**Supplementary information**

**Nature’s contribution to people in Drylands**

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**Supplementary Text S1. Description of the 18 NCPs, and databases and weights used**

**Indicator setting**

Most of the biophysical value of NCPs cannot be accurately spatially observed at the global scale. We construct 18 methods for assessing NCPs in this study for only rapid assessment. To give prominence to the contribution of the ecosystem itself as indicated by land cover changes between 1992 and 2018, the climatic fluctuation as well as the increasing demand from society have been static in the evaluation. Note that we did not change people’s needs between 1992 and 2018 for two reasons. First, if people’s current needs are greater than past needs, then nature’s contribution will be more valuable. People needs more from nature, so the strength of NCP will be greater, e.g., more pollution leads to a greater importance of vegetation surrounding urban areas and farmland. Conversely, if there is no pollution, air and water purification from nature is not needed. Second, there is a paucity of spatial data on people’s needs in the 1990s.

Based on the two indicator dimensions, namely, nature’s potential contribution from the prospective of nature’s potential provision and actual contribution to people from the perspective of actual human requirements, the indicator settings in these NCP estimations before the mean value calculated at the subbasin scale is listed as follows.

*Indicator in NCP1 (habitat creation and maintenance)*

We set the values of urban areas and croplands as 0 and natural systems as 1. The species richness of amphibians, birds and mammals is a commonly used indicator (Howard et al. 2020) of global biodiversity richness (Butchard et al. 2010). We used the following biodiversity maps: “Richness 10km AMPHIBIANS dec2017 EckertIV”, “Richness 10km Birds v7 EckertIV breeding no seabirds” and “Richness 10km MAMMALS mar2018 EckertIV”. These maps were summed after min-max normalization as a weight of importance for habitat creation and maintenance. This ecosystem classification value was multiplied by the biodiversity weight to form an assessment of NCP1.

*Indicator in NCP2 (pollination and dispersal of seeds and other propagules)*

Pollinators are under increasing threat from human activities and climate change (IPBES 2016). However, spatial pollinator datasets are generally unavailable, except for isolated areas (Dicks et al. 2021, Potts et al. 2016). A potential proxy of the contribution of pollinators to cropland is the extent of natural vegetation (mixed ecosystems, forest, shrubland, grassland) within a 3 km buffer of cropland (Schulp et al. 2014, O’Connor et al. 2021). Mixed cropland-natural systems can also support pollinators (Lasway et al. 2022), so along with natural ecosystems within 3 km of cropland were assigned a value of 1, and other systems a value of 0. We considered the production of cross-pollinated crops as a benefit to humans. We used the most up-to-date global synergy cropland layer in the SPAM dataset, and summed the yield layer of 21 cross-pollinated crops (Yu et al. 2020), which included maize, pearl millet, sorghum, sweet potato, yams, cassava, coconut, oil palm, sunflower, rapeseed, sugarcane, sugar beet, cotton, other fibre crops, Arabica and Robusta coffee, cocoa, tea, tobacco, temperate fruit, and tropical fruit. The ecosystem classification value was multiplied by yield weight to form the basic NCP2 assessment*.*

*Indicator in NCP3 (regulation of air quality)*

The value of urban ecosystem services is highly uncertain and is seldomly mapped (Keeler et al. 2019), particularly in drylands (Akhtar et al. 2022). Plant leaf area index (LAI) been been used as a proxy of the potential for removal of pollutants (Wang et al. 2014), so we used LAI of natural and mixed ecosystems as an indicator of potential regulation of air quality by nature. We averaged the continuous 5-year GIMMS LAI3g between 1988 and 1992 (“LAI 1992”), the GIMMS LAI3g between 2011 and 2015, because 2015 was the final year of this LAI product (“LAI 2018”). Values for urban ecosystems and croplands were assigned a value of 0 and others a value of 1, and then multiplied by the mean LAI values. For the actual contribution, we used the proportion of urban land as both the pollution pressure of human activity and human quality of life requirement. Thus, the value of air quality regulation would be higher for a larger area of developed land with a greater LAI. The proportion of built up land at the subbasin scale was multiplied by the mean values of LAI in natural and mixed ecosystems at the subbasin scale to form the basic assessment of NCP3.

*Indicator in NCP4 (regulation of climate)*

Gross primary productivity (GPP) is the largest carbon flux component within terrestrial ecosystems and plays an essential role in regulating the global carbon cycle (Zhao and Running 2010, Zheng et al. 2020). The GPP of annual plants is not a good indicator of carbon sequestration, so we used the GPP of woody plants (perennials) as a measure potential climate regulation, with potential climate regulation increasing with increasing woody plant production. As climate regulation provides a global benefit, we did not include a local requirement indicator in our calculations. However, a high-resolution greenhouse gas emission map could be used as the actual local requirement if the data exist. The values of forest and shrub ecosystems were set at 1, and others at 0. We averaged the continuous 5-year GPP for 1988-1992 (“GPP 1992”) and for 2013-2017 (“GPP 2018”) because 2017 was the final year of this GPP product. This ecosystem classification value was multiplied by the mean weighted GPP values to form the basic assessment of NCP4.

*Indicator in NCP5 (regulation of ocean acidification)*

Mangroves are forests that have high carbon stocks in the ocean carbon budget, and can potentially regulate ocean acidification (Worthington et al. 2020, Richards et al. 2020). We obtained global mangrove data (1996 to 2016) and summed the average subbasin level mangrove area in 1996 (“Mangrove 1996”) and the average subbasin level mangrove area in 2016 (“Mangrove 2016”). Similar to NCP4, we did not introduce a local indicator because ocean acidification regulation is a global benefit. However, a high-resolution coastal greenhouse gas emission map could be used as the actual local requirement if the data exist. Mangrove area at the subbasin scale was used to form the basic assessment of NCP5.

*Indicator in NCP6 (regulation of freshwater quantity, location and timing)*

Terrestrial evapotranspiration (ET) is a commonly used indicator of the water cycle. A greater ET indicates a greater potential contribution of the terrestrial ecosystem to the regulation of freshwater quantity, location and timing (Sterling et al. 2013). We averaged, continuous 5-year values of “synthesized ET” data for 1988-1992 (“ET 1992”) and 2014-2018 data (“ET 2018”). Urban and cropland areas were assigned a value of 0, and others a value of 1, and these were multiplied by the mean ET values. For actual contribution, a high ET in drylands should be avoided because it could reduce local streamflow and therefore freshwater supply for humans (Feng et al. 2016). We used the mean annual streamflow from FLO1K data (log10-transformed 1960–2015 data) to indicate the actual requirement for flow regulation by ecological processes, which include evapotranspiration. These values were multiplied to form the basic assessment of NCP6.

*Indicator in NCP7 (regulation of freshwater and coastal water quality)*

Riparian and coastal areas with natural vegetation provide effective nutrient retention and removal and therefore have the potential to sustain the quality of marine and fresh water (Mayer et al. 2007, Sweeney and Newbold 2014). We used a 3 km buffer around permanent water bodies in the 2000 to 2015 MOD44B database to mask the natural vegetated ecosystem classification. Values of mixed natural, forest, shrubland, grassland, wetland and water ecosystem classes were set as 1, and the others were set as 0. For actual contribution, we used the pesticide risk map (“global pesticide risk scores”) as a weight indicator. The greater the pressure from water pollution, such as from pesticides, the greater is the requirement for the regulation of freshwater therefore the greater the contribution to people (how much the people need). Consequently, the ecosystem value was multiplied by the pesticide risk to form the basic assessment of NCP7.

*Indicator in NCP8 (formation, protection and decontamination of soils and sediments)*

Prevention of soil erosion is a high priority in soil conservation (Wuepper et al. 2019). Conversion of natural systems to cropland can result in greater erosion (Sahu and Mohanty 2023). Although cropland has a degree of soil retention, it should not be regarded as of “nature’s contribution” because the function could be higher with natural vegetation. Thus, the values of the urban and cropland ecosystem classes were set at 0 and the others at 1. The Revised Universal Soil Loss Equation (RUSLE) was applied to the soil erosion estimation using existing data from Liu et al. (2018). The value of nature’s potential contribution was calculated as potential erosion without vegetation cover minus actual soil erosion (Fu et al. 2007). For actual contribution, our data were weighted by the value of topsoil organic carbon from the Harmonized World Soil Database. This because soil organic carbon is a good proxy of soil stability (Redmile-Gordon et al. 2020). Consequently, the soil retention value was multiplied by the soil organic carbon value to form the basic assessment of NCP8.

*Indicator in NCP9 (regulation of hazards and extreme events)*

For potential hazard regulation we selected three common hazards, including landslides, desertification, floods and storm tides, that are distributed in mountains, drylands, and humid and coastal areas. Slopes greater than 15o slope were deemed to require protection by native vegetation (Zhu et al. 2021). The values of mixed natural, forest and shrub ecosystem classes above the 15o slope were set at 1 and the others at 0. Using a dense tree cover to control land degradation in drylands is unfeasible due to low water storage in drylands (Ramon-Vallejo et al. 2002). Therefore, using values of the aridity index lower than 0.2 from the “Global-Aridity\_ET0” database, the values of mixed natural, grassland and shrubland ecosystem classes were set at 1, and the others set at 0.

Inland and coastal wetlands have the capacity to store and regulate floods and storm tides (Reis et al. 2017). Consequently, within the floodplain extent of the GFPLAIN 250 m resolution dataset, we fixed the mixed natural, forest, shrubland, wetland and water ecosystem classes at 1 and the others at 0. For the actual contribution, major food crops require hazard prevention. Accordingly, we used the aggregated value of the production of all crops as a weight (“spam2010V1r1 global V agg VP CROP A”). The unified set of the ecosystem class values was totalled as the proportion at the subbasin scale and multiplied by the aggregated value of production at the subbasin scale to form the basic assessment of NCP9.

*Indicator in NCP10 (regulation of detrimental organisms and biological processes)*

We are unaware of any global databases of detrimental organisms and biological processes. However, bird biodiversity could be potential effective proxy of detrimental organisms, as birds are upper-level predators in food webs (Letourneau et al. 2009). Moreover, major food crops provide an actual requirement for reducing detrimental organisms such as pests. Accordingly, we used the aggregated value of production mapped in NCP9 as the weight. The value of bird diversity in natural and mixed ecosystems was an existing assessment in the NCP1 calculation so multiplied the values of these two assessments to form the basic assessment of NCP10.

*Indicator in NCP11 (energy)*

In theory, all vegetation could be considered as planted bioenergy crops. However, here we considered the mixed cropland, mixed natural, shrubland, and grassland ecosystem classes to have a greater capacity for bioenergy exploitation than cropland and forest ecosystems. The values of these four ecosystem classes were set as 1, and the others were set as 0 in the calculation. Spatially explicit landscape-scale bioenergy data are rare (Dale et al. 2016). Typical bioenergy crops with a high carbon capture and storage are crop plants with high lignocellulose contents (Hanssen et al. 2020). We used the “best crop” data from the dataset yields of lignocellulosic bioenergy crops (Li et al. 2020) and multiplied the values of these two assessments to form the basic assessment of NCP11.

*Indicator in NCP12 (food and feed)*

For potential contribution, the values of the cropland and mixed cropland ecosystem classes were assigned as 1, and the others 0. For actual perspective, crop production data is available but not as raster data (Su et al. 2021). We summed the yields of 22 food crops from the latest global synergy cropland layer in the SPAM dataset (Yu et al. 2020). Livestock were not considered because they have the potential to be fed by crops.The data names were prefixed as “spam2010V1r1 global Y”. We multiplied the values of these two assessments to form the basic assessment of NCP12.

*Indicator in NCP13 (materials, companionship and labour)*

All ecosystems have the potential to provide materials, but the amount and requirement for companionship and labour are different. Forestry is a key indicator that supports both national development and local livelihoods (Elbakidze et al. 2013, Lund et al. 2018). In the potential perspective, we used the forest ecosystem as a sketch map for the absence of a global forestry raster map. The value of the forest ecosystem class was set at 1, and the others at 0. The shrubland ecosystem class was set as 0 as it is distributed mainly in dryland and unsuitable for extensive forestry. For actual contribution, the biomass of aboveground carbon was upscaled using the nearest neighbour method as a weight to indicate the yield of forestry. We multiplied the values of these two assessments to form the basic assessment of NCP13.

*Indicator in NCP14 (medicinal, biochemical and genetic resources)*

Natural products are importance sources of drugs (Newman and Cragg 2012). For potential contribution, all natural and mixed ecosystems were considered to have biochemical and genetic resources. Because there was no spatially explicit dataset for medicinal products from nature, we use Shannon's diversity index as a substitute, but excluded the urban and cropland ecosystem classes. For actual contribution, the rural population has a direct requirement for local natural medicinal resources. Rural location was extracted from the dataset “GHS SMOD POP2015 GLOBE R2016A 54009”, and multiplied by a population density dataset (“GHS POP E2015 GLOBE R2019A 54009”) to form the weight, and averaged at the subbasin scale. We multiplied the values of these two assessments at the subbasin scale to form the basic assessment of NCP14.

*Indicator in NCP15 (learning and inspiration)*

People are now less likely to have direct contact with natural environments and wildlife in their everyday lives (Soga and Gaston 2016). Assessments of the loss of local and indigenous knowledge from nature are mostly restricted to case studies with no spatially explicit databases (Eswani et al. 2018). For the potential perspective, we considered that learning and inspiration could depend on being exposed to a variety of different natural ecosystems. Therefore, we used Shannon's diversity index, a landscape diversity indicator, for all ecosystem classes. In the actual perspective, data on night-time light (1992 to 2018) were set as an indicator for the development of local society. Accordingly, more diverse ecosystems would be associated with greater societal development and a greater requirement for social learning and inspiration from the local landscape. The values of the diversity index and mean night-time light at the subbasin scale were multiplied to form the basic assessment of NCP15.

*Indicator in NCP16 (physical and psychological experiences)*

All ecosystems can provide physical and psychological experiences for humans, and here we focus on two essential indicators for uniqueness in the potential contribution and accessibility in the actual contribution. We used World Heritage ecosystems as our uniqueness value because of their high status in NCP governance due to their scarcity (Morrison et al. 2020). Accessibility indicated that the experience of nature could be realized by a visit (Balmford et al. 2014). The kernel density algorithm in ArcGIS was used, with default search radii, to interpolate the vector points of World Heritage sites and the vector lines of roads to raster maps, and the resolution was consistent with the ecosystem classification. The experience of the natural ecosystem was set at 1 and the urban and cropland ecosystem classes at 0 in our calculations. This ecosystem classification value was multiplied by the densities of World Heritage sites and roads as weights to form the basic assessment of NCP16.

*Indicator in NCP17 (supporting identities)*

Supporting identities provides a sense of place, are place-based, and often have spiritual significance for indigenous cultures (Pascua et al. 2017, Daniel et al. 2012). For potential contribution, all local landscapes have the capacity to support identities, including long-standing urban landscapes. Thus, landscape change could be considered a loss of capacity for supporting original identities. Based on our ecosystem classification, we used the European Space Agency Climate Change Initiative-land cover (ESA CCI-LC) change (1992 to 2005) dataset to enumerate the changing proportion at the subbasin scale (“1992”). We then used the land cover change in 2005-2018 period to enumerate the changing proportion at the subbasin scale (“2018”). Landscape change was set as 1, and areas of no change at 0. In the actual perspective, the gridded population on the changed landscape indicated the actual amount of local people with changing identity. The larger the number of people suffering from landscape change, the lower the value of supporting identities. Landscape change was multiplied by the number of populations to form the basic assessment of NCP17, and then a reverse normalization was processed.

*Indicator in NCP18 (maintenance of options)*

Previous studies have clarified the spatial distribution of vulnerable species, how humanity changes the planet, and how this drives extinctions (Pimm et al. 2014). Many land use projections indicate the future amount and pattern of landscapes (Stehfest et al. 2019). However, the maintenance of options includes so many aspects of nature that it cannot be simplified by biodiversity or landscape composition. According to the notion of a maintenance of options that do not belong to a single NCP category, all of the 17 NCPs need to be maintained into the future. There is no simple algorithm that could simultaneously anticipate the risk of loss of all 17 NCPs, we posit that diversity is positively related to the stability and diversity of the 17 contributions (Ives and Carpenter 2007). Consequently, the greater the diversity of NCPs, the greater the potential and actual ability of the overall contributions of nature to be maintained in the future. This was calculated as the Shannon's diversity index of 17 NCPs after normalisation, to form the basic assessment of NCP18.

**Table S1.** Pearson’s correlation coefficients (*r*) between population size and the value of each of the 18 contributions for drylands and non-drylands. ns = not significant.

|  |  |  |  |
| --- | --- | --- | --- |
| **NCP code** | **Description** | **Dryland** | **Non-dryland** |
| NCP1 | Habitat | -0.06 | -0.03 |
| NCP2 | Crop pollination | 0.07 | 0.12 |
| NCP3 | Air quality | 0.20 | 0.27 |
| NCP4 | Climate | -0.04 | -0.08 |
| NCP5 | Oceans | 0.14 | 0.06 |
| NCP6 | Water quantity/flow | 0.05 | 0.03 |
| NCP7 | Water quality | 0.07 | 0.13 |
| NCP8 | Soil protection | ns | 0.05 |
| NCP9 | Hazard regulation | 0.11 | 0.20 |
| NCP10 | Pest regulation | 0.13 | 0.22 |
| NCP11 | Bioenergy | -0.04 | ns |
| NCP12 | Food | 0.19 | 0.23 |
| NCP13 | Woody material | ns | -0.05 |
| NCP14 | Medicine | 0.41 | 0.46 |
| NCP15 | Learning inspiration | 0.33 | 0.32 |
| NCP16 | Experience | 0.09 | 0.19 |
| NCP17 | Identity | -0.57 | -0.61 |
| NCP18 | Options | 0.13 | 0.16 |

**Table S2.** Breakdown of magnitude of the contribution by NCP for drylands and non-drylands for the six continents

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| NCP code | North America | | | Europe | | South America | | Africa | | Asia | | Oceania | |
| Dryland | Non-dryland | Dryland | | Non-dryland | Dryland | Non-dryland | Dryland | Non-dryland | Dryland | Non-dryland | Dryland | Non-dryland | |
| NCP01 | 0.43 | 0.33 | 0.18 | | 0.29 | 0.52 | 0.87 | 0.42 | 0.83 | 0.24 | 0.41 | 0.39 | 0.48 | |
| NCP02 | 0.10 | 0.08 | 0.35 | | 0.38 | 0.28 | 0.34 | 0.11 | 0.29 | 0.11 | 0.21 | 0.08 | 0.12 | |
| NCP03 | 0.03 | 0.09 | 0.10 | | 0.28 | 0.02 | 0.05 | 0.01 | 0.04 | 0.01 | 0.08 | 0.01 | 0.09 | |
| NCP04 | 0.14 | 0.28 | 0.05 | | 0.14 | 0.13 | 0.56 | 0.10 | 0.57 | 0.01 | 0.24 | 0.14 | 0.70 | |
| NCP05 | 0.01 | 0.01 | 0.00 | | 0.00 | 0.00 | 0.02 | 0.01 | 0.02 | 0.00 | 0.02 | 0.01 | 0.11 | |
| NCP06 | 0.17 | 0.47 | 0.22 | | 0.44 | 0.27 | 0.85 | 0.15 | 0.77 | 0.12 | 0.54 | 0.10 | 0.60 | |
| NCP07 | 0.19 | 0.27 | 0.38 | | 0.32 | 0.14 | 0.26 | 0.04 | 0.16 | 0.09 | 0.22 | 0.03 | 0.27 | |
| NCP08 | 0.03 | 0.06 | 0.04 | | 0.06 | 0.01 | 0.06 | 0.01 | 0.09 | 0.01 | 0.11 | 0.01 | 0.30 | |
| NCP09 | 0.08 | 0.05 | 0.20 | | 0.12 | 0.06 | 0.11 | 0.08 | 0.19 | 0.06 | 0.13 | 0.04 | 0.04 | |
| NCP10 | 0.07 | 0.07 | 0.14 | | 0.11 | 0.14 | 0.25 | 0.14 | 0.39 | 0.09 | 0.21 | 0.05 | 0.08 | |
| NCP11 | 0.47 | 0.11 | 0.20 | | 0.21 | 0.48 | 0.40 | 0.39 | 0.32 | 0.12 | 0.13 | 0.54 | 0.35 | |
| NCP12 | 0.17 | 0.10 | 0.80 | | 0.55 | 0.18 | 0.21 | 0.10 | 0.20 | 0.21 | 0.26 | 0.08 | 0.09 | |
| NCP13 | 0.11 | 0.36 | 0.13 | | 0.43 | 0.09 | 0.57 | 0.04 | 0.49 | 0.01 | 0.40 | 0.07 | 0.71 | |
| NCP14 | 0.03 | 0.06 | 0.26 | | 0.28 | 0.05 | 0.05 | 0.04 | 0.14 | 0.12 | 0.15 | 0.00 | 0.07 | |
| NCP15 | 0.13 | 0.18 | 0.43 | | 0.47 | 0.08 | 0.09 | 0.03 | 0.03 | 0.12 | 0.13 | 0.01 | 0.06 | |
| NCP16 | 0.34 | 0.18 | 0.53 | | 0.69 | 0.15 | 0.17 | 0.17 | 0.26 | 0.13 | 0.26 | 0.14 | 0.23 | |
| NCP17 | 0.99 | 0.99 | 0.97 | | 0.96 | 0.99 | 0.99 | 0.99 | 0.97 | 0.98 | 0.96 | 1.00 | 0.99 | |
| NCP18 | 0.74 | 0.63 | 0.87 | | 0.91 | 0.68 | 0.84 | 0.53 | 0.88 | 0.54 | 0.75 | 0.58 | 0.83 | |

A graph of the number of dryland and non dryland

Description automatically generated

**Fig. S1.** Mean (± SE) value of nature’s contribution to people for drylands and non-drylands for 1992 and 2018. Contributions were significantly lower in drylands in both years.

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