# **Supplementary Materials**

## ***Supplementary Material 1.***

## ***Assessment of LULC changes***

The Sahel region experienced considerable land use and land cover changes during the last two decades. The Modis500 LULC data for the period between 2001 and 2018 points at very informative LULC trends (Table S1.1.). During this period, according to Modis500 LULC data, grasslands in the Sahel expanded by 13 million ha, whereas, the barren areas declined by 8.6 million ha. Another major difference between 2001 and 2018 across the region is an apparent reduction of cropped areas, in total by 0.75 million hectares for the entire region. An important definitional point to clarify here is that cropland category under the Modis500 LULC dataset includes under croplands actually cropped areas, and does not include fallowed lands. Fallowed lands in Modis500 LULC dataset are included under other land uses, e.g. primarily grasslands. On the other hand, fallowed lands are included under croplands within the national or international statistics. Moreover, despite high resolution of pixel size (25 hectares), this Modis500 LULC database underrepresents croplands due to small farm sizes across the Sahel and frequent interspersion of cropped areas within other biomes. Combination of croplands and cropland/natural vegetation mosaics as a single “croplands” category in our analysis, however, is meant to remedy this aspect, at least to some extent.

In general, for all the countries of the Sahel, FAOSTAT shows 120 million hectares of croplands (according to FAOSTAT definition this includes actually cropped areas, including permanent crops, e.g. orchards, temporary meadows and pastures, and fallows) in 2017, whereas Modis500 LULC data shows 84 million hectares (only areas actually cropped with annual crops). This issue of imprecise identification and mapping of croplands (as they are defined in FAOSTAT and national statistics) is not particular to Modis500 LULC data, but remains a shortcoming of all remotely sensed LULC mapping products. For example, van Vliet et al. (2013) highlight the wide discrepancies in the measurement of actual extent of croplands across the Sahel region. The same uncertainty about the true extent of croplands is emphasized by Samasse et al.(2020) who indicate that none of the existing cropland maps reach 75% accuracy. Their analysis using much more granular Landsat 8 data (pixel size = 0.09 ha) for Mali, Niger, Burkina Faso, Mauritania and Senegal finds the extent of croplands to equal 31,6 million hectares during 2013-2015, while the FAOSTAT data shows 33.2 million hectares, the Modis500 LULC data used shows 13.3 million ha of cropped areas for the same countries. However, Samasse et al. (2020) also indicate that they included fallows within croplands.

In the Sahel, crop-fallow rotation practices are extensively used (Tong et al., 2020). Indeed, Tong et al. (2020), using various cropland datasets, found the share of fallow lands within croplands varies between 57%-62%. FAOSTAT does not contain information about share of fallows within croplands for all the Sahelian countries, but for those countries where these data are available, the share of temporary fallows and temporary pastures within croplands varies from 16% to 24%. Hence, the discrepancy of cropland extent by the Modis500 LULC dataset and official statistics could be, to a large extent, explained by fallow land and temporary pastures. These fallow areas and temporary pastures are likely to be included within grassland category in this Modis500 LULC dataset, because Tong et al. (2020) identify that fallow areas in the Sahel region are represented by continuous herbaceous vegetation cover. This lack of distinguishing of fallows from grasslands makes it difficult to properly identify potential cropland areas and their extent, however, for the economic analysis of ecosystem services provided by different biomes, this is not disruptive. Fallow lands are *de facto* used as grasslands, hence, they need to be valued economically as grasslands. It would be highly inaccurate to give them the values of croplands when these fallow lands do not produce any crops, but are mainly used for livestock grazing. Similarly, orchards are by definition included under croplands in official statistics, whereas Modis500 LULC is likely to include them under woodlands/shrublands/forests. These orchards also *de facto* provide a range of ecosystem services similar to woodlands/shrublands/forests and valuing them as “only” croplands would underestimate the values of their ecosystem services. Hence, for the purposes of economic valuation of ecosystem services by different LULC, Modis500 LULC dataset provides not only spatially explicit representation of various LULCs but also such a representation which is amenable for more accurate valuation of ecosystem services by various LULC.

**Table S1.1. LULC transition matrix for the Sahel region, 2001-2018**

|  |  |  |
| --- | --- | --- |
| **Land use and land cover in 2001, in thousand ha** | **Land use and land cover in 2018, in thousand ha** | **Total** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Wetland** | **Cropland** | **Settlement** | **Barren lands** | **Water bodies** |
| **Forest** | 4,607 | 1 | 778 | 1,394 | 87 | 98 | 4 | 0 | 0 | **6,969** |
| **Shrubland** | 6 | 17,783 | 3 | 7,631 | 3 | 11 | 3 | 380 | 0 | **25,819** |
| **Woodland** | 173 | 0 | 1,725 | 434 | 5 | 190 | 5 | 0 | 0 | **2,531** |
| **Grassland** | 1,392 | 2,535 | 845 | 365,000 | 228 | 16,710 | 111 | 1,914 | 20 | **388,755** |
| **Wetland** | 33 | 0 | 3 | 186 | 1,636 | 10 | 6 | 4 | 8 | **1,887** |
| **Cropland** | 105 | 2 | 115 | 17,384 | 12 | 67,268 | 149 | 7 | 0 | **85,041** |
| **Settlements** | 0 | 0 | 0 | 0 | 0 | 0 | 1,255 | 0 | 0 | **1,255** |
| **Barren lands** | 0 | 1,017 | 0 | 9,853 | 47 | 4 | 5 | 465,000 | 38 | **475,965** |
| **Water bodies** | 0 | 0 | 0 | 4 | 32 | 0 | 0 | 37 | 1,415 | **1,489** |
| **Total** | **6,315** | **21,338** | **3,469** | **401,887** | **2,050** | **84,292** | **1,537** | **467,343** | **1,481** |  |
| **Net gain/loss** | **-654** | **-4,481** | **937** | **13,132** | **163** | **-750** | **282** | **-8,622** | **-8** |  |

Source: Modis500 LULC

**Table S1.2. Land use and land cover transition matrix for Africa, 2001-2018**

|  |  |  |
| --- | --- | --- |
| **Land use and land cover in 2001, in thousands ha** | **Land use and land cover in 2018, in thousands ha** | **Total loss** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Wetland** | **Cropland** | **Settlement** | **Barren land** | **Water bodies** |
| **Forest** | 241,940 | 222 | 19,715 | 17,445 | 433 | 231 | 7 | 1 | 1 | **279,995** |
| **Shrubland** | 352 | 159,885 | 559 | 29,092 | 8 | 943 | 17 | 2,773 | 1 | **193,630** |
| **Woodland** | 21,987 | 174 | 78,026 | 19,542 | 98 | 546 | 15 | 2 | 1 | **120,392** |
| **Grassland** | 15,767 | 29,157 | 13,074 | 1,075,000 | 1,183 | 28,225 | 381 | 3,168 | 66 | **1,166,022** |
| **Wetland** | 148 | 2 | 50 | 715 | 7,014 | 39 | 7 | 33 | 113 | **8,121** |
| **Cropland** | 134 | 335 | 320 | 27,633 | 28 | 125,764 | 263 | 10 | 2 | **154,490** |
| **Settlement** | 0 | 0 | 0 | 0 | 0 | 0 | 5,013 | 0 | 0 | **5,013** |
| **Barren land** | 0 | 6,818 | 0 | 12,182 | 119 | 37 | 22 | 1,017,500 | 153 | **1,036,832** |
| **Water bodies** | 0 | 5 | 1 | 103 | 317 | 10 | 0 | 234 | 22,073 | **22,744** |
| **Total gain** | **280,329** | **196,599** | **111,746** | **1,181,712** | **9,201** | **155,795** | **5,726** | **1,023,719** | **22,410** |  |
| **Net gain/loss** | **335** | **2,969** | **-8,646** | **15,691** | **1,079** | **1,304** | **713** | **-13,112** | **-334** |

Source: own analysis based on MODIS Land Cover Type Product (MCD12Q1) global maps of land use and cover at 500-m spatial resolution[[1]](#footnote-1)

Note: Despite high resolution of pixel size (25 hectares), this MODIS LUCC database underrepresents croplands because it does not include fallowed land under cropland category, and also small farm sizes across the Sahel and frequent interspersion of cropped areas within other biomes could lead to the lower extent of cropland areas represented.

## ***Supplementary Material 2.***

The analysis of ecosystem services valuation studies from across the Sahel region points at a large dispersion of these ecosystem values by LULC across the region. Hence, in this assessment, we use the median values for the economic valuation of the costs of land degradation, but also provide the outcomes when minimum and maximum values are used, in order to provide a more robust range of possible estimates. A summary of the median, minimum and maximum values of the ecosystem services by LULC is given in Tables S2.1., S2.2., and S2.3., respectively. The median, maximum and minimum values for provisioning services of croplands, shown in the same tables, are based on net cropland values per hectare compiled from FAOSTAT database. Cropland values are given for comparison purposes based on their values from across the Sahel, whereas in the actual analysis country-and-year specific cropland values are used. Provisioning ecosystem services make up from 2% to 99% of the total services depending on the biome. The highest share of provisioning services is consistently with croplands.

**Table S2.1. Median values of ecosystem services in the Sahel region, (USD 2007 per hectares)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Ecosystem services**  | **Forests** | **Woodlands and Shrublands** | **Grassland** | **Wetlands** | **Cropland** | **Barren land** |
| **Provisioning services** | **284** | **192** | **49** | **423** | ***280*** | **0** |
| Food | 132 | 33 | 36 | 25 |  |  |
| Water | 33 |  |  | 257 |  |  |
| Raw materials | 76 | 42 | 12 | 16 |  | 0 |
| Genetic resources | 38 | 25 |  | 68 |  |  |
| Medicinal resources | 5 | 2 | 1 | 46 |  |  |
| Ornamental resources |  | 90 |  | 11 |  |  |
| **Regulating services** | **1838** | **216** | **316** | **2664** | **38** | **0** |
| Air quality regulation | 14 |  | 23 | 67 |  |  |
| Climate regulation | 1343 | 49 | 75 | 109 | 2 |  |
| Disturbance moderation |  |  |  |  |  |  |
| Regulation of water flows | 55 | 33 |  |  | 19 |  |
| Waste treatment | 153 |  |  | 2206 | 4 |  |
| Erosion prevention | 221 | 104 | 140 | 179 | 2 |  |
| Nutrient cycling | 19 | 10 | 78 | 103 |  |  |
| Pollination | 19 | 19 |  |  | 9 |  |
| Biological control | 14 | 1 |  |  | 2 |  |
| **Habitat services** | **24** | **215** | **0** | **45** | **0** | **0** |
| Nursery service | 8 |  |  | 29 |  |  |
| Genetic diversity | 16 | 215 |  | 16 |  |  |
| **Cultural services** | **6** | **6** | **5** | **55** | **1** | **0** |
| Esthetic information |  |  |  |  |  |  |
| Recreation | 6 | 6 | 5 | 12 | 1 |  |
| Inspiration |  |  |  |  |  |  |
| Spiritual experience |  |  |  | 41 |  |  |
| Cognitive development |   |   |   | 2 |   |   |
| **Total** | **2152** | **629** | **370** | **3187** | **319** | **0** |

**Table S2.2. Minimum values of ecosystem services in the Sahel region, (USD 2007 per hectares)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Ecosystem services** | **Forests** | **Woodlands and Shrublands** | **Grassland** | **Wetlands** | **Cropland** | **Barren land** |
| **Provisioning services** | **139** | **133** | **5** | **84** | **72** | **0** |
| Food | 103 | 1 | 3 | 1 |  |  |
| Water | 8 |  |  | 2 |  |  |
| Raw materials | 19 | 15 | 1 | 1 |  | 0 |
| Genetic resources | 8 | 25 |  | 68 |  |  |
| Medicinal resources | 1 | 2 | 1 | 1 |  |  |
| Ornamental resources |  | 90 |  | 11 |  |  |
| **Regulating services** | **412** | **158** | **237** | **166** | **8** | **0** |
| Air quality regulation | 14 |  | 23 | 67 |  |  |
| Climate regulation | 132 | 3 | 8 | 11 | 2 |  |
| Disturbance moderation |  |  |  |  |  |  |
| Regulation of water flows | 6 | 21 |  |  | 1 |  |
| Waste treatment | 119 |  |  | 1 | 1 |  |
| Erosion prevention | 115 | 104 | 128 | 81 | 2 |  |
| Nutrient cycling | 6 | 10 | 78 | 6 |  |  |
| Pollination | 14 | 19 |  |  | 1 |  |
| Biological control | 6 | 1 |  |  | 1 |  |
| **Habitat services** | **11** | **1** | **0** | **24** | **0** | **0** |
| Nursery service | 7 |  |  | 8 |  |  |
| Genetic diversity | 4 | 1 |  | 16 |  |  |
| **Cultural services** | **1** | **6** | **1** | **22** | **1** | **0** |
| Esthetic information |  |  |  |  |  |  |
| Recreation | 1 | 6 | 1 | 1 | 1 |  |
| Inspiration |  |  |  |  |  |  |
| Spiritual experience |  |  |  | 19 |  |  |
| Cognitive development |  |  |  | 2 |  |  |
| **Total** | **563** | **298** | **243** | **296** | **81** | **0** |

**Table S2.3. Maximum values of ecosystem services in the Sahel region, (USD 2007 per hectares)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Ecosystem services** | Forests | Woodlands and Shrublands | Grassland | Wetlands | Cropland | Barren land |
| **Provisioning services** | **998** | **370** | **183** | **8790** | **8627** | **0** |
| Food | 167 | 51 | 158 | 3859 |  |  |
| Water | 46 |  |  | 1000 |  |  |
| Raw materials | 599 | 197 | 24 | 3753 |  |  |
| Genetic resources | 94 | 25 |  | 68 |  |  |
| Medicinal resources | 92 | 7 | 1 | 99 |  |  |
| Ornamental resources |  | 90 |  | 11 |  |  |
| **Regulating services** | **4393** | **274** | **397** | **5283** | **117** | **0** |
| Air quality regulation | 14 |  | 23 | 67 |  |  |
| Climate regulation | 3097 | 95 | 143 | 780 | 2 |  |
| Disturbance moderation |  |  |  |  |  |  |
| Regulation of water flows | 345 | 45 |  |  | 48 |  |
| Waste treatment | 188 |  |  | 4119 | 7 |  |
| Erosion prevention | 524 | 104 | 153 | 156 | 3 |  |
| Nutrient cycling | 133 | 10 | 78 | 161 |  |  |
| Pollination | 51 | 19 |  |  | 30 |  |
| Biological control | 41 | 1 |  |  | 27 |  |
| **Habitat services** | **54** | **430** | **0** | **703** | **0** | **0** |
| Nursery service | 24 |  |  | 687 |  |  |
| Genetic diversity | 30 | 430 |  | 16 |  |  |
| **Cultural services** | **209** | **6** | **185** | **159** | **1** | **0** |
| Esthetic information |  |  |  |  |  |  |
| Recreation | 209 | 6 | 185 | 91 | 1 |  |
| Inspiration |  |  |  |  |  |  |
| Spiritual experience |  |  |  | 66 |  |  |
| Cognitive development |  |  |  | 2 |  |  |
| **Total** | **5654** | **1080** | **765** | **14935** | **8745** | **0** |

**Table S2.4. Costs of land restoration activities across the Sahel (USD 2007)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Costs of action**  | **Forest** | **Woodland** | **Shrubland** | **Wetland** | **Cropland** | **Grassland** |
| **Establishment costs** | 645 | 154 | 154 | 5577 | 297 | 297 |
| **Maintenance costs** | 225 | 50 | 50 | 300 | 69 | 69 |
| **Survival rate** | 60% | 60% | 60% | 100% | 100% | 60% |
| **Establishment years**  | 30 | 10 | 10 | 10 | 1 | 1 |

Sources: see Data section

## ***Supplementary Material 3.***

**Figure S3.1. Annual cost of land degradation, gains from land improvement and net changes in the TEV of ecosystems using minimum economic values for ecosystem services.**

**Figure S3.2. Annual cost of land degradation, gains from land improvement and net changes in the TEV of ecosystems using maximum economic values for ecosystem services.**

**Table S3.1. Dynamics of annual costs of land degradation by country across the Sahel region (median ecosystem values), million USD 2007.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Countries** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** |
| Burkina Faso | 3 | 43 | 15 | 3 | 1 | 161 | 8 | 68 | 4 | 57 | 5 | 3 | 2 | 33 | 1 | 11 | 6 |
| Chad | 125 | 95 | 262 | 69 | 160 | 43 | 72 | 374 | 44 | 1146 | 21 | 583 | 107 | 98 | 78 | 164 | 105 |
| Djibouti | 2 | 2 | 2 | 2 | 2 | 2 | 6 | 6 | 7 | 12 | 10 | 7 | 6 | 4 | 3 | 11 | 16 |
| Eritrea | 33 | 11 | 10 | 12 | 22 | 13 | 54 | 22 | 20 | 17 | 17 | 12 | 12 | 11 | 11 | 54 | 49 |
| Ethiopia | 524 | 628 | 480 | 321 | 542 | 661 | 445 | 454 | 464 | 467 | 425 | 448 | 398 | 467 | 782 | 990 | 1271 |
| Mali | 338 | 140 | 36 | 130 | 59 | 36 | 64 | 68 | 87 | 52 | 56 | 57 | 59 | 40 | 49 | 295 | 186 |
| Mauritania | 9 | 11 | 9 | 9 | 9 | 10 | 18 | 19 | 24 | 49 | 29 | 18 | 22 | 11 | 10 | 220 | 273 |
| Niger | 51 | 115 | 178 | 93 | 53 | 64 | 80 | 333 | 65 | 243 | 60 | 52 | 62 | 73 | 81 | 183 | 123 |
| Nigeria | 972 | 977 | 1031 | 922 | 1007 | 4010 | 794 | 1809 | 910 | 4656 | 824 | 761 | 629 | 854 | 1307 | 1760 | 1806 |
| Sudan | 296 | 65 | 43 | 489 | 304 | 63 | 247 | 351 | 90 | 52 | 744 | 61 | 51 | 426 | 40 | 208 | 154 |
| Senegal | 342 | 10 | 29 | 6 | 73 | 92 | 5 | 16 | 10 | 228 | 7 | 31 | 27 | 10 | 165 | 72 | 61 |
| **Sahel region** | **2823** | **2181** | **2160** | **2223** | **2322** | **5262** | **2052** | **3703** | **1858** | **7119** | **2463** | **2249** | **1657** | **2361** | **2681** | **4400** | **4442** |

## ***Supplementary Material 4.***

**Table S4.1. Costs of action vs Inaction by country under Scenario 1 (in millions USD 2007)**

|  |  |
| --- | --- |
| **Countries** |  |
| **Cost of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration** |
| **Burkina Faso** | 254 | 535 | 0.47 |
| **Chad** | 1207 | 1317 | 0.92 |
| **Djibouti** | 276 | 146 | 1.89 |
| **Eritrea** | 549 | 340 | 1.61 |
| **Ethiopia** | 39335 | 23536 | 1.67 |
| **Mali** | 1384 | 1589 | 0.87 |
| **Mauritania** | 712 | 710 | 1.00 |
| **Niger** | 1148 | 1110 | 1.03 |
| **Nigeria** | 26514 | 11194 | 2.37 |
| **Sudan** | 2348 | 2902 | 0.81 |
| **Senegal** | 587 | 767 | 0.77 |
| **Sahel** | **74314** | **44148** | **1.68** |

Note: cost of inaction corresponds to cost of land degradation, while cost of action corresponds to cost of land restoration.

**Table S4.2. Costs of action vs Inaction by country under Scenario 2 (in millions USD 2007)**

|  |  |
| --- | --- |
| **Countries** |  |
| **Costs of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration**  |
| **Burkina Faso** | 952 | 566 | 1.68 |
| **Chad** | 2227 | 1340 | 1.66 |
| **Djibouti** | 180 | 113 | 1.60 |
| **Eritrea** | 338 | 251 | 1.34 |
| **Ethiopia** | 15171 | 16156 | 0.94 |
| **Mali** | 3150 | 1590 | 1.98 |
| **Mauritania** | 834 | 567 | 1.47 |
| **Niger** | 2085 | 1133 | 1.84 |
| **Nigeria** | 20272 | 8564 | 2.37 |
| **Sudan** | 4024 | 2630 | 1.53 |
| **Senegal** | 1222 | 768 | 1.59 |
| **Sahel** | **50453** | **33678** | **1.49** |

**Table S4.3. Costs of action vs Inaction by country under Scenario 3 (in millions USD 2007)**

|  |  |
| --- | --- |
| **Countries** |  |
| **Costs of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration**  |
| **Burkina Faso** | 1553 | 604 | 2.6 |
| **Chad** | 3872 | 1457 | 2.7 |
| **Djibouti** | 383 | 152 | 2.5 |
| **Eritrea** | 730 | 349 | 2.1 |
| **Ethiopia** | 33057 | 23266 | 1.4 |
| **Mali** | 5348 | 1898 | 2.8 |
| **Mauritania** | 1551 | 754 | 2.1 |
| **Niger** | 3632 | 1241 | 2.9 |
| **Nigeria** | 35159 | 10869 | 3.2 |
| **Sudan** | 7059 | 3150 | 2.2 |
| **Senegal** | 2087 | 922 | 2.3 |
| **Sahel** | **94430** | **44663** | **2.1** |

**Table S4.4. Costs of action vs Inaction by country under Scenario 4, (in millions USD 2007)**

|  |  |
| --- | --- |
| **Countries** | **Scenario 4** |
| **Costs of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration** |
| **Burkina Faso** | 2416 | 647 | 3.7 |
| **Chad** | 6854 | 1517 | 4.5 |
| **Djibouti** | 904 | 162 | 5.6 |
| **Eritrea** | 1756 | 369 | 4.8 |
| **Ethiopia** | 87961 | 25088 | 3.5 |
| **Mali** | 9054 | 2100 | 4.3 |
| **Mauritania** | 3075 | 797 | 3.9 |
| **Niger** | 6452 | 1297 | 5.0 |
| **Nigeria** | 70661 | 12889 | 5.5 |
| **Sudan** | 12706 | 3347 | 3.8 |
| **Senegal** | 3586 | 1027 | 3.5 |
| **Sahel** | **205426** | **49240** | **4.2** |

**Table S4.5. Costs of action vs Inaction by country under Scenario 5, (in millions USD 2007)**

|  |  |
| --- | --- |
| **Countries** |  |
| **Costs of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration**  |
| **Burkina Faso** | 268 | 566 | 0.5 |
| **Chad** | 1329 | 1485 | 0.9 |
| **Djibouti** | 312 | 181 | 1.7 |
| **Eritrea** | 620 | 423 | 1.5 |
| **Ethiopia** | 45886 | 30821 | 1.5 |
| **Mali** | 1510 | 1790 | 0.8 |
| **Mauritania** | 795 | 852 | 0.9 |
| **Niger** | 1264 | 1264 | 1.0 |
| **Nigeria** | 31269 | 15441 | 2.0 |
| **Sudan** | 2593 | 3310 | 0.8 |
| **Senegal** | 645 | 865 | 0.7 |
| **Sahel** | **86491** | **56999** | **1.5** |

**Table S4.6. Costs of action vs Inaction by country under Scenario 6, (in millions USD 2007)**

|  |  |
| --- | --- |
| **Countries** |  |
| **Costs of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration**  |
| **Burkina Faso** | 278 | 587 | 0.5 |
| **Chad** | 1413 | 1619 | 0.9 |
| **Djibouti** | 337 | 209 | 2.5 |
| **Eritrea** | 669 | 490 | 2.1 |
| **Ethiopia** | 50763 | 37674 | 1.1 |
| **Mali** | 1598 | 1946 | 0.7 |
| **Mauritania** | 853 | 965 | 0.8 |
| **Niger** | 1345 | 1387 | 0.6 |
| **Nigeria** | 34897 | 20212 | 1.4 |
| **Sudan** | 2764 | 3627 | 0.7 |
| **Senegal** | 685 | 942 | 0.6 |
| **Sahel** | **108843** | **76270** | **1.4** |

**Table S4.7. Costs of action vs Inaction by country under Scenario 7, (in millions USD 2007)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Countries** | **Costs of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration**  |
| **Burkina Faso** | 761 | 357 | 2.1 |
| **Chad** | 1104 | 901 | 1.2 |
| **Djibouti** | 42 | 68 | 0.6 |
| **Eritrea** | 141 | 190 | 0.7 |
| **Ethiopia** | 8040 | 6626 | 1.2 |
| **Mali** | 2633 | 963 | 2.7 |
| **Mauritania** | 148 | 342 | 0.4 |
| **Niger** | 533 | 851 | 0.6 |
| **Nigeria** | 18087 | 5742 | 3.2 |
| **Sudan** | 2717 | 1818 | 1.5 |
| **Senegal** | 1120 | 438 | 2.6 |
| **Sahel** | **36325** | **18295** | **1.93** |

**Table S4.8. Costs of action vs Inaction by country under Scenario 8, (in millions USD 2007)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Costs of inaction** | **Cost of Action** | **Returns from each $ invested in land restoration**  |
| **Burkina Faso** | 2,416 | 582 | 4.2 |
| **Chad** | 6,854 | 1,432 | 4.8 |
| **Djibouti** | 904 | 165 | 5.5 |
| **Eritrea** | 1,756 | 374 | 4.7 |
| **Ethiopia** | 84,353 | 24,827 | 3.4 |
| **Mali** | 6,193 | 1,628 | 3.8 |
| **Mauritania** | 3,075 | 811 | 3.8 |
| **Niger** | 6,452 | 1,280 | 5.0 |
| **Nigeria** | 48,722 | 11,991 | 4.1 |
| **Sudan** | 12,706 | 3,196 | 4.0 |
| **Senegal** | 4,248 | 1,117 | 3.8 |
| **Sahel** | **177,680** | **47,404** | **3.7** |

## ***Supplementary Material 5.***

**Table S5.1. Benefit-cost ratios of action by biome and country under Scenario 1**

|  |  |
| --- | --- |
|  | **Scenario 1, returns from each $ invested in restoration by biome**  |
| **Country** | **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 3.6 | 2.9 | . | 1.1 | 0.8 | 0.4 |
| **Chad** | . | 2.4 | . | 2.1 | 0.7 | 0.5 |
| **Djibouti** | . | . | . | 4.7 | . | 0.7 |
| **Eritrea** | . | 3.3 | . | 3.9 | . | 0.6 |
| **Ethiopia** | 6.2 | 2.6 | 1.1 | 1.3 | 0.6 | 0.7 |
| **Mali** | 3.6 | 2.4 | 1.1 | 1.4 | 0.7 | 0.7 |
| **Mauritania** | . | 2.4 | . | 1.4 | . | 0.7 |
| **Niger** | . | 2.5 | . | 2.1 | 0.3 | 0.6 |
| **Nigeria** | 5.1 | 1.7 | 0.9 | 0.9 | 1.2 | 0.7 |
| **Sudan** | 3.6 | 2.8 | . | 2.0 | 0.6 | 0.5 |
| **Senegal** | 3.6 | 2.6 | 1.1 | 1.1 | 0.5 | 0.7 |
| **Sahel** | **5.4** | **2.2** | **0.9** | **1.4** | **0.9** | **0.5** |

**Table S5.2. Benefit-cost ratios of action by biome and country under Scenario 2**

|  |  |
| --- | --- |
|  | **Scenario 2, returns from each $ invested in restoration by biome** |
| **Country** | **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 0.6 | 1.1 | . | 0.7 | 2.5 | 1.7 |
| **Chad** | . | 1.0 | . | 1.1 | 2.2 | 1.9 |
| **Djibouti** | . | . | . | 2.3 | . | 2.5 |
| **Eritrea** | . | 1.2 | . | 1.9 | . | 2.4 |
| **Ethiopia** | 0.8 | 1.0 | 0.7 | 0.7 | 2.3 | 2.5 |
| **Mali** | 0.6 | 1.0 | 0.7 | 0.8 | 2.3 | 2.5 |
| **Mauritania** | . | 1.0 | . | 0.8 | . | 2.5 |
| **Niger** | . | 1.0 | . | 1.1 | 1.0 | 2.2 |
| **Nigeria** | 0.7 | 0.8 | 0.5 | 0.5 | 4.4 | 2.5 |
| **Sudan** | 0.6 | 1.1 | . | 1.1 | 1.9 | 1.9 |
| **Senegal** | 0.6 | 1.0 | 0.7 | 0.7 | 1.8 | 2.5 |
| **Sahel** | **0.7** | **0.9** | **0.6** | **0.8** | **3.3** | **2.0** |

**Table S5.3. Benefit-cost ratios of action by biome and country under Scenario 3**

|  |  |
| --- | --- |
| **Country** | **Scenario 3, returns from each $ invested in restoration by biome**  |
| **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 1.0 | 2.9 | . | 1.1 | 3.3 | 2.6 |
| **Chad** | . | 2.4 | . | 2.1 | 2.9 | 2.9 |
| **Djibouti** | . | . | . | 4.7 | . | 3.7 |
| **Eritrea** | . | 3.3 | . | 3.9 | . | 3.6 |
| **Ethiopia** | 1.6 | 2.6 | 1.1 | 1.3 | 3.3 | 3.7 |
| **Mali** | 1.0 | 2.4 | 1.1 | 1.4 | 3.4 | 3.7 |
| **Mauritania** | . | 2.4 | . | 1.4 | . | 3.7 |
| **Niger** | . | 2.5 | . | 2.1 | 1.3 | 3.3 |
| **Nigeria** | 1.3 | 1.7 | 0.9 | 0.9 | 6.4 | 3.7 |
| **Sudan** | 1.0 | 2.8 | . | 2.0 | 2.6 | 2.9 |
| **Senegal** | 1.0 | 2.6 | 1.1 | 1.1 | 2.7 | 3.7 |
| **Sahel** | **1.4** | **2.2** | **0.9** | **1.4** | **4.8** | **3.0** |

**Table S5.4. Benefit-cost ratios of action by biome and country under Scenario 4**

|  |  |
| --- | --- |
| **Country** | **Scenario 4, returns from each $ invested in restoration by biome**  |
| **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 3.6 | 9.8 | . | 3.0 | 4.1 | 3.8 |
| **Chad** | . | 7.8 | . | 5.2 | 3.6 | 4.1 |
| **Djibouti** | . | . | . | 11.0 | . | 5.1 |
| **Eritrea** | . | 11.4 | . | 9.1 | . | 5.0 |
| **Ethiopia** | 6.2 | 8.5 | 3.0 | 3.3 | 4.5 | 5.1 |
| **Mali** | 3.6 | 7.8 | 3.0 | 3.6 | 4.5 | 5.1 |
| **Mauritania** | . | 7.7 | . | 3.7 | . | 5.1 |
| **Niger** | . | 8.0 | . | 5.2 | 1.6 | 4.6 |
| **Nigeria** | 5.1 | 5.4 | 2.3 | 2.3 | 8.5 | 5.1 |
| **Sudan** | 3.6 | 9.1 | . | 4.9 | 3.2 | 4.1 |
| **Senegal** | 3.6 | 8.4 | 3.0 | 3.0 | 3.6 | 5.1 |
| **Sahel** | **5.4** | **7.1** | **2.5** | **3.6** | **6.4** | **4.3** |

**Table S5.5. Benefit-cost ratios of action by biome and country under Scenario 5**

|  |  |
| --- | --- |
| **Country** | **Scenario 5, returns from each $ invested in restoration by biome**  |
| **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 2.6 | 2.4 | . | 1.0 | 0.8 | 0.4 |
| **Chad** | . | 2.0 | . | 1.8 | 0.7 | 0.5 |
| **Djibouti** | . | . | . | 4.0 | . | 0.7 |
| **Eritrea** | . | 2.7 | . | 3.3 | . | 0.6 |
| **Ethiopia** | 4.5 | 2.1 | 1.0 | 1.1 | 0.6 | 0.7 |
| **Mali** | 2.6 | 2.0 | 1.0 | 1.2 | 0.7 | 0.7 |
| **Mauritania** | . | 2.0 | . | 1.2 | . | 0.7 |
| **Niger** | . | 2.1 | . | 1.8 | 0.3 | 0.6 |
| **Nigeria** | 3.7 | 1.4 | 0.8 | 0.8 | 1.2 | 0.7 |
| **Sudan** | 2.6 | 2.2 | . | 1.7 | 0.6 | 0.5 |
| **Senegal** | 2.6 | 2.1 | 1.0 | 1.0 | 0.5 | 0.7 |
| **Sahel** | **3.9** | **1.8** | **0.8** | **1.2** | **0.9** | **0.5** |

**Table S5.6. Benefit-cost ratios of action by biome and country under Scenario 6**

|  |  |
| --- | --- |
| **Country** | **Scenario 6, returns from each $ invested in restoration by biome**  |
| **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 2.0 | 2.0 | . | 0.9 | 0.8 | 0.4 |
| **Chad** | . | 1.8 | . | 1.7 | 0.7 | 0.5 |
| **Djibouti** | . | . | . | 3.6 | . | 0.7 |
| **Eritrea** | . | 2.3 | . | 3.0 | . | 0.6 |
| **Ethiopia** | 3.8 | 1.9 | 0.9 | 1.0 | 0.6 | 0.7 |
| **Mali** | 2.0 | 1.8 | 0.9 | 1.1 | 0.7 | 0.7 |
| **Mauritania** | . | 1.8 | . | 1.1 | . | 0.7 |
| **Niger** | . | 1.8 | . | 1.7 | 0.3 | 0.6 |
| **Nigeria** | 2.8 | 1.3 | 0.7 | 0.7 | 1.2 | 0.7 |
| **Sudan** | 2.0 | 2.0 | . | 1.6 | 0.6 | 0.5 |
| **Senegal** | 2.0 | 2.0 | 0.92 | 0.9 | 0.5 | 0.7 |
| **Sahel** | **3.0** | **1.6** | **0.76** | **1.1** | **0.9** | **0.5** |

**Table S5.7. Benefit-cost ratios of action by biome and country under Scenario 7**

|  |  |
| --- | --- |
| **Country** | **Scenario 7, returns from each $ invested in restoration by biome**  |
| **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 0.1 | 0.2 | . | 0.7 | 2.3 | 0.3 |
| **Chad** | . | 0.2 | . | 0.7 | 2.0 | 0.3 |
| **Djibouti** | . | . | . | 0.9 | . | 0.3 |
| **Eritrea** | . | 0.2 | . | 0.8 | 1.0 | 0.3 |
| **Ethiopia** | 0.1 | 0.2 | 0.7 | 0.7 | 3.7 | 0.3 |
| **Mali** | 0.1 | 0.2 | 0.7 | 0.7 | 3.7 | 0.3 |
| **Mauritania** | . | 0.2 | . | 0.7 | 1.6 | 0.3 |
| **Niger** | . | 0.2 | . | 0.7 | 0.9 | 0.3 |
| **Nigeria** | 0.1 | 0.2 | 0.4 | 0.4 | 7.0 | 0.3 |
| **Sudan** | 0.1 | 0.2 | . | 0.7 | 1.8 | 0.3 |
| **Senegal** | 0.1 | 0.2 | 0.7 | 0.7 | 2.9 | 0.3 |
| **Sahel** | **0.1** | **0.2** | **0.5** | **0.7** | **3.8** | **0.3** |

**Table S5.8. Benefit-cost ratios of action by biome and country under Scenario 8**

|  |  |
| --- | --- |
| **Country** | **Scenario 8, returns from each $ invested in restoration by biome**  |
| **Forest** | **Wetland** | **Woodland** | **Shrubland** | **Cropland** | **Grassland** |
| **Burkina Faso** | 3.5 | 9.8 | . | 3.0 | 2.1 | 4.2 |
| **Chad** | . | 8.0 | . | 5.1 | 1.8 | 4.4 |
| **Djibouti** | . | . | . | 10.8 | . | 4.9 |
| **Eritrea** | . | 11.4 | . | 8.9 | . | 4.9 |
| **Ethiopia** | 6.1 | 8.5 | 3.0 | 3.3 | 3.4 | 3.8 |
| **Mali** | 3.5 | 7.8 | 3.0 | 3.6 | 3.4 | 4.0 |
| **Mauritania** | . | 7.7 | . | 3.6 | . | 4.9 |
| **Niger** | . | 8.1 | . | 5.1 | 0.8 | 4.7 |
| **Nigeria** | 5.1 | 5.5 | 2.8 | 2.8 | 4.3 | 4.9 |
| **Sudan** | 3.5 | 9.1 | . | 4.9 | 1.6 | 4.4 |
| **Senegal** | 3.5 | 8.4 | 3.0 | 3.0 | . | 4.0 |
| **Sahel** | **5.4** | **7.2** | **2.8** | **3.6** | **4.3** | **4.2** |

## ***Supplementary Material 6.***

**Table S6.1. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 1**

|  |  |
| --- | --- |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 0.9 | 1.9 | 1.9 | 2.4 | 2.6 | 3.8 |
| Forest |  | 9.2 | 9.2 | 3.6 | 1.9 |  |
| Shrubland |  |  |  | 1.1 | 0.9 | 7.3 |
| Woodland |  |  |  | 1.1 | 0.5 |  |
| Cropland |  |  |  | 0.9 |  | 1.9 |
| Grassland |   |   |   |   | 0.5 | 0.7 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

**Table S6.2. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 2**

|  |  |
| --- | --- |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 0.5 | 0.9 | 0.9 | 1.0 | 1.0 | 1.3 |
| Forest |  | 1.1 | 1.1 | 0.6 | 0.3 |  |
| Shrubland |  |  |  | 0.7 | 0.6 | 3.4 |
| Woodland |  |  |  | 0.7 | 0.3 |  |
| Cropland |  |  |  | 3.3 |  | 5.9 |
| Grassland |   |   |   |  | 1.8  | 2.5 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

**Table S6.3. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 3**

|  |  |
| --- | --- |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 0.9 | 1.9 | 1.9 | 2.4 | 2.6 | 3.8 |
| Forest |  | 2.3 | 2.3 | 1.0 | 0.6 |  |
| Shrubland |  |  |  | 1.1 | 0.9 | 7.3 |
| Woodland |  |  |  | 1.1 | 0.5 |  |
| Cropland |  |  |  | 4.8 |  | 7.9 |
| Grassland |   |   |   |   | 2.8 | 3.7 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

**Table S6.4. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 4**

|  |  |
| --- | --- |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 2.6 | 6.0 | 6.0 | 7.7 | 8.6 | 13.3 |
| Forest |  | 9.2 | 9.2 | 3.6 | 1.9 |  |
| Shrubland |  |  |  | 3.0 | 2.4 | 17.0 |
| Woodland |  |  |  | 3.0 | 1.4 |  |
| Cropland |  |  |  | 6.4 |  | 9.8 |
| Grassland |   |   |   |   | 4.0 | 5.1 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

**Table S6.5. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 5**

|  |  |
| --- | --- |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 0.8 | 1.6 | 1.6 | 2.0 | 2.1 | 3.0 |
| Forest |  | 6.6 | 6.6 | 2.6 | 1.4 |  |
| Shrubland |  |  |  | 1.0 | 0.8 | 6.2 |
| Woodland |  |  |  | 1.0 | 0.4 |  |
| Cropland |  |  |  | 0.9 |  | 1.9 |
| Grassland |   |   |   |   | 0.5 | 0.7 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

**Table S6.6. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 6**

|  |  |
| --- | --- |
|  | **Scenario 6** |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 0.7 | 1.4 | 1.4 | 1.6 | 1.8 | 2.6 |
| Forest |  | 4.9 | 4.9 | 2.0 | 1.1 |  |
| Shrubland |  |  |  | 0.9 | 0.7 | 5.6 |
| Woodland |  |  |  | 0.9 | 0.7 |  |
| Cropland |  |  |  | 0.9 |  | 1.9 |
| Grassland |   |   |   |   | 0.5 | 0.7 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

**Table S6.7. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 7**

|  |  |
| --- | --- |
|  | **Scenario 7** |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 |
| Forest |  | 0.1 | 0.1 | 0.1 | 0.0 |  |
| Shrubland |  |  |  | 0.7 | 0.2 | 1.0 |
| Woodland |  |  |  | 0.7 | 0.1 |  |
| Cropland |  |  |  | 3.8 |  | 5.9 |
| Grassland |   |   |   |   |   | 0.3 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

**Table S6.8. Benefit-cost ratios of restoring a degraded biome compared to its current use, Scenario 8**

|  |  |
| --- | --- |
|  | **Scenario 8** |
| **2001** | **2018** |
| **Forest** | **Shrubland** | **Woodland** | **Grassland** | **Cropland** | **Barren** |
| Wetland | 2.6 | 6.0 | 6.0 | 7.7 | 10.2 | 13.3 |
| Forest |  | 9.0 | 9.0 | 3.5 | 3.1 |  |
| Shrubland |  |  |  | 3.0 | 4.1 | 16.5 |
| Woodland |  |  |  | 3.0 | 2.5 |  |
| Cropland |  |  |  | 4.3 |  | 4.9 |
| Grassland |   |   |   |   | 4.1 | 4.9 |

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

## ***Supplementary Material 7.***

**Table S7.1. Definition of biomes used in the study**

|  |  |
| --- | --- |
| **Biome** | **International Geosphere-Biosphere Programme (IGBP) definition** |
| Forests | Woody vegetation with height >2m & covering at least 60% of land area.  |
| Woodland | Biome with tree cover of 30-60% (canopy > 2m) |
| Shrubland | Dominated by woody perennials (1-2m height) > 10% cover. |
| Grassland | Lands with herbaceous types of cover. Tree and shrub cover is less than 30%.  |
| Cropland | Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note, perennial woody crops are classified as forest or shrubland. At least 60% of area is cultivated cropland. |
| Barren lands | Barren or sparsely vegetated (bare soil and rocks). Lands with exposed soil, sand or rocks, with less than 10% vegetated cover throughout the year |
| Wetland | Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present either in salt, brackish, or fresh water |

For more definitions, please see http://earthobservatory.nasa.gov/Experiments/Biome/vocabulary.php

## ***Supplementary material 8***

**Assumptions for land restoration activities**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Forest** | **Woodland** | **Shrubland** | **Wetland** | **Cropland** | **Grassland** |
| **Establishment period** | 30 | 10 | 10 | 10 | 1 | 1 |
| **Staggered entrance into full potential of ecosystem service provision** | First 5 years (20% of the full potential), 2nd 5 years (33% of potential), next 10 years (50 of potential), next 5 years (80% of potential) | First 5 years (50% of the full potential), 2nd 5 years (80% of potential) | First 5 years (50% of the full potential), 2nd 5 years (80% of potential) | First 5 years (50% of the full potential), 2nd 5 years (80% of potential) | Full potential is reached one year after restoration | Full potential is reached one year after restoration |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |

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