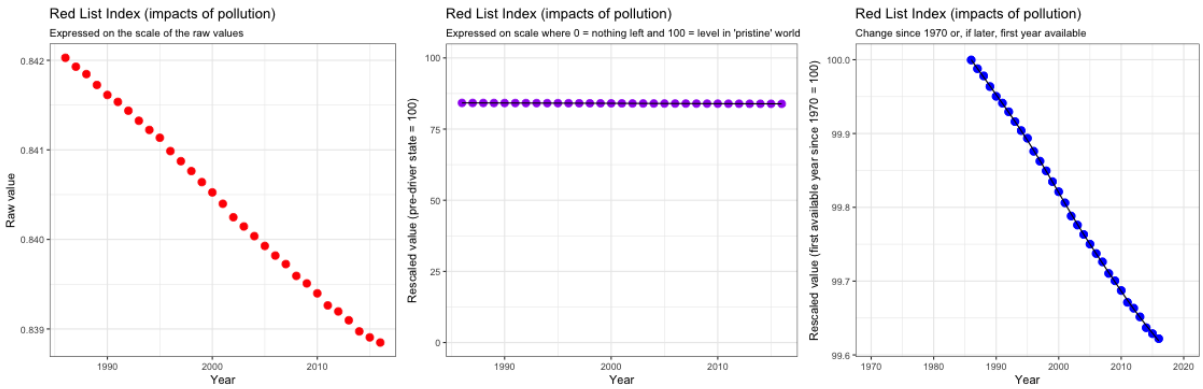
People depend upon biodiversity and use wildlife in a variety of ways. For example, birds, mammals and amphibians are hunted, trapped and collected for food, sport, pets, medicine, materials (e.g. fur and feathers) and other purposes. The *Red List Index (impacts of utilisation)* illustrates the changing status of three species groups (birds, mammals and amphibians) owing to the balance between negative trends driven by unsustainable exploitation, and positive trends driven by measures to reduce overexploitation. It excludes changes in status driven by other factors (such as habitat loss or climate change).



Red List Index for impacts of utilisation on bird, mammal and amphibian species: status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1986.

Subset: Red List Index (Impacts of pollution)

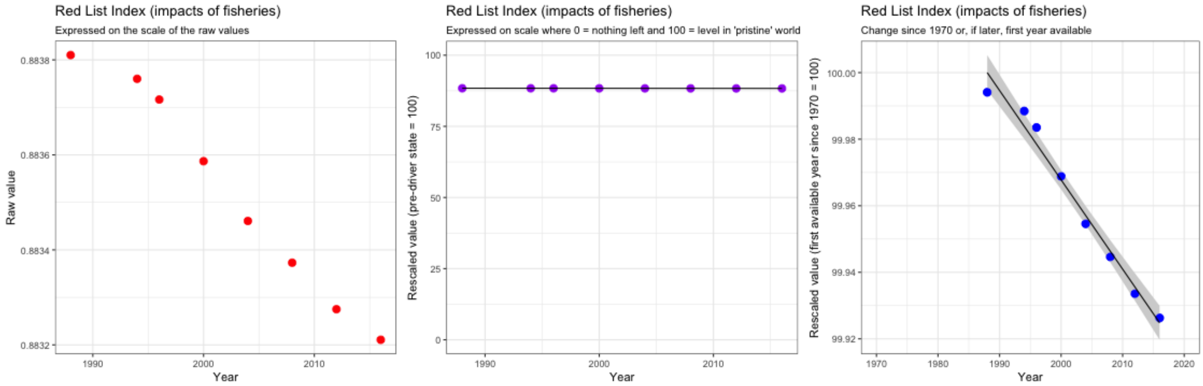
This indicator shows trends in the status of birds, mammals and amphibians worldwide driven only by the negative impacts of pollution or the positive impacts of its control. All other changes are excluded, whether from improved knowledge, or genuine impacts of other threats or their control.



Red List Index for impacts of pollution on bird, mammal and amphibian species: status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1986.

Subset: Red List Index (Impacts of fisheries)

Fishing practices can have a number of direct and indirect effects on non-target species for example, as bycatch, mortality in fishing gear, or through reductions in food supply. This disaggregated version of the Red List Index (RLI) shows trends in the status of birds and mammals worldwide driven only by the negative impacts of fisheries or the positive impacts of measures to control or manage fisheries sustainably. Trends driven by other factors are filtered out.



Red List Index for impacts of fisheries and fishery management on bird and mammal species: status and trend. A) Change over time. B) Trends in the Index displayed on a scale where 100% represents a pristine world. C) Trendline showing change since 1988.

A downwards trend in the graph line (i.e. decreasing Red List Index values) means that the expected rate of species extinctions is increasing i.e. that the rate of biodiversity loss is increasing. While the absolute values for average rate of change in index value are small, these represent substantial losses of biodiversity in terms of species moving towards extinction.

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S 2.2.7 Indicators of species population – geographic distribution

S 2.2.7.1 Extent of suitable habitat (mammals)

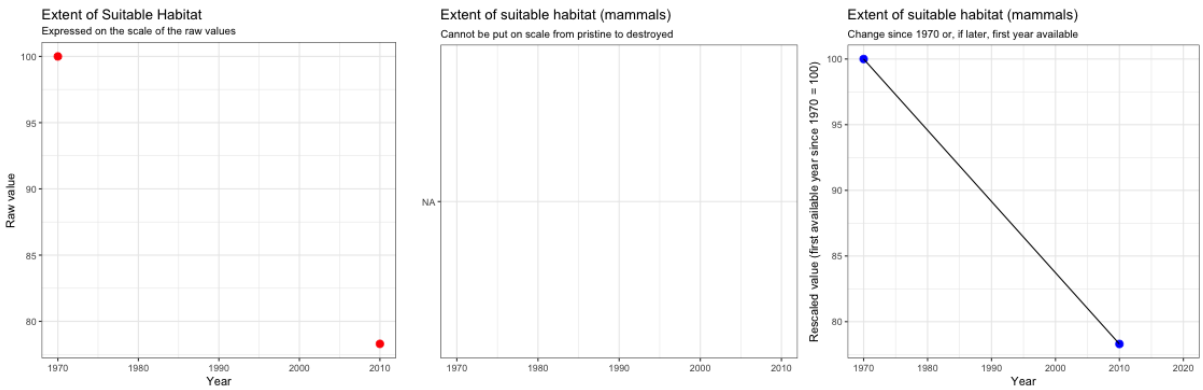
Indicator status: Other
EBV class: Species populations
Measures changes in species' range sizes
Indicator type: Representative
The indicator is based on data pertaining to thousands of mammals across the world
Years covered: 1970 – 2010, single time step

Mammalian species have seen an average decline of about 25% in the extent of suitable habitat since 1970.

Overview

Human populations have encroached upon terrestrial habitat through land conversion for agriculture and urban development, as well as the depletion of habitat quality through harvesting, pollution and fragmentation. This indicator examines the impact that human encroachment has had upon the extent of habitat suitable for mammals within the last 50 years.

Status and trend



Extent of suitable habitat (mammals): status and trend. A) Change over time. B) No baseline value for a pristine world is yet available for this indicator. C) Trendline showing change since 1970.

The extent of habitat suitable for mammals has declined by approximately 25% in the last 50 years.

Sampling methodology and data selection

For each species, IUCN extent of occurrence range maps were refined using IUCN Global Mammal Assessment habitat suitability models (Rondinini et al 2011; Visconti et al. 2011; Visconti et al 2015). The indicator is then calculated as the geometric mean, across all terrestrial mammal species with sufficient range information. This means that the indicator does not change in direct proportion to average range size, but instead reflects the average *proportional* change in species' range size.

References

Rondinini, C., Di Marco, M., Chiozza, F., Santulli, G., Baisero, D., Visconti, P., . . . Boitani, L. (2011). Global habitat suitability models of terrestrial mammals. Philosophical Transactions of the Royal Society B: Biological Sciences, 366(1578), 2633.

Visconti, P., Bakkenes, M., Baisero, D., Brooks, T., Butchart Stuart, H. M., Joppa, L., . . . Rondinini, C. (2015). Projecting Global Biodiversity Indicators under Future Development Scenarios. Conservation Letters, 9(1), 5-13. doi:10.1111/conl.12159

Visconti, P., Pressey, R. L., Giorgini, D., Maiorano, L., Bakkenes, M., Boitani, L., . . . Rondinini, C. (2011). Future hotspots of terrestrial mammal loss. Philosophical Transactions of the Royal Society B: Biological Sciences, 366(1578), 2693.

S 2.2.7.2 Mammalian range size

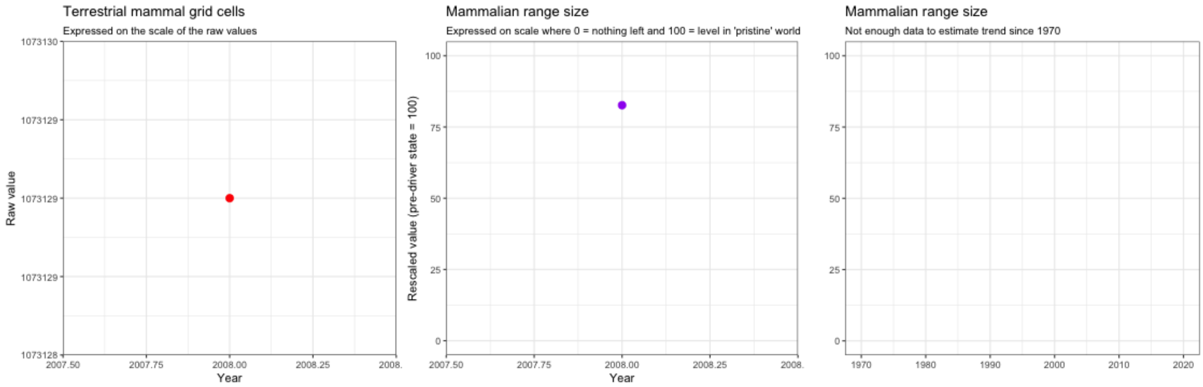
Indicator status: Other
EBV class: Species populations
Measures changes in species' range sizes
Indicator type: Representative
The indicator is based on data pertaining to thousands of mammal species across the world
Years covered: 2008

Mammalian diversity has been drastically altered by humans, with diversity being markedly lower virtually everywhere outside of sub-Saharan Africa than it would be in the complete absence of human actions over time.

Overview

Although our focus is often on recent biodiversity loss, in reality anthropogenic pressures such as habitat loss, hunting and invasive species have caused mammalian range contractions and extinctions over the last few millennia (Faurby and Svenning, 2015). This indicator examines the difference in current mammalian diversity to what it would be like in the complete absence of human activity.

Status and trend



Mammalian range size: current status A) Mean range size. B) Mean range size expressed as a percentage of the pre-impact estimate. C) No trendline data available.

Current mammalian diversity is much lower virtually everywhere, apart from sub-Saharan Africa, than the natural mammalian diversity would be in the absence of human activities. Current mammalian species diversity is highest in sub-Saharan Africa, whereas in the absence of human activities Africa’s mammalian diversity would be similar to other continents. Natural mammalian diversity in the absence of human activities would be highest in the southern Rocky Mountains, Mexico and northern Argentina, whilst most of the Americas and Eurasia would have diversities similar to sub-Saharan Africa (Faurby and Svenning, 2015).

Sampling methodology and data selection

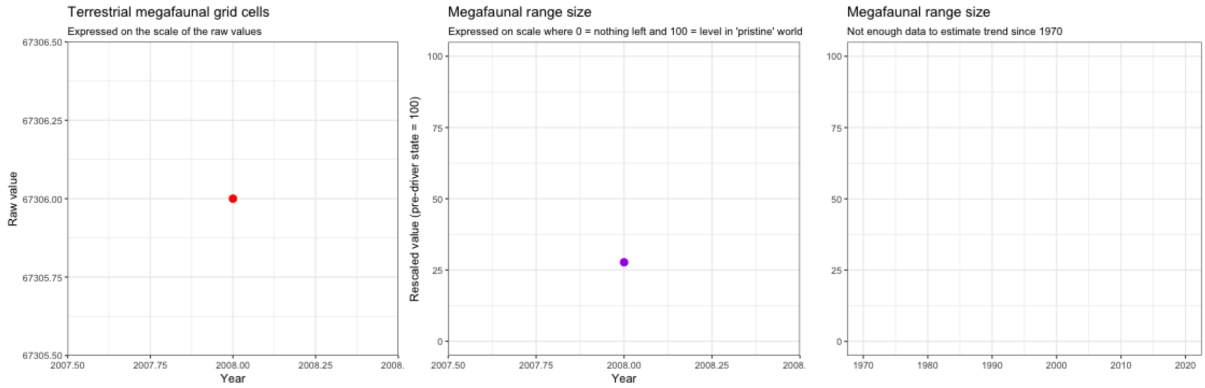
The analysis included all mammals for which Late Pleistocene or Holocene records exist. The potential current ranges of these species in the absence of human activity was estimated. Ranges were constrained by factors such as dispersal restraints, biotic constraints and non-climatic abiotic limiting factors so that the ranges were limited to areas that would be inhabited without human interference rather than the entire climatic niche of a species. Species were identified as likely to have had their ranges altered by human interference through the following criteria: 1) IUCN Red-List categories (vulnerable, endangered, critically endangered, extinct, extinct in the wild or data deficient), 2) body mass of >1kg, and 3) occurrence in large isolated island-like systems (Australia, New Guinea or Madagascar). For these target species systematic searches were carried out for evidence of human influences on ranges. When evidence of human impact was found ranges were modified accordingly. Non-target species ranges were also modified if evidence of human-caused range changes was found although systematic searches were not carried out. A total of 1085 species’ ranges were modified. If a species became globally extinct post human arrival this was assumed to be caused by humans; however, regional extinctions were assigned to either human or climatic causes. The potential ranges of mammalian species in the complete absence of human activities over time were then compared to current mammalian species ranges. All diversity measures were calculated on equal area projections (approximately 1^{o} x 1^{o} at the equator).

S 2.2.7.2.1 Subset: Megafaunal range size

Indicator status: Other
EBV class: Species populations
Measures changes in species' range sizes
Indicator type: Sensitive
The indicator is based on data pertaining to megafauna - taxa which are known to have been particularly impacted by anthropogenic impacts
Years covered: 2008

Megafaunal diversity has been dramatically reduced with an average range loss of approximately 75% from that which would be considered likely in the absence of humans

Status and trend



Megafaunal range size: current status A) Mean range size. B) Mean range size expressed as a percentage of the pre-impact estimate. C) No trendline data available.

Megafaunal range size has dramatically reduced with a loss of approximately 75% from that which would be considered likely in the absence of humans. This reduction is much greater than that observed for all mammals, emphasizing the particular impact that humans have had over the millennia on megafauna through harvesting and habitat conversion (Faurby & Svenning 2015).

Subset data selection

Data was processed as described above, but only ranges pertaining to megafauna species were included in the analysis.

References

Faurby, S. and Svenning, J.-C. 2015. Historic and prehistoric human-driven extinctions have reshaped global mammal diversity patterns Stevens, G. (Ed.). Diversity and Distributions, 21(10): 1155–1166.

S 2.2.7.3 Species Habitat Index

Indicator status: Core indicator

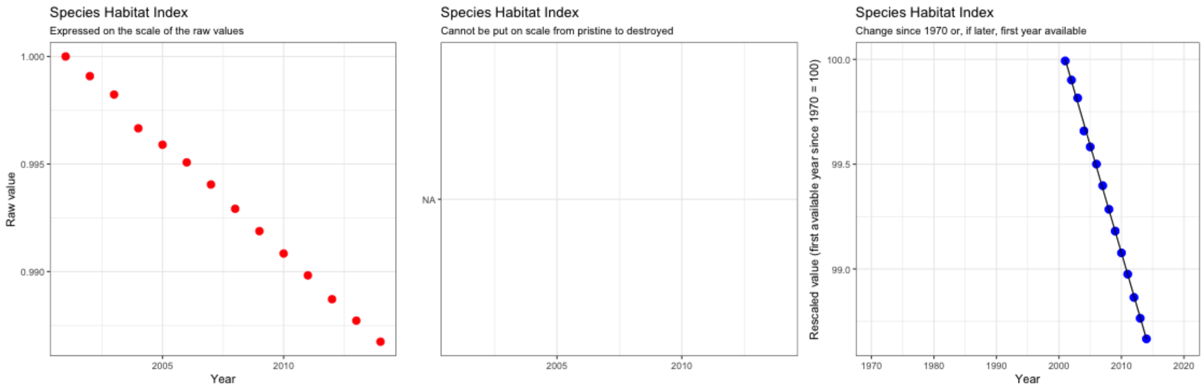
EBV class: Species populations
The data is based upon changes in population and range size of species
Indicator type: Representative
This indicator is calculated using data from a broad range of species worldwide
Years covered: 2001-2014, annual time-steps

The Species Habitat Index has steadily declined since 2001, reflecting ongoing declines in the average geographic range size of over 20,000 terrestrial vertebrate, invertebrate and plant species.

Overview

The Species Habitat Index quantifies changes in the suitable habitats of single species to provide aggregate estimates of potential population losses and extinction risk increases in a region or worldwide.

Status and trend



Species Habitat Index: status and trends. A) Change over time. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline showing change since 2001.

The Species Habitat Index has lost approximately 1.5% of its value since the assessment began in 2001. The average recent rate of change of the Index is -1% per decade. This is a slower rate of change than the most comparable indicator, the Red List Index.

Sampling methodology and data selection

The indicator is based upon data collated by the Map of Life project (https://mol.org/indicators). Highly temporally and spatially resolved remote sensing maps are used to produce extent of suitable habitat maps for single species through correlative modelling and expert opinion. Maps are validated with field data. Changes in habitat extent (and therefore risk of extinction) are recalculated annually. The Species Habitat Index is then calculated as the arithmetic mean, across all species, of the proportional change in species range. Changes in risk of extinction for species within defined areas, such as countries, can be aggregated. Results can also be disaggregated for species groups of interest. The Species Habitat Index is calculated with over 20 000 species of terrestrial vertebrates, invertebrates and plants.

References

https://mapoflife.github.io/indicators/static/app/files/habitat/IPBES_Core_Indicators_Factsheet_Species_Habitat_Index_Jan2018ForWeb.pdf

https://mol.org/indicators/

https://mol.org/datasets/

S 2.2.8 Indicators of species population – population size

S 2.2.8.1 Fish stocks biologically sustainable

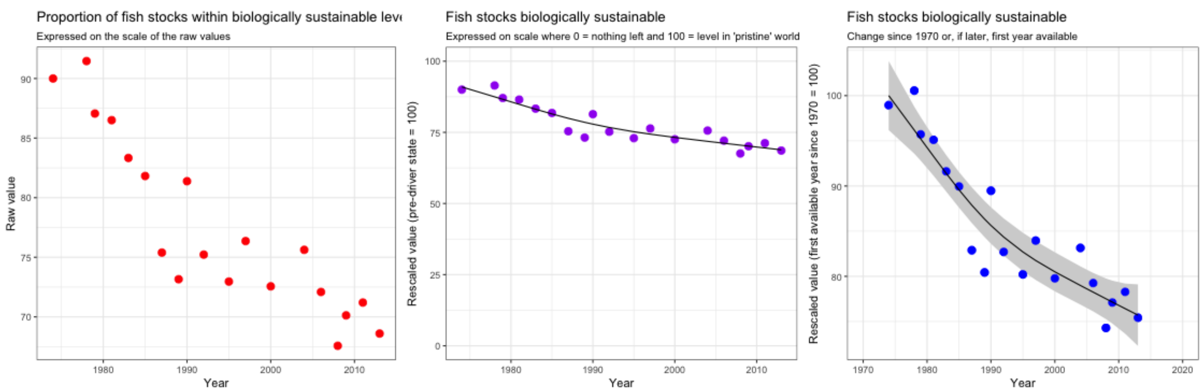
Indicator status: Core indicator
EBV class: Ecosystem structure
Ecosystem extent and fragmentation
Indicator type: Representative, Sensitive
A broad range of species that are expected to be detrimentally impacted by fishing are sampled
Years covered: 1974-2013, variable time-steps

Nearly a third of all fish stocks are harvested unsustainably – more than double the proportion 45 years ago.

Overview

Fisheries are an important source of food, income, jobs, and recreation for people around the world. Global marine fisheries produced just over 80 million tonnes of fish in 2014, providing about 17% of people's animal protein intake, and directly employed about 57 million people world-wide (FAO, 2016), thus making significant contributions to food security and the economy. However, fishing has also impact on fish stocks and their relevant marine ecosystems. With the continued increase of the world population, demand for fish will increase and so will pressure on fish resources. The *Proportion of stocks in safe biological limits* is a measure of the sustainability of fishery resources.

Status and trend



Proportion of fish stocks within biologically sustainable levels: status and trend. A) Change over time. B) Same data presented on a percentage scale, with all fish stocks being biologically sustainable in the absence of fishing pressure. C) Trendline showing change since 1974.

The proportion of fish stocks within biologically sustainable levels has declined dramatically in the 40 years since monitoring began. In 1974 most fish stocks (90%) were fished sustainably, but in 2013 only 69% of stocks were. Unless these trends are reversed, it is expected that the 31% of global fish stocks that are now fished unsustainably will not be able to recover leading to consequences for marine biodiversity as well as human health and wellbeing.

Sampling methodology and data selection

The FAO calculates maximum sustainable yield for each assessment unit then examines how close the actual yield of landed fish is to the maximum. Stock is characterised as overexploited if the actual yield is greater than the maximum sustainable yield. If it is close then the stock is classified as fully exploited, and if it is under then the stock is classified as under-exploited. Stocks classified as fully or under-exploited are considered to be within biologically sustainable levels. The FAO assessment is based on FAO's statistical areas, i.e. a species within the statistical area is considered an assessment unit, which is different from the classical concept of unit fish stock. The stocks monitored for this indicator account for about 80% of global fish landings.

References

FAO (2016). *The State of World Fisheries and Aquaculture 2016* (Food and Agriculture Organization of the United Nations, Rome, 2016).

S 2.2.8.2 Living Planet Index

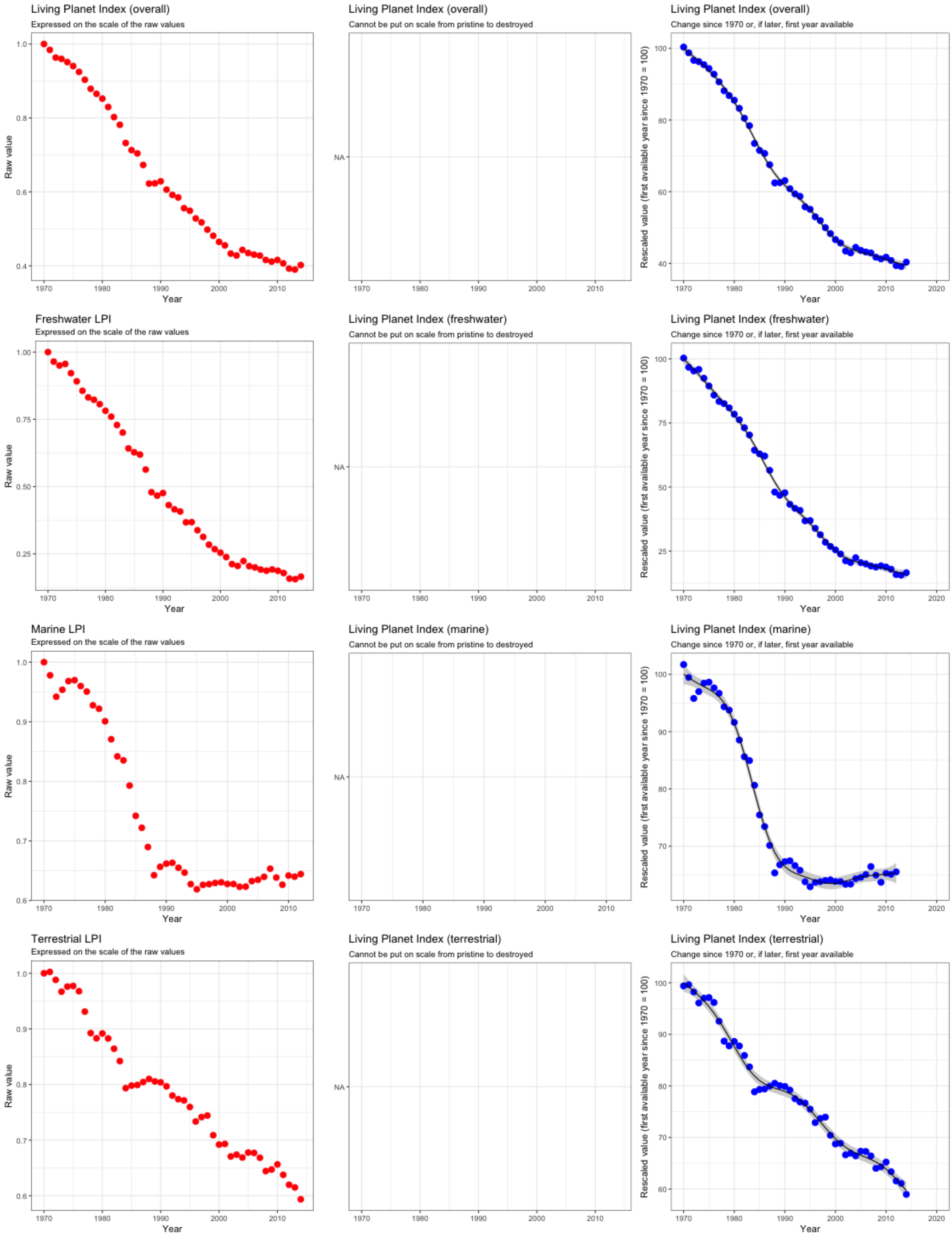
Indicator status: Highlighted indicator
EBV class: Species populations
Metric of population abundance
Indicator type: Representative, Sensitive
Based on multiple major taxonomic groups. Calculation gives more weight to changes in rare species
Years covered: 1970-2014, annual time-steps

The Living Planet Index has declined dramatically since 1970, losing about 13% of its value per decade.

Overview

Wild species are under pressure across all biomes and regions of the world. These declines ultimately result from humanity's demands on the biosphere which result in habitat loss, over-exploitation, pollution, spread of invasive species and climate change. Decline in species populations not only threatens biodiversity, but also ecosystem services which the human race depends on for a multitude of purposes including provision of food, medicine and basic materials. The *Living Planet Index* (LPI) measures trends in vertebrate populations of threatened and non-threatened species and is used as a proxy for monitoring biodiversity change in different habitats. The LPI is not only a global index but can also be calculated for selected regions, nations, biomes or taxonomic groups, provided that there are sufficient data available.

Status and trend



Living Planet Index: status and trend. Top row: A) Change in LPI through time. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline showing change since 1970. Second row: as top row, for the freshwater populations only. Third row: as top row, for the marine populations only. Fourth row: as top row, for the terrestrial populations only.

The time series shows a continual decrease in the LPI, meaning vertebrate population sizes have declined more, on average, than increased. This implies that diversity will have reduced, even if none of those species populations have declined to zero (extinction). At 13% loss per decade, the LPI has one of the highest rates of change of the indicators of population size. The freshwater LPI has experienced greater loss since 1970 than the marine or terrestrial LPI. The rate of loss of the marine LPI has decreased in recent years (post-1990) possibly due to global efforts to promote sustainable fishing.

Sampling methodology and data selection

The LPI can be thought of as a biological analogue of a stock market index that tracks the value of a set of stocks and shares traded on an exchange. The Global LPI is the aggregate of three equally weighted indices of vertebrate populations from terrestrial, freshwater and marine systems. The method has recently been adapted with a new weighting procedure to give a better representation of global vertebrate diversity and to correct for a bias towards well studied species from Europe and North America (McRae et al. 2017). The result is a steeper decline than in other versions of the LPI as a result of placing more weight on highly diverse regions and species groups which, on average, are declining faster. The LPI is calculated using geometric means rather than arithmetic means; as a result, it is more sensitive to changes in small populations than to changes in large populations, and is not directly proportional to the average size of vertebrate populations or the global number of vertebrate animals (Buckland et al. 2011). The Global LPI was calculated using time-series data on more than 16,000 populations of over 4,000 species of mammal, bird, reptile, amphibian and fish from all around the globe. The changes in the population of each species were aggregated and shown as an index relative to 1970, which was given a value of 1.

References

Buckland, S.T., Studeny. A.C., Magurran, A.E., Illian, J.B., and Newson, S.E. The geometric mean of relative abundance indices: a biodiversity measure with a difference. Ecosphere 29(2), 100.

Collen, B.E.N., Loh, J., Whitmee, S., McRae, Amin, R. and Baillie, J.E., 2009. Monitoring change in vertebrate abundance: the Living Planet Index. Conservation Biology, 23(2), pp.317-327.

Loh, J., Green, R.E., Ricketts, T., Lamoreux, J., Jenkins, M., Kapos, V. and Randers, J., 2005. The Living Planet Index: using species population time series to track trends in biodiversity. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 360(1454), pp.289-295.

McRae L, Deinet S, Freeman R. (2017) The Diversity-Weighted Living Planet Index: Controlling for Taxonomic Bias in a Global Biodiversity Indicator. PLoS ONE 12(1): e0169156.

S 2.2.8.3 Predatory fish biomass

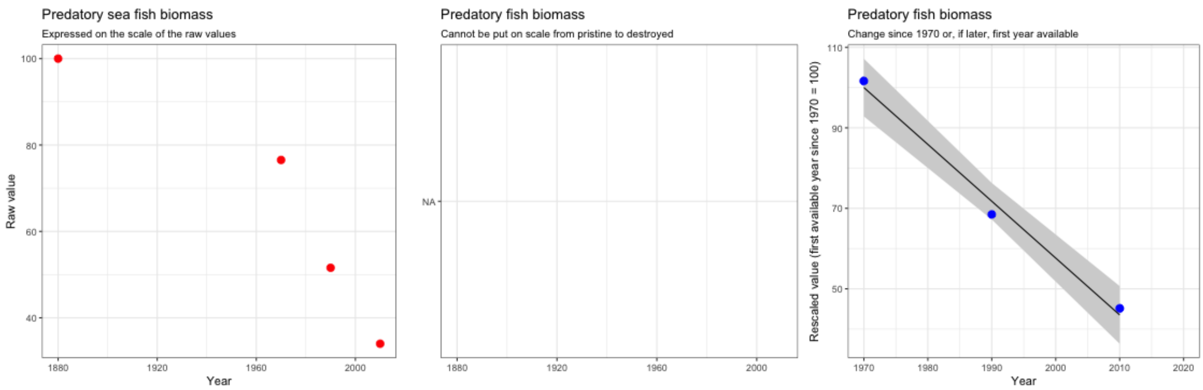
Indicator status: Other indicator
EBV class: Species populations
Indicator measures fish biomass
Indicator type: Sensitive, Underpin NCP
Predatory fish are selectively harvested for consumption
Years covered: 1880-2010, variable time steps

The world's oceans now hold only about one third as many predatory fish as they did in 1880.

Overview

Humans have selectively removed fish from our oceans for millennia. Many of the harvested species, especially those larger species that are harvested as 'table fish', have been eradicated from accessible areas and severely depleted in others. This indicator inspects the impact of fishing on ecosystem structure through the comparison of temporal trends in the abundance of small pelagic prey fish (see Prey Fish Biomass indicator) with large predatory fish.

Status and trend



Predatory fish biomass: status and trend. A) Change in predatory fish biomass. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trend in predatory fish biomass since 1970.

Predatory fish biomass declined by approximately two thirds from 1880 to 2010. The rate of decline is accelerating, with over half of the total decline occurring between 1970 and 2010. Much of this decline is likely attributable to human harvest (Christensen et al. 2014). Taken together with the increase in the abundance of prey fish (see *Prey Fish Biomass*), this indicator reveals a shift in the structure of marine ecosystems that is likely to lead to changes in marine ecosystem functioning (Christensen et al. 2014).

Sampling methodology and data selection

Ecosystem food web models provide information on the distribution of biomass within specified taxonomic or functional groups at given points in time and space. Data from

230 such models, amounting to 68 039 predictions of fish biomass by cell and year, was used to assess the importance of 11 predictor variables (year, latitude, bottom depth, distance from coast, density of seamounts, absolute primary production, average of surface and bottom temperature, zooplankton biomass, macrobenthos biomass, mesopelagic fish biomass, upwelling index, and FAO statistical areas) and to build a final model of the change of fish biomass over time (Christensen et al. 2014). The spatial distribution of predatory biomass was produced through the projection of modelled coefficients onto global maps of the predictor parameters with 0.5^{o} resolution. Predatory species were defined as those species with a trophic level greater than 3.5.

To produce the trend in predatory fish biomass over time, the modelled change/year within each time interval was multiplied by the number of years in the corresponding interval.

References

Christensen, V., Coll, M., Piroddi, C., Steenbeek, J., Buszowski, J., Pauly, D. (2014) A century of fish biomass decline in the ocean. Marine Ecology Progress Series 512: 155-166.

S 2.2.8.4 Prey fish biomass

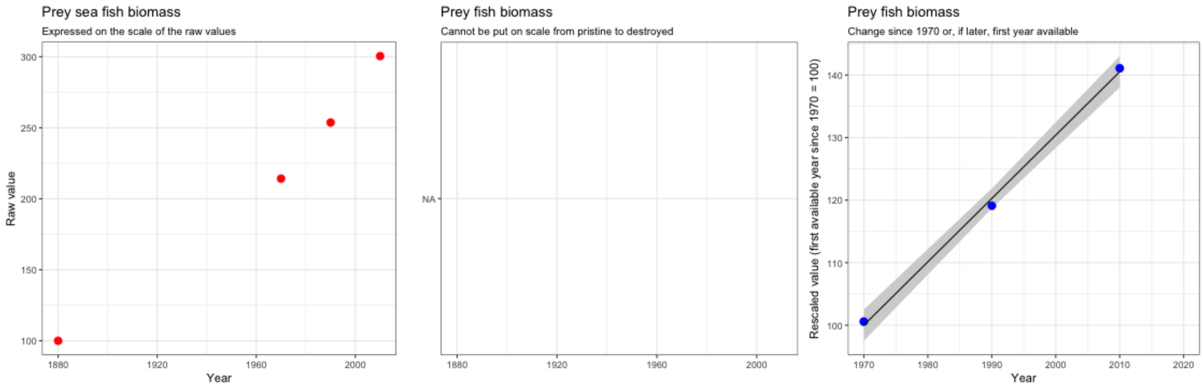
Indicator status: Other indicator
EBV class: Species populations
Indicator measures fish biomass
Indicator type: Representative
This indicator is based upon globally representative data.
Years covered: 1880-2010, variable time steps

There are now around three times as many prey fish in the oceans as there were in 1880.

Overview

Humans have selectively removed fish from our oceans for millennia. Many harvested species, especially those larger species that are harvested as ‘table fish’, have been eradicated from accessible areas and severely depleted in others. This indicator inspects the impact of fishing on ecosystems through the comparison trends in the abundance of small pelagic prey fish with large predatory fish (see Predatory Fish Biomass indicator).

Status and trend



Prey fish biomass: status and trend. A) Change in prey fish biomass. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available C) Trendline in prey fish biomass since 1970.

Prey fish biomass increased by approximately 200% in the 130 years up to 2010. This increase is likely linked to the anthropogenic removal of the higher trophic level species (Christensen et al. 2014). Taken together with the decline in predatory fish (see *Predatory Fish Biomass*), this indicator reveals a shift in the structure of marine ecosystems that is likely to had led to changes in marine ecosystem functioning (Christensen et al. 2014).

Sampling methodology and data selection

Ecosystem food web models provide information on the distribution of biomass within specified taxonomic or functional groups at given points in time and space. Data from 230
such models, amounting to 68 039 predictions of fish biomass by cell and year, was used to assess the importance of 11 predictor variables (year, latitude, bottom depth, distance from coast, density of seamounts, absolute primary production, average of surface and bottom temperature, zooplankton biomass, macrobenthos biomass, mesopelagic fish biomass, upwelling index, and FAO statistical areas) and to build a final model of the change of fish biomass over time (Christensen et al. 2014). The spatial distribution of prey biomass was produced through the projection of modelled coefficients onto global maps of the predictor parameters with 0.5° resolution. Prey species were defined as those species with a trophic level between 2.0 and 3.0. To produce the trend in prey fish biomass over time, the modelled estimate of change/year was multiplied by the number of years in the corresponding interval.

References

Christensen, V., Coll, M., Piroddi, C., Steenbeek, J., Buszowski, J., Pauly, D. (2014) A century of fish biomass decline in the ocean. Marine Ecology Progress Series 512: 155-166.

S 2.2.8.5 Wild Bird Index (habitat specialists)

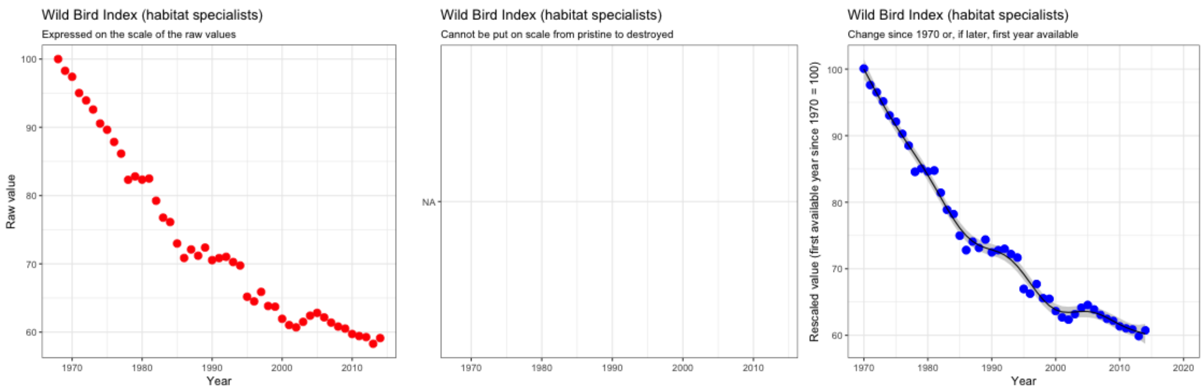
Indicator status: Other indicator
EBV class: Species populations
This indicator monitors changes in population sizes
Indicator type: Sensitive
This indicator focuses on specialist species, and its calculation gives more weight to changes in rare species
Years covered: 1968-2014, annual time-steps

The Wild Bird Index for habitat specialists has lost over 40% of its value since the baseline was established in 1968.

Overview

Aichi Target 5 calls for loss of "all natural habitats" to be halved, and degradation and fragmentation to be "significantly reduced". While remote sensing data are useful for quantifying the rate of clearance of forest and some other habitats, they are less useful for quantifying habitat degradation, whereas birds can be useful indicators of environmental health. In addition, Aichi Target 7 calls for areas under agriculture, aquaculture and forestry to be managed sustainably, ensuring conservation of biodiversity, and so the Wild Bird Index is able to measure that specific ambition. Wild Bird Indices show the average trends in relative abundance for suites of bird species that are characteristic of different habitats (forest, grassland, arid land and farmland), based on systematic surveys and monitoring schemes. These data are currently only available for North America and Europe; this indicator is therefore multi-regional rather than truly global.

Status and trend



Wild Bird Index (habitat specialists): status and trend. A) Change over time. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Index as a percentage of the value in 1970.

The Wild Bird Index (comprising habitat specialists) has declined with the index losing over 40% of its value since the baseline was established in 1968. With an average recent rate of change at -9%, the rate of change is higher than most other species population indicators. This is likely a reflection of the increased sensitivity of specialist species to anthropogenic pressures. However, this group includes birds that have adapted to anthropogenic land uses (i.e. farmland specialists). In areas of human encroachment these species are likely to fare better whereas other species targeted by this indicator (such as forest specialists) are likely to fare worse. These opposing responses may be increasing the variability in response within areas of dense farmland and weakening the signal of the index. It is always important to consider the disaggregated trends by major habitat to aid interpretation (Hoffmann et al 2018). It should be noted that trends in the Wild Bird Index should not be considered as representative of global trends, nor of trends for biodiversity in general, as populations trends within other regions and/or for other taxonomic groups may be different.

Sampling methodology and data selection

Average population trends of a suite of representative wild birds are measured across a large set of sampling plots as an indicator of the general health of the wider environment. By their nature, these sampling schemes tend to focus on the more widespread and abundant bird species, and the rarer species tend not to be covered. Single-species indices are combined using geometric means to produce a multi-species indicator represented by a single line on a graph, indexed to an arbitrary year for presentational purposes (usually 100 in the start year). Each species is weighted equally, meaning that the indicator measures changes in species composition and relative abundance (Gregory & van Strien 2010; Sheehan et al. 2010), but the use of geometric rather than arithmetic means has the consequence that the indicator is not directly proportional to the total number of habitat-specialist birds if evenness changes (Buckland et al. 2011). The indicator is based on systematic monitoring and robust sampling. However, long-term trends are only available for two temperate developed regions currently, and only for birds (in Europe and North America), although national bird monitoring programmes have recently been established in a number of African countries and provisional indicators published (Wotton et al. 2018).

References

Buckland, S.T., Studeny. A.C., Magurran, A.E., Illian, J.B., and Newson, S.E. The geometric mean of relative abundance indices: a biodiversity measure with a difference. Ecosphere 29(2), 100.

Gregory, R.D. and van Strien, A., 2010. Wild bird indicators: using composite population trends of birds as measures of environmental health. Ornithological Science, 9(1), pp.3-22.

Gregory, R.D., van Strien, A., Vorisek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B. & Gibbons, D.W. (2005) Developing indicators for European birds. Philosophical Transactions of the Royal Society B, 360, 269-288.

Hoffmann, M., Brooks, T.M., Butchart, S.H.M., Gregory, R.D. & McRae, L. 2018. Trends in Biodiversity: Vertebrates. In: D.A. DellaSala & M.I. Goldstein (eds). The Encyclopedia of the Anthropocene, vol. 3, p. 175-184. Oxford: Elsevier.

Sheehan, D.K., Gregory, R.D., Eaton, M.A., Bubb, P.J. and Chenery, A.M., 2010. The wild bird index – guidance for national and regional use. UNEP-WCMC, Cambridge, UK.

Wotton, S.R., Eaton, M.E., Sheehan, D., Munyekenye, F., Burfield, I.J., Butchart, S.H.M., Moleofi, K., Nalwanga-Wabwire, D., Ndang'ang'a, P.K., Pomeroy, D., Senyatso, K.J. & Gregory, R.D. (2017). Developing biodiversity indicators for African birds. *Oryx,* 1-12.

S 2.2.8.6 Wild mammal biomass

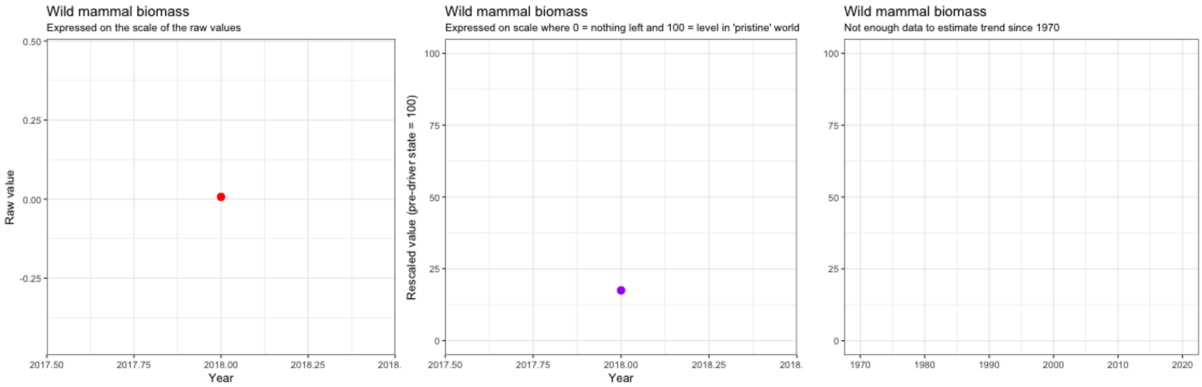
Indicator status: Other indicator
EBV class: Species populations
Indicator measures biomass
Indicator type: Underpin NCP
Wild mammals are a food source for many people worldwide.
Years covered: 2018

Global biomass of wild mammals has declined by over 75% because of human activity.

Overview

Humans comprise more biomass than all wild mammal species combined (Bar-On et al. 2018) and fulfilling the needs of such a large global population has had a dramatic impact on the distribution of most other mammals. We have greatly increased the abundance of a few domesticated mammalian species and have caused widespread decline of other species through deliberate eradication and habitat conversion.

Status and trend



Wild mammal biomass: status. A) Estimated value. B) Estimate expressed as percentage of original pre-impact condition. C) No trendline data available.

Over 75% of wild mammal biomass has been removed through human activity. Marine and terrestrial mammal biomass are respectively one fifth and one seventh those of pre-human impact levels (Bar-On et al. 2018).

Sampling methodology and data selection

Terrestrial: The relationship between the density of a specific species and individual body mass, population density, and sample area was assessed using study-level data pertaining to 350 terrestrial mammal species (Novosolov et al. 2017). This knowledge was then used to extrapolate the total number of individuals expected across the globe for 3700 mammal species (with known range and mass) (Bar-On et al. 2018). Biomass was then estimated by multiplying the total number of individuals with mean body mass. Total global wild mammal biomass estimates were also extracted from Smil (2011), and Barnosky (2008) and the final estimate was calculated from the geometric mean of the three sources (Bar-On et al. 2018). The pristine condition for terrestrial mammal biomass was taken from Barnosky (2008).

Marine: Whale biomass was taken as a proxy of total marine mammal biomass (Bar-On et al. 2018). Data on present-day and pristine (unimpacted) marine mammal biomass was extracted from Christensen (2006).

References

Bar-On, Y.M., Phillips, R., Milo, R. (2018) The biomass distribution on Earth. Proceedings of the National Academy of Sciences, 115(25), 6506.

Barnosky AD (2008) Megafauna biomass tradeoff as a driver of Quaternary and future extinctions. Proceedings of the National Academy of Sciences 105 (Supplement 1):11543–11548.

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Smil V (2011) Harvesting the biosphere: the human impact. Popul Dev Rev 37(4):613–636.

S 2.2.9 Indicators of species traits

S 2.2.9.1 Functional richness (Madingley)

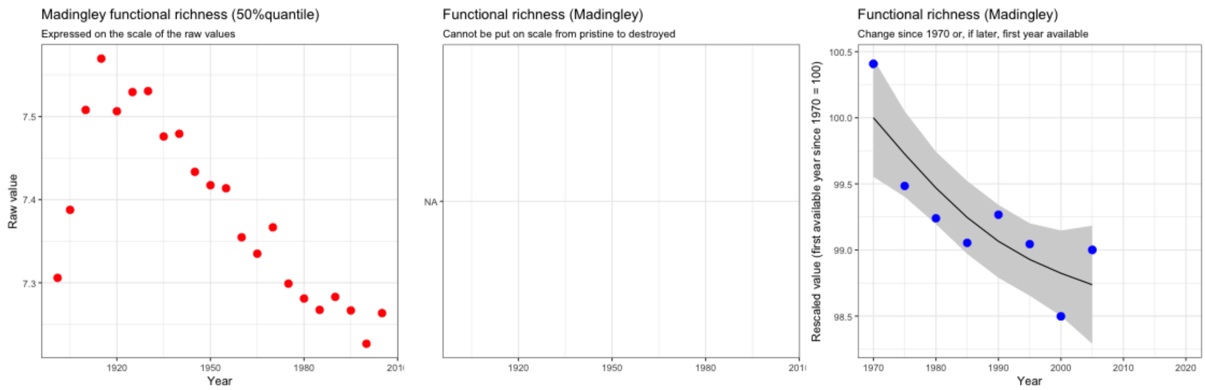
Indicator status: Other indicator
EBV class: Species traits
Measures changes in the breadth of traits within a community
Indicator type: Representative
The indicator is derived from a global general ecosystem model
Years covered: 1901-2005, 5-year time steps

Functional richness increased dramatically in the first 20 years of the last century but has since steadily decreased, according to the Madingley general ecosystem model.

Overview

The functional richness of a community describes the diversity of traits that are available to exploit the full range of ecological niches present as well as adapt to future changes. When anthropogenic pressures cause a decline in trait richness, especially when such pressures are selective in their removal (as is likely as specific traits may render species more sensitive to pressures or more desirable for human harvesting), the fitness of a community may decline due to inefficient exploitation of resources or lack of adaptive capacity.

Status and trend



Functional richness (Madingley): status and trend A) Change over time. B) Trendline not possible as no baseline value (for a pristine or at least much less impacted world) available. C) Trendline showing change since 1970.

Functional richness increased dramatically in the first 20 years of the last century but has since steadily decreased. Functional Richness has been shown to have a stronger relationship with ecosystem functioning, both respect to standing stocks of biomass (Lefcheck et al., 2015) and ecological processes such as pollination, pest control or dung removal (Gagic et al., 2015). This decline in functional richness therefore suggests declining rates of ecosystem function at the global scale, however the magnitude of the decline in function is difficult to quantify generically as the relationship between functional richness and functioning varies across function (Gagic et al., 2015).

Sampling methodology and data selection

The Madingley model is a process-based model that describes ecosystem structure and function within marine and terrestrial realms. Most organisms are included within the flexible modelling framework, allowing exploration of the impacts of the environment, human pressures and species interactions on scales from local cohorts to global biodiversity as well as across time (Harfoot et al. 2014). The data described here was modelled using land use inputs from the LUH2 harmonised land use dataset and climate variables from the IPSL model outputs from 1951 to 2099 at 0.5-degree resolution (McSweeney and Jones, 2016). Climate for the period 1901 to 1951 was generated from randomly sampling the climate of the years 1951 to 1960.

References

Gagic, V., Bartomeus, I., Jonsson, T., Taylor, A., Winqvist, C., Fischer, C., Slade, E.M., Steffan-Dewenter, I., Emmerson, M., Potts, S.G. and Tscharntke, T., 2015. Functional identity and diversity of animals predict ecosystem functioning better than species-based indices. Proceedings of the Royal Society of London B: Biological Sciences, 282(1801), p.20142620.

Harfoot, M.B., Newbold, T., Tittensor, D.P., Emmott, S., Hutton, J., Lyutsarev, V., Smith, M.J., Scharlemann, J.P. and Purves, D.W., 2014. Emergent global patterns of ecosystem structure and function from a mechanistic general ecosystem model. PLoS biology, 12(4), p.e1001841.

Lefcheck, J.S. and Duffy, J.E., 2015. Multitrophic functional diversity predicts ecosystem functioning in experimental assemblages of estuarine consumers. Ecology, 96(11), pp.2973-2983.

S 2.2.9.2 Mammalian body mass

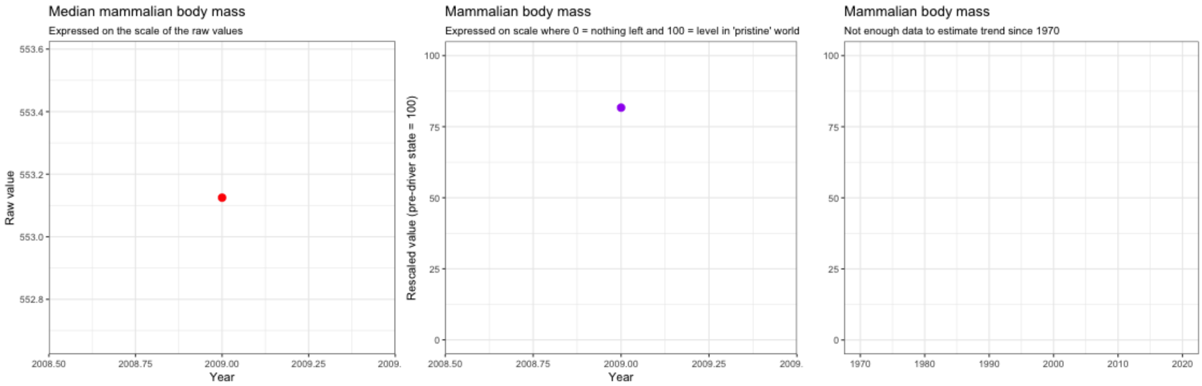
Indicator status: Other
EBV class: Species traits
Measures changes in body mass
Indicator type: Representative, Sensitive
The indicator is based on data pertaining to thousands of mammal species across the world
Years covered: 2009

The median body mass of mammalian species within 1^o grid cells has decreased by approximately 20% through human history due to anthropogenic drivers.

Overview

Humanity has had a devastating impact on many large mammal species, driving them to extinction, or near extinction, through consumption, deliberate eradication of predators, and removal of habitat. This global extermination of large mammals will have had consequences on global macroecological patterns such as body mass distribution but how much of an impact requires knowledge of the counterfactual – an estimation of body mass distributions in the absence of humans. This indicator investigates the impact humans have had in re-shaping mammalian body mass distribution through modelling the distribution that would have been expected without human influence and comparing that with present-day distribution.

Status and trend



Mammalian body mass: status and trend. A) Current median mammalian body mass. B) Data rescaled to show change from a pristine world. C) No trendline data available.

Median terrestrial mammalian body mass is 553g; this represents a decrease of approximately 20% from that which would be expected in a world free of human influences. The influence of humans showed spatial variation, with higher median body mass associated with pristine areas, remote from human activity (Santini et al. 2017).

Sampling methodology and data selection

Data pertaining to 5242 terrestrial mammal species was analysed by Santini et al. (2017), using geographic range polygons published by the Red List of the IUCN and body mass data from Pacifici et al. (2013). Body mass distribution (median, maximum and skewness) was assessed as the assemblage level – where the assemblage was constructed using species presence within 1^{o} grid cells. Body mass distribution was modelled using environmental predictors, and human-influence predictors. Order richness was also included in the models to account for the influence that species richness may have on body mass distribution. Twelve environmental predictors and order richness were included in a principal components analysis then the first two principal components along with the human-influence variables were included in the model selection process. Using species area relationship models, the mean and maximum body mass per grid cell was predicted for two scenarios: one with observed human impacted and one with minimal human impact. To calculate a scenario with no human influence, the process was repeated using historical range maps obtained from Faurby and Svenning (2015). Note that this indicator does not consider any evolutionary change in species' body mass that human activity has prompted; the effect of such changes would be slight compared to the effects of size-selective changes in species distributions.

References

Faurby, S., & Svenning, J. C. (2015). Historic and prehistoric human-driven extinctions have reshaped global mammal diversity patterns. Diversity and Distributions, 21(10), 1155-1166. doi:10.1111/ddi.12369

Pacifici, M., Santini, L., Di Marco, M., Baisero, D., Francucci, L., Grottolo Marasini, G., . . . Rondinini, C. (2013). Generation length for mammals. Nature Conservation, 5, 89-94.

Santini, L., González-Suárez, M., Rondinini, C., & Di Marco, M. (2017). Shifting baseline in macroecology? Unravelling the influence of human impact on mammalian body mass. Diversity and Distributions, 23(6), 640-649. doi:10.1111/ddi.12555

S 2.2.9.3 Region-based Marine Trophic Index

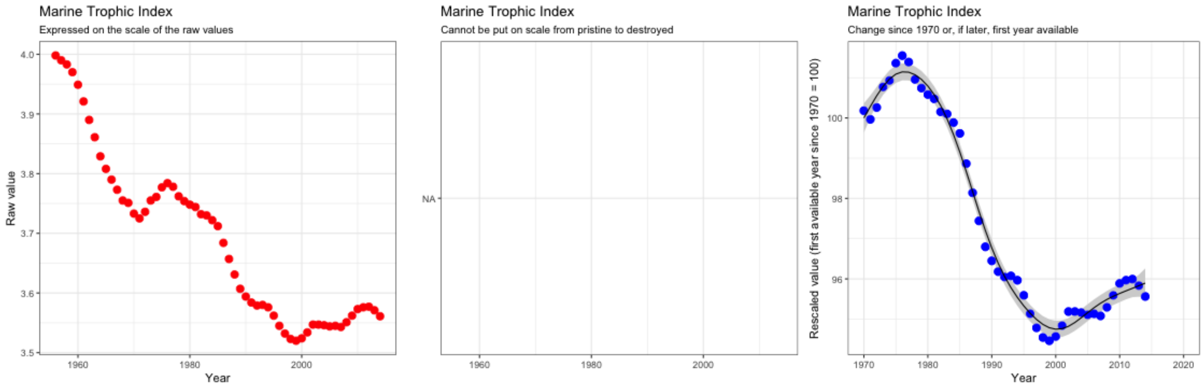
Indicator status: Core indicator
EBV class: Species traits
Trophic level is a trait
Indicator type: Underpin NCP
Relevant to fishing stocks
Years covered: 1956-2014, annual time-steps

The Marine Trophic Index fell sharply for most of the latter half of the twentieth century, indicating the dramatic pressure that fishing was putting on marine food webs, but improvement has been observed in the last two decades.

Overview

Fish currently supply the greatest percentage of the world’s protein consumed by humans. However, most of the world’s fisheries are being fished at levels above their maximum sustainable yield and many regions are severely overfished. The Region-based Marine Trophic Index (RMTI) measures the mean trophic level of landed stock and hence indicates the extent of ‘fishing down the food webs’. This provides a measure of whether fish stocks, especially of large bodied fish, are being overexploited and whether fisheries are being sustainably managed. The RMTI differs from the MTI as it allows for fishing zones to be relocated as new fishing grounds are exploited.

Status and trend



Region-based Marine Trophic Index: status and trend. A) Change over time. B) Trendline not calculated as not possible to evaluate pristine value. C) Trendline showing change since 1970.

The RMTI has shown a steep decline in value since 1956, but has been relatively stable since the mid-1990's, even showing some improvement in recent years. The decline against the baseline in index value represents a decline in the abundance and diversity of fish species high in the food chain. However, the data is based upon catch data which is likely to be biased as some nations are less likely to record and report fishing data, or, if data is reported, it may be lacking taxonomic or geographic detail.

Sampling methodology and data selection

To calculate the MTI, the potential catch that can be obtained given the observed trophic structure of the actual catch is used to assess the fisheries in an initial (usually coastal) region. Actual catch exceeding potential catch indicates exploitation of a new fishing region. The MTI of the new region can then be calculated and subsequent regions are determined in a sequential manner. This method improves upon the use of the Fishing-in-Balance (FiB) index in conjunction with the original MTI calculated over the whole time series because assumptions of fleet and stock stationarity over the entire time series and geographic area are removed.

References

Pauly D, Watson R (2005) Background and interpretation of the “Marine Trophic Index” as a measure of biodiversity. Philosophical Transactions of the Royal Society-Biological Sciences 360: 415-423.

Kleisner, K., Mansour, H., Pauly, D., 2014, Region-based MTI: resolving geographic expansion in the Marine Trophic Index. Marine Ecology Progress Series, 512, 185-199.

Appendix AA. Section 2.2.6. Global-scale analysis of attribution of trends to drivers

Full description of the methodology used for the systematic review of literature

The global-scale analysis of attribution of trends to drivers was conducted to answer to the following overarching questions of the IPBES Global Assessment on Biodiversity and Ecosystem Services:

- Which are the **most important direct anthropogenic biophysical drivers** determining **changes in the state of nature**?
- What is the **relative magnitude of the impacts** of each direct driver on changes in the state of nature?

These questions were addressed at the global scale but also at the level of:

- the four IPBES regions (Africa, Americas, Europe and Central Asia, Asia and the Pacific),
- the terrestrial, freshwater and marine realms,
- and the different classes of the Essential Biodiversity Variables (EBV) framework (Pereira et al., 2013)

An analysis of the scientific literature was carried out following five successive steps that aimed to identify and extract adequate information from the most relevant natural science studies:

1. Search of studies published in the scientific literature through a structured, transparent and repeatable procedure
2. Selection of potentially suitable studies for the analysis based on their titles, keywords and abstracts
3. Prioritization of the most relevant studies based on their full-text analysis
4. Extraction of information from the studies identified as most relevant for the analysis
5. Analysis and synthesis of the information extracted from the most relevant studies

Step 1. Structured search of potentially relevant studies in the scientific literature

The search of natural science studies in the literature was performed using *search strings* that were built by combining search terms covering the different aspects of the questions listed above, i.e. **relative impacts** of **direct drivers** on the **changes in the state of nature**. The structured search of the scientific literature was carried out on the 05/09/2018 in Web of Science. The search strings were used in this search engine to find the most relevant studies in the literature based on their titles, keywords and abstracts.

Changes in the state of nature were captured with a series of **indicators** that are well accepted in the scientific literature and/or described in the IPBES conceptual framework:

- IPBES core indicators[1]

[1] https://www.ipbes.net/indicators-data-ipbes-assessments and https://www.ipbes.net/core-indicators

- IPBES highlighted indicators[2]
- Non-IPBES indicators considered as relevant for the analysis (but not included in the IPBES core or highlighted indicators)

The main objective of this section was to assess and compare the relative impact of the different direct drivers on a number of indicators reflecting changes in the state of nature. For this reason, those indicators that are intrinsically related to a single driver or a limited subset of drivers were not included in the analysis. Selected indicators are not explicitly linked to one of the direct drivers but can potentially be affected by any of the direct drivers used in this assessment. The search strings used to reflect the different indicators are reported in Table 1.

The **direct anthropogenic biophysical drivers** were represented with the general classification developed in the frame of the IPBES Global Assessment (Chapter 2 – Drivers) and based on five main categories of direct drivers: Climate change, Land/sea use change, Direct exploitation, Pollution, and Invasive alien species. An additional category ("Other") was used for direct threats to biodiversity that do not fit clearly into one of the five main categories defined above, such as direct fires or human disturbances due to recreational activities. A list of search terms was first established based on the detailed description of each direct driver in *Chapter 2 – Drivers* of this Global Assessment. Then, the IUCN classification of direct threats to biodiversity from Salafsky et al. (2008) was used to extend the list of search terms for each driver. Finally, search terms were added based on Vörösmarty et al. (2010) and Halpern et al. (2008) to reflect driver classification systems that are widely used in the literature on freshwater and marine realms, respectively. The search terms from these different sources (Table 2) were combined to build unique search strings for each direct driver (Table 3).

The search procedure was structured so as to maximize the chances to identify and analyze the content of studies addressing and comparing the impact of at least two direct drivers on the state of nature. To do so, the search strings of different rows in Table 3 were combined to represent pairwise combinations of drivers using the Boolean operator "AND" between the rows. As six categories of drivers were defined, fifteen pairwise combinations of search strings were produced to identify studies examining the impacts of all possible pairs of drivers. For instance, studies addressing climate change and pollution were identified using the following search string: ((search string for *climate change* in Table 3) AND (search string for *pollution* in Table 3)). Each of the fifteen pairwise combinations of search strings reflecting the pairs of drivers from Table 3 was then combined with each of the search strings reflecting the individual indicators listed in Table 1. Therefore, a large number of relatively short search strings were produced to identify studies analysing the impacts of two drivers at a time on each indicator of changes in the state of nature.

[2] https://www.ipbes.net/indicators-data-ipbes-assessments and https://www.ipbes.net/highlighted-indicators

Table 1. Search strings used in the structured search of the scientific literature to characterize different dimensions of the changes in the state of nature.

Type of indicator	Name of indicator	Search strings	Realm[3]	EBV class
IPBES core indicators[4]	Proportion of fish stocks within biologically sustainable levels	fish* AND stock* AND ("sustainab*" OR safe)	Marine	Species populations
	Proportion of local breeds, classified as being at risk, not-at-risk or unknown level of risk of extinction	"local breed*" AND (livestock* OR (domestic AND animal*)) AND (risk OR extinct* OR threat*)		Genetic composition
	Red List Index	"red list ind*"		Species populations
IPBES highlighted indicators[5]	BioTime - Local Species Abundance	((species OR assemblage*) AND abundance AND (local OR location* OR sample*)) AND (global OR world*) AND ("time series" OR "time-series" OR temporal)	Mostly marine	Species populations
	BioTime - Local Species Richness	((species OR assemblage*) AND (richness OR diversit*) AND (local OR location* OR sample*)) AND (global OR world*) AND ("time series" OR "time-series" OR temporal)	Mostly marine	Community composition
	BioTime – Local Species Turnover	((species OR assemblage*) AND (turnover OR (composition* AND (change OR similarit*))) AND (local OR location* OR sample*)) AND (global OR world*) AND ("time series" OR "time-series" OR temporal)	Mostly marine	Community composition
	Living Planet Index	"living planet ind*" OR "living planet report*"		Species populations
	Mean length of fish	("mean length*" OR "average length*") AND fish*	Marine	Species traits
	Mean Species Abundance	"mean species abundance" OR GLOBIO	Terrestrial	Community composition
	Proportion of predatory fish	(proportion OR ratio OR percentage) AND "predator* fish*"	Marine	Species traits
Non-IPBES indicators	Area of mangrove forest cover	(extent OR area OR cover* OR proportion OR percentage OR land OR landscape) AND mangrove* AND forest*		Ecosystem structure

[3] Some indicators are linked to (a) particular realm(s) by definition.
[4] We used IPBES *core* indicators identified as "status" indicators of "nature/biodiversity and ecosystem functions" (https://www.ipbes.net/core-indicators).
[5] We used IPBES *highlighted* indicators identified as "status-only" indicators (and not other types of indicators according to the DPSIR classification system) and specific to the box "nature/biodiversity and ecosystem functions" in the IPBES conceptual framework (https://www.ipbes.net/highlighted-indicators).

Extent of Intact Forest Landscapes	(extent OR area OR cover* OR proportion OR percentage OR land OR landscape) AND intact* AND forest*	Terrestrial	Ecosystem structure
Extent of Remaining Primary Vegetation	(extent OR area OR cover* OR proportion OR percentage) AND (primary OR natural) AND vegetation	Terrestrial	Ecosystem structure
Extent of Remaining Wilderness	(extent OR area OR cover* OR proportion OR percentage OR land OR landscape) AND wilderness*	Terrestrial	Ecosystem structure
Global Bird Species Richness	(global OR world*) AND bird* AND "species richness"		Community composition
IUCN Red List of Threatened Species[6]	(IUCN OR "red list") AND (threat* OR extinct*) AND species NOT "red list ind*"		Species populations
Leaf Area Index	"leaf area ind*"	Terrestrial	Ecosystem structure
Net Primary Productivity	"net primary product*"		Ecosystem function
Percentage of Live Coral Cover	(extent OR area OR cover* OR proportion OR percentage) AND coral AND live	Marine	Ecosystem structure
Predatory Fish Biomass	predator* AND fish* AND (biomass OR abundance)	Marine	Species populations
Prey Fish Biomass	prey* AND fish* AND (biomass OR abundance)	Marine	Species populations
Wild Bird Index	"wild bird ind*"		Species populations

[6] Studies reporting on the "Red List Index" (i.e. changes over time in the number of species in each category of extinction risk on the IUCN Red List of Threatened Species) were not considered here, as this index is considered as a separate IPBES core indicator.

Table 2. Search terms used in the structured search of the scientific literature to capture the direct (natural-)anthropogenic biophysical drivers.

IPBES direct drivers	Search terms			
	Chapter 2 – Drivers	**Salafsky et al. (2008)**[7]	**Vörösmarty et al. (2010)**	**Halpern et al. (2008)**
Climate change	"climat* change" OR "chang* climat*" OR ("increas* temperature*" OR "global warming") OR (chang* AND precipitation*) OR ((extreme OR severe) AND (weather OR climat*)) OR heatwave* OR drought* OR storm* OR flood* OR "sea level rise"	"climat* change" OR "chang* climat*" OR ((extreme OR severe) AND (weather OR climat*)) OR ("habitat shift*" AND climate) OR ("habitat alteration" AND climate) OR drought* OR (temperature* AND extreme) OR storm* OR flood*	"soil salinization" OR "potential acidification" OR "thermal alteration" OR ((consumptive OR human OR agricultural) AND "water stress")	"sea temperature" OR (UV OR ultraviolet)
Pollution	(pollut* OR contamin* OR emission* OR spill-over* OR disposal* OR deposition* OR dump* OR discharge*) OR ((noise OR light OR gas* OR particle* OR particulate* OR nitrogen OR sulphur* OR phosphor* OR waste* OR garbage OR sewage OR pesticide* OR fertilizer* OR nutrient* OR "oil spill*" OR metal OR salinization OR salinisation OR acidification OR solid OR plastic) AND (soil OR water OR ocean OR marine OR atmosphere OR air))	((water OR solid OR garbage) AND (waste OR sewage)) OR ((industrial OR military OR agricultur* OR forest*) AND effluent*) OR "air-borne pollutant*"	(nitrogen OR phosphor* OR mercury OR pesticide* OR organic) AND (load* OR deposition)	"nutrient input" OR ((organic OR non-organic OR ocean*) AND pollution)
Land/sea use change	("land use chang*" OR "land cover chang*" OR "land* system* chang*" OR "land* chang*" OR "land* degradation" OR "land* conversion" OR "land management") OR ("sea use chang*" OR "seascape chang*" OR ((marine OR ocean) AND use AND change*)) OR ("habitat loss*" OR "habitat degradation*" OR "habitat chang*" OR "habitat conversion" OR "habitat modification*" OR "habitat fragmentation"	((residential OR housing OR commercial OR industrial OR touris* OR recreation*) AND (extent OR area OR cover*) AND (develop* OR expan* OR increas*)) OR (agricultur* OR crop* OR "cultivated area*" OR farmland OR "wood plantation*" OR "forest* plantation*" OR "pulp* plantation*" OR (livestock AND (farm* OR ranch* OR graz*)) OR aquaculture)	"cropland" OR "impervious surfaces" OR "livestock density" OR "wetland disconnectivity" OR "dam density" OR "river fragmentation" OR "aquaculture pressure" OR "flow disruption"	"commercial activity"

[7] Only the 1st and 2nd levels of classification of threats in Table 1 from Salafsky et al. (2008) were used to develop the search terms because the 3rd level includes more specific and non-exhaustive examples.

	OR “habitat management”) OR (biofuel* OR biogas*) OR (urbanisation OR ((urban* OR cities) AND (develop* OR expan* OR increas*))) OR (deforestation OR afforestation OR (forest AND plantation*)) OR ((aquaculture* OR agricultur* OR crop* OR “cultivated area*” OR farmland OR pasture) AND ((develop* OR expan* OR increas* OR intensification OR extensification OR abandon* OR chang*) OR (livestock OR overgraz*)))	OR (energy AND (drill* OR min* OR quarry*)) OR (((transport* OR service) AND (network* OR corridor* OR infrastructure*)) OR road* OR rail* OR “ship* lane*” OR “flight path*”) OR (“system* modification*” OR (dams OR (water AND (management OR use))))		
Direct exploitation	((((natur* AND resource*) OR material* OR (biomass OR “fossil fuel*” OR ore* OR mineral*)) OR ((biological AND resource*) OR wildlife OR animal* OR population*) OR water) AND ((overextraction OR overexploitation) OR (extraction OR exploitation OR withdraw*) OR depletion OR (hunting OR poaching OR “bush meat*”))) OR (soil* AND (erosion OR acidification OR degradation))	((biologic* AND resource*) OR (animal* OR plant*)) AND ((extraction OR exploitation OR use*) OR (hunting OR collect* OR gather*) OR (harvest* OR logging*) OR (fisher* OR fishing))	fishing OR fisher*	fishing OR (bycatch OR by-catch)
Invasive alien species	((invasive OR invasion) AND (alien OR exotic OR non-native OR pest* OR disease) AND species) OR “biological invasion*”	((invasive OR invasion) AND (alien OR non-native OR pest*) AND species) OR (introduc* AND (species OR material))	non-native AND fish*	“biological invasion*” OR “species invasion*”
Other drivers[8]	“human perturb*” OR “human disturbance*” OR fire*	“human intrusion* OR “human disturbance*” OR “recreational activit*” OR ((war OR civil OR military*) AND (exercise* OR activit*))	sediment AND (load* OR deposition)	“direct human pressure*” OR “benthic structure*”

[8] Other (natural-)anthropogenic drivers include human activities or anthropogenic pressures that are either not directly linked to any of the IPBES direct drivers (e.g. direct human disturbances) or act at the interface between several of them (e.g. fires – see Supplementary Material for Chapter 2 NCP - NCP #9 Regulation of hazards and extreme events).

Table 3. Search strings developed based on different sources (Table 2) and used in the structured search of the scientific literature to capture the direct (natural-)anthropogenic biophysical drivers.

IPBES direct drivers	Search strings
Climate change	(“climat* change” OR “chang* climat*” OR (“increase* temperature*” OR “thermal alteration” OR “global warming”) OR (chang* AND precipitation*) OR ((extreme OR severe) AND (weather OR temperature OR precipitation OR climat*)) OR heatwave* OR drought* OR storm* OR flood* OR (UV OR ultraviolet) OR “sea level rise” OR “soil salinization” OR (“habitat shift*” AND climate) OR (“habitat alteration” AND climate) OR ((consumptive OR human OR agricultural) AND “water stress”))
Pollution	((pollut* OR contamin* OR emission* OR spill-over* OR disposal* OR deposition* OR load* OR dump* OR discharge*) OR ((noise OR light OR gas* OR particle* OR particulate* OR nitrogen OR sulphur* OR phosphor* OR waste* OR garbage OR sewage OR pesticide* OR fertilizer* OR nutrient* OR “oil spill*” OR metal OR salinization OR salinisation OR acidification OR solid OR plastic OR mercury OR nutrient* OR pollutant*) AND (soil OR water OR ocean OR marine OR atmosphere OR air)) OR ((industrial OR military OR agricultur* OR forest*) AND effluent*))
Land/sea use change	((“land use chang*” OR “land cover chang*” OR “land* system* chang*” OR “land* chang*” OR “land* degradation” OR “land* conversion” OR “land management”) OR ((marine OR ocean OR sea*) AND use AND change*) OR (“habitat loss*” OR “habitat degradation*” OR “habitat chang*” OR “habitat conversion” OR “habitat modification*” OR “habitat fragmentation” OR “habitat management”) OR (biofuel* OR biogas*) OR ((residential OR urban* OR cities OR housing OR commercial OR industrial OR touris* OR recreation*) AND (extent OR area OR cover* OR proportion* OR percentage*) AND (develop* OR expan* OR increas*)) OR (deforestation OR afforestation OR “wood plantation*” OR “forest* plantation*” OR “pulp* plantation*”) OR ((aquaculture* OR agricultur* OR crop* OR “cultivated area*” OR farmland OR pasture) AND (develop* OR expan* OR increas* OR intensification OR extensification OR abandon* OR chang*)) OR (livestock AND (farm* OR ranch* OR graz* OR densit*)) OR (energy AND (drill* OR min* OR quarry*)) OR (((transport* OR service) AND (network* OR corridor* OR infrastructure*)) OR road* OR rail* OR “ship* lane*” OR “flight path*”) OR (“system* modification*” OR (dams OR (water AND (management OR use)))))
Direct exploitation	(((((natur* AND resource*) OR material* OR (biomass OR “fossil fuel*” OR ore* OR mineral*)) OR ((biological AND resource*) OR wildlife OR animal* OR plant* OR population*) OR water) AND ((overextraction OR overexploitation) OR (extraction OR exploitation OR withdraw*) OR depletion OR (hunting OR collect* OR gather* OR poaching OR “bush meat*”))) OR ((forest* OR wood OR timber*) AND (harvest* OR logging*)) OR (soil* AND (erosion OR acidification OR degradation)) OR (fisher* OR fishing OR (bycatch OR by-catch)))
Invasive alien species	(((invasive OR invasion) AND (alien OR exotic OR non-native OR pest* OR disease) AND species) OR “biological invasion*” OR (introduc* AND (species OR material)))
Other drivers	(“human perturb*” OR “human intrusion*” OR “human disturbance*” OR fire* OR “recreational activit*” OR ((war OR civil OR military*) AND (exercise* OR activit*)) OR “benthic structure*” OR (sediment AND (load* OR deposition)))

With this approach based on pairs of drivers, there is a risk to overlook important synthetic studies that analyze and compare the global impact of major drivers without mentioning them explicitly in the title, keywords or abstract. Hence, the following search string that combines different search terms was used to broaden the scope of the literature review beyond these specific pairs of drivers (Tables 2-3) and to capture studies that analyse the impacts of major threats to biodiversity in a broader way:

(driver* OR factor* OR determinant* OR “driving force*” OR threat* OR “proximate cause*” OR pressure* OR stressor* OR risk* OR “global change”)
AND
(multi* OR quantif* OR compar* OR partition* OR rank* OR order* OR relative OR interact* OR interplay* OR synerg* OR magnitude* OR rate* OR effect* OR impact* OR influe* OR pace* OR extent OR importan*)

In the same way as for the pairwise combinations of search strings reflecting pairs of drivers, this general search string was then combined with each of the search strings used to reflect different dimensions of the changes in the state of nature (indicators) from Table 1 to identify studies analysing the impact of multiple drivers on each indicator.

Table 4 provides different examples of search strings that were used to identify studies examining the relative impacts of different direct (natural-)anthropogenic biophysical drivers on several dimensions of the changes in the state of nature.

Table 4. Examples of search strings used in the systematic search of the scientific literature to evaluate the relative impact of multiple drivers on changes in the state of nature (see Tables 1-3).

Example	Objective	Search strings used in Web-of-Science
1	Impacts of climate change and pollution on the living planet index	TS = (“living planet index” OR “living planet report”) AND TS = (“climat* change” OR “chang* climat*” OR (“increase* temperature*” OR “thermal alteration” OR “global warming”) OR (chang* AND precipitation*) OR ((extreme OR severe) AND (weather OR temperature OR precipitation OR climat*)) OR heatwave* OR drought* OR storm* OR flood* OR (UV OR ultraviolet) OR “sea level rise” OR “soil salinization” OR (“habitat shift*” AND climate) OR (“habitat alteration” AND climate) OR ((consumptive OR human OR agricultural) AND “water stress”)) AND TS = ((pollut* OR contamin* OR emission* OR spill-over* OR disposal* OR deposition* OR load* OR dump* OR discharge*) OR ((noise OR light OR gas* OR particle* OR particulate* OR nitrogen OR sulphur* OR phosphor* OR waste* OR garbage OR sewage OR pesticide* OR fertilizer* OR nutrient* OR “oil spill*” OR metal OR salinization OR salinisation OR acidification OR solid OR plastic OR mercury OR nutrient* OR pollutant*) AND (soil OR water OR ocean OR marine OR atmosphere OR air)) OR ((industrial OR military OR agricultur* OR forest*) AND effluent*))
2	Impacts of multiple drivers on community composition	TS = ((communit* OR assemblage* OR taxonom* OR species) AND (dominance* OR richness OR turnover OR diversit* OR composition OR similarit*)) OR (“species interaction*” OR “biotic interaction*”) AND TS = (driver* OR factor* OR determinant* OR “driving force*” OR threat* OR “proximate cause*” OR pressure* OR stressor* OR risk* OR “global change”) AND TS = (multi* OR quantif* OR compar* OR partition* OR rank* OR order* OR relative OR interact* OR interplay* OR synerg* OR magnitude* OR rate* OR effect* OR impact* OR influe* OR pace* OR extent OR importan*)
3	Impacts of direct exploitation and invasive alien species on the red list index	TS = (“red list ind*”) AND TS = (((((natur* AND resource*) OR material* OR (biomass OR “fossil fuel*” OR ore* OR mineral*)) OR ((biological AND resource*) OR wildlife OR animal* OR plant* OR population*) OR water) AND ((overextraction OR overexploitation) OR (extraction OR exploitation OR withdraw*) OR depletion OR (hunting OR collect* OR gather* OR poaching OR “bush meat*”))) OR ((forest* OR wood OR timber*) AND (harvest* OR logging*)) OR (soil* AND (erosion OR acidification OR degradation)) OR (fisher* OR fishing OR (bycatch OR by-catch))) AND TS = (((invasive OR invasion) AND (alien OR exotic OR non-native OR pest* OR disease) AND species) OR “biological invasion*” OR (introduc* AND (species OR material)))

Description of the fields used in Web of Science searches: TS = topic.

Step 2. Selection of potentially suitable studies based on their titles, keywords and abstracts

Studies from each individual search carried out in step 1 (N=45,162) were exported to a tab-formatted document with all available attributes, such as AU (author(s)), TI (title), SO (source, i.e. publication name), DT (document type, e.g. article, book, book chapter, proceeding paper, review), AB (abstract, if available), PY (publication year), PD (publication date), DI (digital object identifier, DOI). The following attributes were then calculated automatically for each studies: LK (link to URL based on DI, i.e. "http://dx.doi.org/"&DI) and UI (unique identifier).

As explained above, fifteen different searches were used for each indicator of Table 1 to capture the impact of two drivers at a time and one additional search to capture the relative impacts of multiple drivers in a broader way. For each indicator, the lists of studies obtained from the sixteen searches were pulled together and the number of times each study appeared was counted. Studies appearing more often were assumed to be the ones that address the impact of different types of drivers on the indicator and, hence, the ones that are potentially the most relevant for the attribution analysis. Hence, this number was used to rank the studies by decreasing order of potential relevance for each indicator, so that studies that appeared more frequently were placed at the top when combining the results from the different lists. In case of ties, a second-order ranking based on decreasing publication year was used.

Once sorted by decreasing potential relevance, each study was assigned an ordinal number (RK), starting from 1 for the potentially most relevant ones. For each indicator, studies were sorted by increasing RK value and the first 200 of them (or less if the total number of studies extracted for a given indicator was lower) were retained for the next steps of the analysis (N=3,684). Despite the thorough methodology developed, the actual relevance of these studies for the specific purpose of this attribution analysis was not granted. Therefore, their title, keywords and abstract were examined to define whether they were actually suitable for the analyses.

Additional studies were included manually in the list for each indicator in order to complement the automatic search of studies published in the scientific literature (N=138):

- Important references cited in key sections of the IPBES regional and thematic assessments
- Other suitable scientific studies known to the authors but not captured by the search strings and the procedure implemented above
- Other important studies from the grey literature (not directly available through searches in Web of Science) such as reports (e.g. Living Planet Report, CBD reports) or source databases (e.g. Living Planet Index, Red List Index)
- Source references of each IPBES indicator when relevant (see last column in https://www.ipbes.net/core-indicators and https://www.ipbes.net/highlighted-indicators)
- Articles suggested by reviewers during the two open reviews of the IPBES Global Assessment

In order to ensure traceability during the whole procedure, studies included automatically (step 1) and manually in the analysis were labelled as such.

Studies were considered as suitable and selected for further analyses if they reported on:

- the current or past (i.e. NOT the predicted/projected/modelled future) impacts
- of at least two direct biophysical drivers (see Table 2)

– on changes in the state of nature [9]
– based on at least one of the indicators or one of the EBV classes (see Table 1)

Reviews and studies based on meta-analyses that synthesize the information from other original studies that at least partly satisfy the aforementioned rules were also considered as suitable at this stage.

Step 3. Prioritization of the most relevant studies based on their full-text analysis

Studies selected as suitable in step 2 (N=575) were retained for the full-text analysis. The entire text of these studies (mostly the objectives, methods used and results) was thoroughly examined to assess the following attributes:

- Suitability: yes (by default) / no (if based on the scan of the full text the study is finally considered as not suitable for the analysis, e.g. studies reporting on the impact of a single driver or predicting the future impacts of some drivers)
- Type of analysis: empirical data (i.e. studies using any sort of data, even if from an existing database), review (i.e. qualitative/descriptive synthesis of the existing literature), meta-analysis (i.e. quantitative synthesis of the literature or analysis of multiple datasets from other studies), other (any other option)
- Indicator(s) from Table 1 directly and explicitly targeted by the analysis: none, one of the IPBES/non-IPBES indicators (see column “Name of indicator” in Table 1), more than one of the IPBES/non-IPBES indicators, unclear
- Indicator(s) from Table 1 NOT directly or explicitly targeted by the analysis but for which the study is indirectly relevant (e.g. a study reporting on wilderness areas may provide useful information for the indicator “Extent of Remaining Primary Vegetation” even if it does not explicitly report on this specific indicator): none, one of the IPBES/non-IPBES indicators or EBV classes (see columns “Name of indicator” and “EBV class” in Table 1), more than one of the IPBES/non-IPBES indicators or EBV classes, unclear
- Assessment of temporal changes of the indicators: not applicable (i.e. studies not directly based on empirical data, such as reviews, syntheses…), none (i.e. studies not reporting on observed changes in the state of nature – e.g. focusing on the predicted/projected/modelled future changes), indirect (i.e. studies reporting on indicators that only include an implicit consideration of the temporal dimension[10]), direct and qualitative (i.e. studies reporting on indicators that provide an estimation of the *direction* of changes in the state of nature – e.g. decline, loss, increase, even if using/recycling data from other studies), direct and quantitative (i.e. studies reporting on indicators that provide an estimation of the *magnitude* of changes in the state of nature – e.g. 10% decrease, even if using/recycling data from other studies)

[9] Some studies use indicators with an explicit temporal analysis of their trends (e.g. the “Red List Index”) while other studies use indicators that only include an implicit consideration of the temporal dimension (e.g. the “IUCN Red List of Threatened Species” provides a list of species associated with different at-risk categories partly because of their observed increasing-decreasing population or distribution trends over time). The two types of studies are suitable and were selected for further analyses.

[10] For example, the indicator “IUCN Red List of Threatened Species” provides a list of species associated with different at-risk categories at some point in time at least partly because of their observed increasing-decreasing population or distribution trends until this moment. Even if this indicator does not report on temporal changes directly, its development relies at least partly on information about temporal changes in the state of nature.

- Spatial coverage: not applicable (e.g. for some reviews or experimental studies), local (typically smaller than a country), regional (typically between a single country and several countries), continental (covering all or a representative set of countries of a continent), global (worldwide)
- IPBES region(s) at least partly covered: Americas, Africa, Europe and Central Asia, Asia-Pacific, Americas/Africa, Americas/Europe and Central Asia, Americas/Asia-Pacific, Africa/Europe and Central Asia, Africa/Asia-Pacific, Europe and Central Asia/Asia-Pacific, Americas/Africa/Europe and Central Asia, Americas/Africa/Asia-Pacific, Africa/Europe and Central Asia/Asia-Pacific, all regions, unclear or not specified
- Realm(s) analysed: terrestrial, freshwater, marine, terrestrial/freshwater, terrestrial/marine, freshwater/marine, all realms, unclear or not specified
- Number of drivers analysed or assessed: between 0 and 6 (see Tables 2-3)
- Assessment of *climate change* impact: yes / no
- Assessment of *land/sea use change* impact: yes / no
- Assessment of *direct exploitation* impact: yes / no
- Assessment of *invasive alien species* impact: yes / no
- Assessment of *pollution* impact: yes / no
- Assessment of *other drivers* impact: yes / no
- Type of assessment of the impacts of direct driver on indicators: none, not applicable, *prevalence*-based (i.e. prevalence of different drivers identified as threats among a list of species or any component that form the basis of an indicator), *effect*-based (or dose-response i.e. relating temporal or spatial changes in driver to changes in indicator to assess the impacts of driver), *trait*-based (e.g. assuming decrease of pollution-intolerant/farmland-related species to be indicators of the negative impacts of pollution/agricultural activities)
- Level of assessment of the impacts of direct drivers on indicators (within-driver assessment): none, qualitative (e.g. direction of impact assessed), quantitative (magnitude of impact assessed in quantitative terms)
- Level of assessment of the relative impacts of direct drivers on indicators (among-driver assessment): none (i.e. relative impacts of different drivers not assessed), *nominal* scale (i.e. list of drivers impacting on indicators without qualitative or quantitative comparison), *ordinal* scale (qualitative comparison, i.e. ranking/ordering drivers by order of relative impacts on indicators), *ratio* scale (i.e. relative impact of each driver is quantified, e.g. partitioning approaches) (Hosonuma et al., 2012)
- Level of assessment of the interactive impacts of direct drivers on indicators (interactions between drivers): none, mentioned/discussed (without qualitative/quantitative assessment), qualitative (i.e. qualitative evidence for interaction between drivers), quantitative (i.e. interactions are estimated in quantitative terms)

Studies considered as not suitable during step 3 were removed. Based on some of the attributes defined above, each remaining study was then assigned to a level of priority (high, intermediate or low) using a number of criteria in the following order:

- Studies based on empirical data but NOT using or reporting on direct or indirect assessment of temporal changes of the indicator(s): **low** priority
- Studies analysing or reporting on the impacts of <2 drivers on the indicator(s): **low** priority

- Studies analysing or reporting on the impacts of ≥2 drivers on the indicator(s), but on a *nominal* scale only (i.e. not reporting on the relative impacts of these drivers, neither qualitatively nor quantitatively): **low** priority
- Studies analysing or reporting on the relative impacts of ≥ 2 drivers either qualitatively (*ordinal* scale) or quantitatively (*ratio* scale), but targeting indicator(s) from Table 1 ONLY indirectly and NOT explicitly: **intermediate** priority
- Studies targeting indicator(s) from Table 1 directly/explicitly and analysing or reporting on the relative impacts of ≥ 2 drivers either qualitatively (*ordinal* scale) or quantitatively (*ratio* scale), but at a local scale: **intermediate** priority
- Studies targeting indicator(s) from Table 1 directly/explicitly and analysing or reporting on the relative impacts of ≥ 2 drivers either qualitatively (*ordinal* scale) or quantitatively (*ratio* scale), but published before 2005[11]: **intermediate** priority
- Studies published after/in 2005, targeting indicator(s) from Table 1 directly/explicitly and analysing or reporting on the relative impacts of ≥ 2 drivers either qualitatively (*ordinal* scale) or quantitatively (*ratio* scale) at a regional to global scale: **high** priority

Step 4. Extraction of information on impacts of drivers from the most relevant studies

Studies assigned to a low level of priority were not further considered and the detailed full content analysis focussed on the studies classified as high or intermediate priority (N=189). The attributes extracted from the full content analysis of these studies are listed below.

Identification attributes:

- Unique identifier (UI): see step 2
- Level of analysis within each study: studies may report separately on the impacts of drivers on several indicators, in a number of regions or for different realms[12]. They may also report on the impacts of different drivers on the same indicator but for different taxonomical groups such as birds and mammals. In such a case, each combination is considered as a different “level of analysis” within the same study and each level is identified with an entire number ranging from 1 to the total number of levels included in the analysis. The same principle applies to regions, units of analysis, realms, climate domain, indicator, taxonomical groups and all the different possible combinations between these columns. If the study only includes a single level of analysis, indicate the entire number 1 in this column.

Spatial attributes:

- IPBES unit(s) of analysis: see section XXX (Chapter 2 – Nature) for the list and description of each Unit of analysis
- IPBES region(s): see step 3 for the list of regions

[11] Studies published before the Millennium Ecosystem Assessment (2005) were considered with an intermediate level of priority so as to focus on novel information since this large-scale assessment.
[12] Example: if a study reports on the impacts of different drivers on the Living Planet Index (LPI) for birds and mammals separately, indicate 1 to identify the 1st level of analysis (birds) and 2 to indicate the 2nd level of analysis (mammals). If the same study also reports on the impacts of different drivers on the Living Planet Index (LPI) for birds and mammals altogether, then also indicate 3 to identify a 3rd level of analysis (birds and mammals together). Please note that the information on the taxonomical groups can be provided in other columns.

– Realm(s): see step 3 for the list of realms
– Climate domain(s): polar, boreal, temperate, subtropical, tropical

Temporal attributes:

– Period covered by the study[13]

Indicators:

– Indicator name: see predefined list of IPBES/non-IPBES indicators in Table 1
– Indicator directly and explicitly targeted by the analysis: yes/no (see details in step 3)
– Original indicator name: name of the indicator according to the authors of the study
– EBV class: automatically populated based on the link between indicators and EBV classes in Table 1
– Target taxonomic group (1)[14]: predefined list of most frequently studied groups (i.e. amphibians, birds, fishes, invertebrates, mammals, plants, reptiles, vertebrates)
– Target taxonomic group (2): free-text attribute that may be used to provide more detailed information on the taxonomic coverage of the study
– Temporal change of the indicator during the reported period: qualifier of the reported trend in the indicator(s) (i.e. decrease, increase, stable, unknown/uncertain)
– Direction of distribution or range change: qualifier of the reported geographical shift in the indicator(s) (if applicable) (i.e. towards higher elevation, towards lower elevation, towards greater depth, towards shallower depth, towards higher latitude, towards lower latitude, not specified, uncertain)

Direct drivers:

– IPBES direct driver: see the list in Table 2
– Original direct driver: name of the driver according to the authors of the study
– Information available on within-driver impacts: yes/no (yes: the study reports separately on the impacts of several sub-drivers for the same driver, e.g. impacts of both forest degradation and deforestation – i.e. two components of land use change – on the "Extent of intact forest landscapes")
– Direct driver rank (if the **relative importance of different drivers** is compared – i.e. drivers are either ranked/ordered by importance of impacts or their relative importance is quantified, see next attribute): number from 1 to the number of direct drivers analysed to determine the relative importance of each driver on an *ordinal* scale (1 = most important). It may happen that a study analyses 3 drivers and conclude that 1 of them (A) is more important than the other 2 ones (B and C). In this case, A will receive rank 1 and B and C will both receive rank 2 because there is no information available to differentiate the relative importance of B and C. This rank assignment may involve some judgement by the person in charge of the assessment of the study based on its figures and tables.

[13] This attribute is only applicable to studies analysing empirical data, but NOT to *reviews / meta-analyses* that synthesize information from different studies covering different time periods or to studies that only include an *indirect* consideration of the temporal dimension in the analysis (see "Assessment of temporal changes of the indicators" in step 3).

[14] This attribute is not applicable to item focusing on indicator(s) that is/are not directly or explicitly linked to a particular taxonomic group (e.g. Net Primary Productivity).

- Direct driver magnitude (if the **magnitude of impacts of the drivers** is clearly quantified AND can be compared across the drivers assessed): percentage to determine the relative importance of each driver on a *ratio* scale. The analytical framework used to analyse this information is flexible and can accommodate magnitude estimates that do not necessarily sum up to 100% for the different drivers assessed[15]. This column is optional and was ONLY filled out if the information about the magnitude of impact of each driver is unequivocal and readily available from the study without necessitating personal interpretation or judgement (see next column).
- Relevance of direct driver magnitude assessment for the attribution analysis: yes/no. Some studies provide detailed estimates of the relative **magnitude of impact of different threats** but this information may prove to be **irrelevant for the purpose of this analysis**. For instance, the numbers of species affected by different threats is often reported in the studies and this information may be used here as a prevalence-based estimate of the relative magnitude of impact of the different IPBES direct drivers but ONLY if the threat classification used in the study matches with the IPBES categories of direct drivers[16]. When facing a similar situation, one of these two options was selected: report on the ranks of the different drivers only (even if this assessment is potentially subject to the same limitations, it is often less uncertain to estimate the relative rank of different drivers than their absolute magnitude of impact) or use rules such as the ones described in the example to report on the magnitude of impact of the different drivers, but select "No". If the estimated magnitude of impact of the different drivers is not subject to such limitations, select "Yes".
- Interactions with other direct driver(s) (does the reported driver interact with one or several other driver(s)?): name of the interacting driver(s)
- Type of interaction: qualifier of the interaction between driver(s) (i.e. synergistic, antagonistic, other)

Step 5. Analysis and synthesis of the results extracted from the most relevant studies

A procedure was implemented to check for redundancy across studies, in particular between those included automatically (i.e. from step 1) and manually (i.e. from step 2) in the analysis. If several studies reported on results obtained from the same dataset or if a study was based on the results of another one, the information on the relative importance of different drivers was not duplicated, but only the study associated with the highest level of priority (as defined in step 3) and/or the most

[15] For instance, the numbers of species affected by each driver is often reported in the studies analysing the impacts of different drivers. This information can be used here as a prevalence-based estimate of the relative magnitude of impact of each driver and will be rescaled between 0 and 1 in the analyses.

[16] As an example, invasive species and diseases are often treated separately in the studies but considered together in the IPBES framework. In this case, the number of species affected by the IPBES direct driver "Invasive alien species" (i.e. including invasive species or diseases) could not be inferred in a valid way from the number of species affected by invasive species (example: 100 species) and the number of species affected by diseases (example: 40 species). As an unknown fraction of the species are affected by both threats at the same time, the total number of species affected by the IPBES direct driver "Invasive alien species" is not equal to 140, but ranges between 100 (if all the species affected by invasive species are also affected by diseases) and 140 (if there is no species affected by both threats at the same time). In such a case, we could estimate that around 120 species are affected by the IPBES direct driver "Invasive alien species" (i.e. invasive species or diseases) but this is largely uncertain and it can become tricky to compare this estimated magnitude with the one estimated for another direct driver.

recent publication date was included in the next step of the analysis. After this procedure, a total of 154 studies were retained to estimate the relative impact of direct drivers on the state of nature.

Each study was then associated with a level of importance that was used as a weighting factor in the analysis. Two different weights were calculated for each study based on their spatial coverage and on the number of direct drivers they analysed[17] as follows:

- Spatial coverage: local (weight: 4), regional (weight: 8), continental (weight: 16), global (weight: 32)
- Number of drivers analysed: 2 (weight: 4), 3 (weight: 9), 4 (weight: 16), 5 (weight: 25)

Second, the average value between these two weights was retained as a weighting factor in the next analyses (see 'weighted mean' procedure below).

When some direct drivers were not analysed in a study, they were assumed to be less important than the ones that were analysed. In such case, they were included along with the drivers that were analysed and their rank and/or magnitude of impact was determined as follows:

- Direct driver rank: highest rank (i.e. reflecting lowest importance) among the drivers that were analysed in the study + 1
- Direct driver magnitude (only if the magnitude of impacts of the other drivers is quantified): 0%

For each study, the ranks of the different direct drivers were then reversed so that the highest rank (largest value) was assigned to the most important driver(s) and the lowest rank (smallest value) was assigned to the least important driver(s). These values were then converted into percentages using the approach presented in Table 4 of Hosonuma et al. (2012). For each study, these percentages were used to reflect the relative impact of the drivers when the magnitude of impact was not available or considered as not relevant for the attribution analysis (see details in step 4).

As studies may include several "levels of analysis" (see step 4), the relative impact of the different direct drivers on indicators and/or EBV classes was first averaged within each individual study. Depending on the spatial coverage and the realm(s) analysed in the studies, this aggregation was done for different combinations of spatial scale (global and/or regional) and realms (terrestrial, freshwater and/or marine)[18]. Then, the relative impact of direct drivers was aggregated (weighted mean) across studies for each individual indicator separately. Next, the relative impact of direct drivers was averaged across indicators belonging to each EBV class separately (see Table 1). Finally, the relative impacts of direct drivers were rescaled so that they sum up to 100% for the six categories of drivers at any spatial scale and/or for any realm.

The aggregated and rescaled relative impact of a driver ranges between 0% and 100%, with 0 indicating that the driver has no impact and 1 indicating that the driver is dominant and all the other drivers have no impact. In practice, these extreme values are seldom reached because the focus was on indicators that are potentially impacted by the whole set of drivers used in this assessment. These estimated values should not be interpreted as an absolute magnitude of impact of each driver because both qualitative (ordinal scale: rank) and quantitative (ratio scale: magnitude) information was combined in the analysis. The width of the colour bars in the figures should instead be

[17] Only the five categories of IPBES direct drivers were considered in the calculation.
[18] Some studies report on one indicator for a single realm at global scale, but some other studies may report on several indicators from different EBV classes in different regions and for different realms based on a number of taxonomical groups separately. Hence, it was needed the first aggregate the information about the relative impact of each driver on each indicator within each study before pulling together the information from the different studies.

interpreted as a measure reflecting the relative importance of each driver, i.e. the wider the bar the more important the driver.

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Appendix BB. Section 2.2.6. Global-scale analysis of attribution of trends to drivers

Full list of references used for building Figure GATD

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Appendix CC. Methods for sections 2.2.5.3.2 and 2.2.6.3 (IPLC observed trends and drivers)

The analysis is based on a literature search conducted on 08 December 2017 using standard web-based search engine (Web of Science database), using the query formula ‘TOPIC: (((traditional ecological knowledge) OR (indigenous knowledge) OR (indigenous ecological knowledge) OR (local knowledge) OR (local ecological knowledge) OR (traditional knowledge)) AND ((indigenous (people* OR communit*)) OR (local communit*) OR (aboriginal) OR (native indian) OR (native people*) OR (first nation*) OR pastoralist* OR farmer* OR ((small scale OR small-scale) (societ* OR communit*)) AND (nature OR (natural (resource* OR environment)) OR habitat* OR ((traditional OR indigenous OR environmental OR adaptive OR resource OR ecosystem) management) OR ((small scale OR small-scale) (management OR practice*)) OR (extensive (management OR (land use) OR (land-use))) OR ((traditional OR indigenous) agriculture OR farm* OR (land use) OR (land-use)) OR ((indigenous OR aboriginal) burning) OR (management system) OR hunt* OR gather* OR fisher* OR nontimber OR (non-timber) OR (nature conserv*) OR overgraz* OR overharvest*)) AND (indicator OR reciprocit* OR monitor* OR trend* OR decreas* OR increas* OR change* OR driver* OR degrad* OR deplet* OR (invasive species) OR (new species)))’, with no limit for time-span or language.

The search yielded 8593 titles, refined to excluding the following categories: Business Or Computer Science Artificial Intelligence Or Chemistry Medicinal Or Energy Fuels Or Computer Science Interdisciplinary Applications Or Communication Or Nursing Or Immunology Or Public Administration Or Engineering Multidisciplinary Or Obstetrics Gynecology Or Information Science Library Science Or Mathematics Applied Or Hospitality Leisure Sport Tourism Or Mathematics Interdisciplinary Applications Or Green Sustainable Science Technology Or International Relations Or Psychiatry Or Substance Abuse Or Microbiology Or Clinical Neurology Or Nutrition Dietetics Or Computer Science Theory Methods Or Health Care Sciences Services Or Engineering Electrical Electronic Or Operations Research Management Science Or Health Policy Services Or Economics Or Psychology Clinical Or Medicine General Internal Or Pediatrics Or Business Finance Or Gerontology Or Engineering Civil Or Integrative Complementary Medicine Or Oncology Or Engineering Environmental Or Architecture Or Infectious Diseases Or Medical Informatics Or Computer Science Information Systems. resulting in the end in a list of 6316 hits, all exported.

Out of these, 192 remained after screening title, abstract, and keywords. Regarding the remained 192 articles, full text PDFs were downloaded for throughout analysis.

Papers were considered not relevant at this stage if focusing only on science-based, locally not relevant indicators or considering community-based monitoring programs without using locally developed indictors.

We additionally searched for grey literature using Google and Google Scholar, and included further papers selected based on external review comments and from our own literature databases.

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The following references were used to draw trends for 470 IPLC indicators showed in Figure 2.25.

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Appendix DD. Section 2.2.6 Global-scale analysis of attribution of trends to drivers

Relative impact of direct drivers for specific indicators

Specific indicators for which enough data was available for discussion at the individual level are presented below (see also Figure S1) to illustrate patterns within each EBV class. As there was no indicator with sufficient data for *Genetic composition*, this EBV class is not included below.

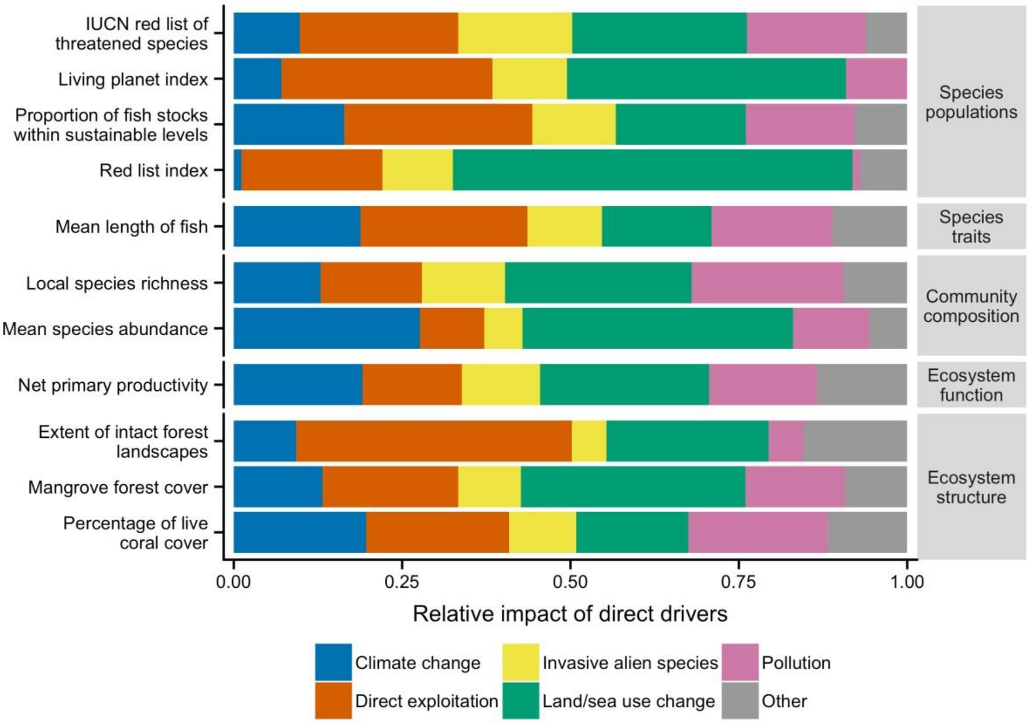

Figure S1. Relative impact of direct anthropogenic biophysical drivers (colour bars) on selected indicators of the state of nature for which sufficient and representative information was available. Indicators are grouped according to the Essential Biodiversity Variables (EBV) framework. No indicator was available for the EBV class *Genetic composition*. The driver category "Other" includes threats that do not clearly belong to any of the five main categories of drivers (e.g. fire, human disturbance, recreational activities, and tourism). The width of each colour bar indicates the estimated relative importance of each driver in determining changes in the state of nature (see details in the main text and in Figure 2.2.23).

<u>Species populations</u>

IUCN Red List of Threatened Species. The most prevalent drivers for threatened or near-threatened species from comprehensively assessed species groups on the IUCN Red List are land/sea use change (26%) (e.g. agricultural expansion and intensification, urban development and system modifications) and direct exploitation (23.5%). Less important drivers are pollution (17.5%), invasive alien species (17%) and climate change (10%). Other threats (e.g. human intrusions and disturbances, recreational activities, war, Salafsky et al., 2008) account for 6% of the relative impact. Invasive alien species is unusually important in amphibians, largely because of the widely-introduced fungus *Batrachochytrium dendrobatidis*, which causes chytridiomycosis in amphibians around the world (Bower, Lips, Schwarzkopf, Georges, & Clulow, 2017; Hof, Araújo, Jetz, & Rahbek, 2011; Stegen et al., 2017). Chytridiomycosis is implicated in the steep decline or extinction of more than 200 species of amphibians (Wake & Vredenburg, 2008) and threatens many more (Rödder et al., 2009). A comprehensive analysis of marine taxa (including mammals, birds, reptiles, fishes, invertebrates and plants) placed direct exploitation as the main threat, followed by land/sea use change (mainly residential and commercial development, transportation and service corridors and aquaculture), pollution and IAS (Joppa et al., 2016). More specifically, for marine mammals pollution is the main driver (e.g. oil spills, chemical wastes, plastic debris), followed by direct exploitation (mainly comprised of bycatch and hunting), invasive alien species, land/sea use change, and climate change (Davidson et al., 2012). For terrestrial and freshwater species the main threats are land/sea use change (mainly agriculture, residential and commercial development, natural systems modification, and energy and mining), followed by direct exploitation, pollution and invasive alien species (Joppa et al., 2016). Furthermore, in a multi-taxon analysis of drivers of extinction risk in freshwater taxa (including some well-studied invertebrate groups), land/sea use change (habitat loss and degradation) is the main threat, followed by pollution and direct exploitation (Collen et al., 2014).

Red List Index (RLI). This indicator assesses the impact of individual drivers on genuine changes in the conservation status of the species (Butchart et al., 2007; Rodrigues et al., 2014). The relative importance of drivers to explain recent trends in RLI (see Table 3.3 in Chapter 3) is as follows: land/sea use change (60%), direct exploitation (21%), invasive alien species (10%), climate change (1%) and pollution (1%). Other threats account for 7%. Furthermore, McGeoch et al. (2010) showed that the most important drivers were land/sea use change (agriculture/aquaculture) for birds, direct exploitation (hunting/trapping) and land/sea use change (agriculture/aquaculture) for mammals, and invasive alien species for amphibians. For bird and mammal species that are plant pollinators, the patterns are similar (Regan et al., 2015).

Living Planet Index (LPI). Threat data for the LPI is collected when available from the individual data sources; this is for around a third of population time-series, half of which are declining (McRae, Deinet, & Freeman, 2017). The relative impacts of threats for declining vertebrate populations globally are land/sea use change (41.5%), direct exploitation (31.5%), invasive alien species (11%), pollution (9%) and climate change (7%). At the regional level, the main driver in Americas, Asia and the Pacific and Europe and Central Asia is land/sea use change, with relative impacts of 41%, 33%, 49%, respectively, followed by direct exploitation (32%, 30%, 25%, respectively). The main driver in Africa is direct exploitation (39%) followed by land/sea use change (33%). The third most important driver varies across regions, being climate change for Africa and Americas (11% and 10%, respectively), IAS for Asia and the Pacific (20%), and pollution for ECA (12%) (Figure S2). The main driver for declining terrestrial and freshwater vertebrate populations are land/sea use change (43% and 46%, respectively), followed by direct exploitation (31% and 27%, respectively) and invasive alien species (12% and 13%, respectively); for declining marine vertebrate populations direct exploitation is the most important driver (49%) followed by land/sea use change (25%) and climate change (11%) (Figure S2) (ZSL/WWF, 2018).

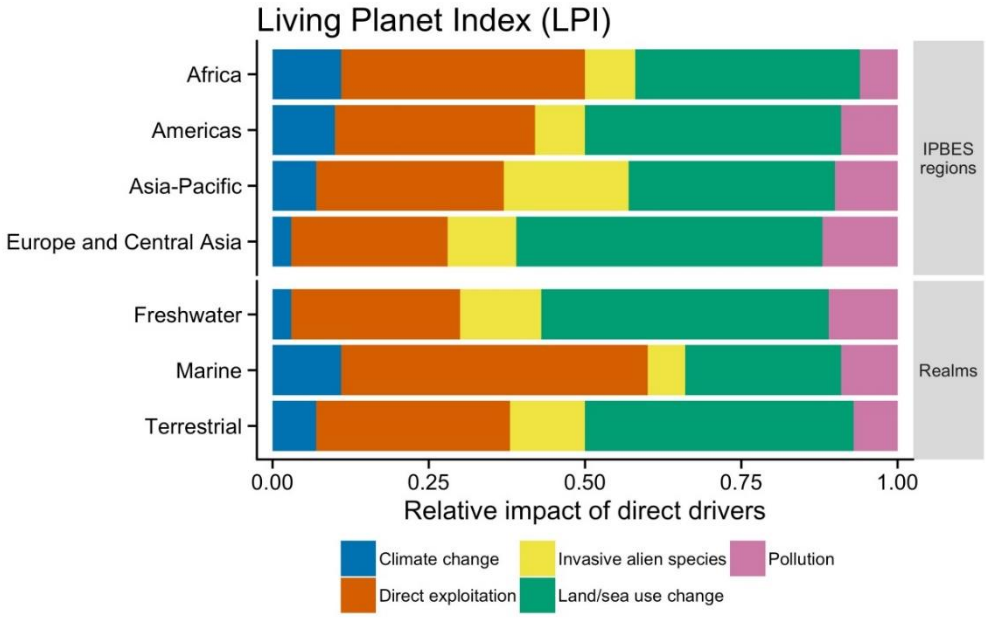

Figure S2. Relative importance of direct drivers for 3,714 populations of 1,653 vertebrate species in each IPBES region (top four rows) (Africa: 720 populations, 316 species; Americas: 1,355 populations, 736 species; Asia-Pacific: 907 populations, 470 species; Europe-Central Asia: 730 populations, 284 species) and for each global biogeographical realm (bottom three rows) (Terrestrial: 1,460 populations, 643 species; Freshwater: 910 populations, 468 species; Marine: 1,344 populations, 609 species). Data are from the Living Planet Index database (ZSL/WWF, 2018). Each population can be associated with up to three impacting drivers based on information in the publication where the data were sourced; data are coded as 'threatened' or 'not threatened' according to the data source or 'unknown' if no information is available; data shown here reflect the 'threatened' populations and represent the frequency of driver categories mentioned in the source publications. Species were not selected to be representative of the habitat but reflect the data available. Data outside IPBES regions were not included.

Proportion of fish stocks within biologically sustainable levels. The main driver is direct exploitation (28%), followed by land/sea use change (19%), climate change (16.5%) and pollution (16%). Invasive alien species (12.5%) and other threats (8%) are less important. Globally, more than two-thirds of all wild capture marine fish stocks are currently being exploited at or beyond the maximum sustainable yield, and many coastal systems including mangrove forests and coral reefs have been depleted mainly due to land-based and marine pollution (Perrings, 2016).

<u>**Species traits**</u>

Mean length of fish. The main driver behind this indicator is direct exploitation (25%). Climate change is unusually important compared to most of indicators (19%), with an impact that is similar to that of pollution (18%) and land/sea use change (16%). Invasive alien species and other threats have the lowest impact (11% in both cases). Selective overfishing since the early 1970s has led to a 60% reduction in body size of top predators, which in combination with ocean stratification due to climate change has increased prey fish populations and modified trophic structure in the North Atlantic sea (Shackell, Frank, Fisher, Petrie, & Leggett, 2010).

<u>**Community composition**</u>

Local species richness. Land/sea use change (28%) is the main driver, followed by pollution (22.5%) and direct exploitation (15%). Climate change (13%) and invasive alien species (12%) have similar impacts; whereas other threats account for 9.5% of impact.

Mean Species Abundance (MSA). The main driver of MSA decline at the global level is land/sea use change (40%). Climate change is second with 27.5%, followed by pollution (11%) and direct exploitation (9.5%). Invasive alien species and other threats have a similar impact (6%). On a more detail level, land-use impacts from crop production, grazing and forestry together amount to almost 60% of the total worldwide loss of terrestrial MSA in the period 1970-2010. Climate change is an increasingly contributing driver, whereas impacts attributed to direct use of natural systems (including hunting, gathering, recreation and tourism) show a considerable, but slightly decreasing proportion for the same period (Kok et al., 2018).

Ecosystem function

Net Primary Productivity (NPP). The main driver behind variation in net primary productivity is land use change (25%), followed by climate change (19%), pollution (16%), direct exploitation (15%) and invasive alien species (11.5%). Other drivers (e.g. fire) account for 13.5% of impact. It has been estimated that NPP has increased by 10% in the period 1950-2010 in the USA forests, due to net carbon gain from regrowing forests subjected to disturbances such as harvesting, fire and insect infestation. Moreover, climate change-related factors (e.g. CO_2 concentration and N deposition) have also contributed to this pattern (Zhang et al., 2012).

Ecosystem structure

Area of mangrove forest. Land use change is the main driver with 33% of relative impact, followed by direct exploitation (20%), pollution (15%), and climate change (13%). Invasive alien species and other threats are less important (9.5%). Patterns of cover change vary between regions. In South Asia, land use change (mainly due to conversion to agriculture, shrimp farms and human settlements), overharvesting and pollution drove a net loss of 12,000 hectares of mangrove forest in the period 2000-2012 (Giri et al., 2015). In contrast, land/sea use change (associated with replacing of salt marsh vegetation, reduction in freshwater supply and sediment accumulation due to river damming) together with climate change (causing sea level rising and inland salinization), are the main drivers of increased mangrove cover in the period 1958-2004 in Northeast Brazil (Lacerda, Menezes, & Mussi Molisani, 2007).

Extent of intact forest landscape. Although the global net loss of forest extent has been decreasing in the last decades, the area reduction of intact forest ecosystems has significantly increased at the same time. Direct exploitation (mainly due to timber harvesting and forest logging) is the most important threat at the global level (41%), followed by land/sea use change (24%) (e.g. agricultural expansion, energy and mining, fragmentation by infrastructure and growth of the road network). Other threats (15.5%) (e.g. uncontrolled fires) have more impact than climate change (9.5%). Pollution and invasive alien species are the least important drivers with a relative impact of 5% each. There is important variation at the regional level; for example, mining and energy production (oil and gas extraction, and hydropower) is the leading threat in Australia (64%), agricultural expansion is of primary importance in tropical South America (65%), and wildfire is the main threat in northern boreal regions (91% in North America and 56% in northern Eurasia) (Potapov et al., 2017).

Percentage of live coral cover. Direct exploitation and pollution are the most important drivers with a relative impact of 21%, followed closely by climate change with 19.5%. Land/sea use change has a relative impact of 17%. Other threats (12%) and invasive alien species (10%) are less important drivers.

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