Combined impacts of future climate-driven vegetation changes and socio-economic pressures on protected areas in Africa
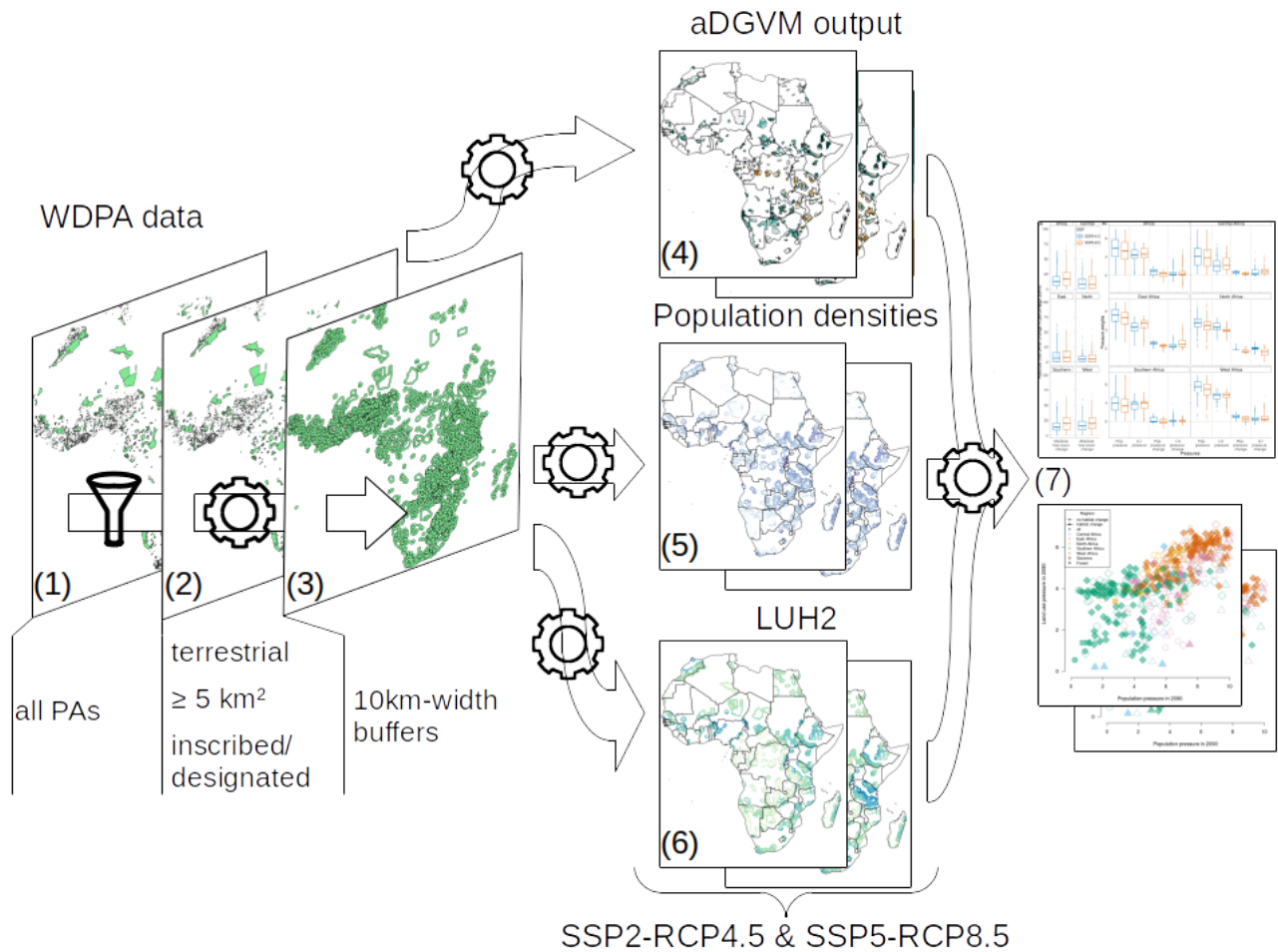
Conservation Biology

Supporting Information

Appendix S1 Overview of data used to analyse global change pressure on African protected areas (PAs). African PAs from the WDPA data base (1) were filtered to only include terrestrial PAs that are equal to or bigger than 5 km² and are officially "inscribed" or "designated" (2). For this PA selection, buffers of 10-km-width were created (3). For each PA, aDGVM simulated tree cover and biomass within their perimeters were derived (4). Using population densities from (Gao, 2019) and land use types from LUH2 data (Hurtt et al., 2020), population pressure (5) and land-use pressure (6) in the perimeters of PAs were derived. These human pressures in the buffer areas were used as proxies for future human pressures exerted on PAs. For (4)-(6) data for two RCP-SSP scenarios, i.e. SSP2-RCP4.5 and SSP5-RCP8.5, were used to investigate differences between two future scenarios. These data for PAs were then used to analyse in which continental regions global change pressures were high and where individual pressures co-occurred (7). aDGVM - adaptive Dynamic Global Vegetation Model; LUH2 - Land-Use Harmonization; RCP - representative concentration pathway; SSP - shared socio-economic pathway; WDPA - world database on protected areas (UNEP-WCMC & IUCN, 2019).

Appendix S2 List of protected areas used in this analysis. Geographical location and administrative boundaries of protected areas in Africa used in this study were derived from the World Database on Protected Areas (WDPA; UNEP-WCMC & IUCN, 2019). Terrestrial protected areas in Africa of a size bigger than 5 km^2 were selected for the analysis. Protected areas without spatial polygon data available were excluded from this study as well as protected areas whose designation status is 'proposed' or 'not reported'. Transfrontier PAs in our analysis and their buffers did not lie in multiple regions. The table can be found in a separate file.

Appendix S3 Weighting scheme for land-use pressure factors based on LUH2[a] land use types and age classes.

Aggregated land use types	Age[b]	Pressure[c]	LUH2 land use types
Primary vegetation		0	forested primary land & non-forested primary land
Secondary vegetation			
mature	>100 years	1	potentially forested primary land & potentially non-forested primary land
intermediate	30-100 years	2	
young	<30 years	3	
Pastures		4	managed pasture & rangeland
Cropland		7	C_3 annual crops, C_3 perennial crops, C_4 annual crops, C_4 perennial crops & C_3 nitrogen-fixing crops
Urban		10	urban

[a]Land-Use Harmonization (LUH2) data (Hurtt et al., 2020)

[b]Based on Newbold et al. (2015). Age is only used to classify secondary vegetation in subgroups.

[c]Based on Venter et al. (2016). For each grid cell the fraction covered by each aggregated land use type was multiplied with the assigned pressure and then summed over all aggregated land use types. The maximum land-use pressure in a grid cell is ten (100% urban area).

Appendix S4 Classification scheme for grouping vegetation into four different biomes (simplified from Martens et al., 2021).

Biome	Tree cover	Total aboveground biomass
Desert	-*	<1.5t/ha
Grassland	<10%	>1.5t/ha
Savanna	10-70%	>1.5t/ha
Forest	>70%	>1.5t/ha

*Variable was not used for classification of deserts.

Appendix S5 Classification scheme for habitat loss for the four biomes.

Biome	aDGVM[a] variable	Level of change[b]
Desert	aboveground biomass	>0.5t/ha
Grassland	tree cover[c]	>5p.p.
Savanna	tree cover[c]	>10p.p or <-10p.p.[d]
Forest	tree cover[c]	<-20%[d]

[a] adaptive Dynamic Global Vegetation Model

[b]Habitat loss for each biome is determined by change between 2000-2019 and 2080-2099 of the given aDGVM output variable.

[c]Level of change is based on percentage points for tree cover.

[d]Habitat loss is defined following (Aleman et al., 2016); p.p., percentage points.

Appendix S6 Regions used for grouping protected areas based on regions of the African Union

(Council of Ministers, Organization of African Unity, 1976)

| Region	Countries
Central Africa	Burundi, Cameroon, Central African Republic, Chad, Congo Republic, DR Congo, Equatorial Guinea, Gabon, São Tomé and Principe
East Africa	Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Rwanda, Seychelles, Somalia, South Sudan, Sudan, Tanzania, Uganda
North Africa	Algeria, Egypt, Libya, Mauritania, Morocco, Sahrawi Republic, Tunisia
Southern Africa	Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, Zimbabwe
West Africa	Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo
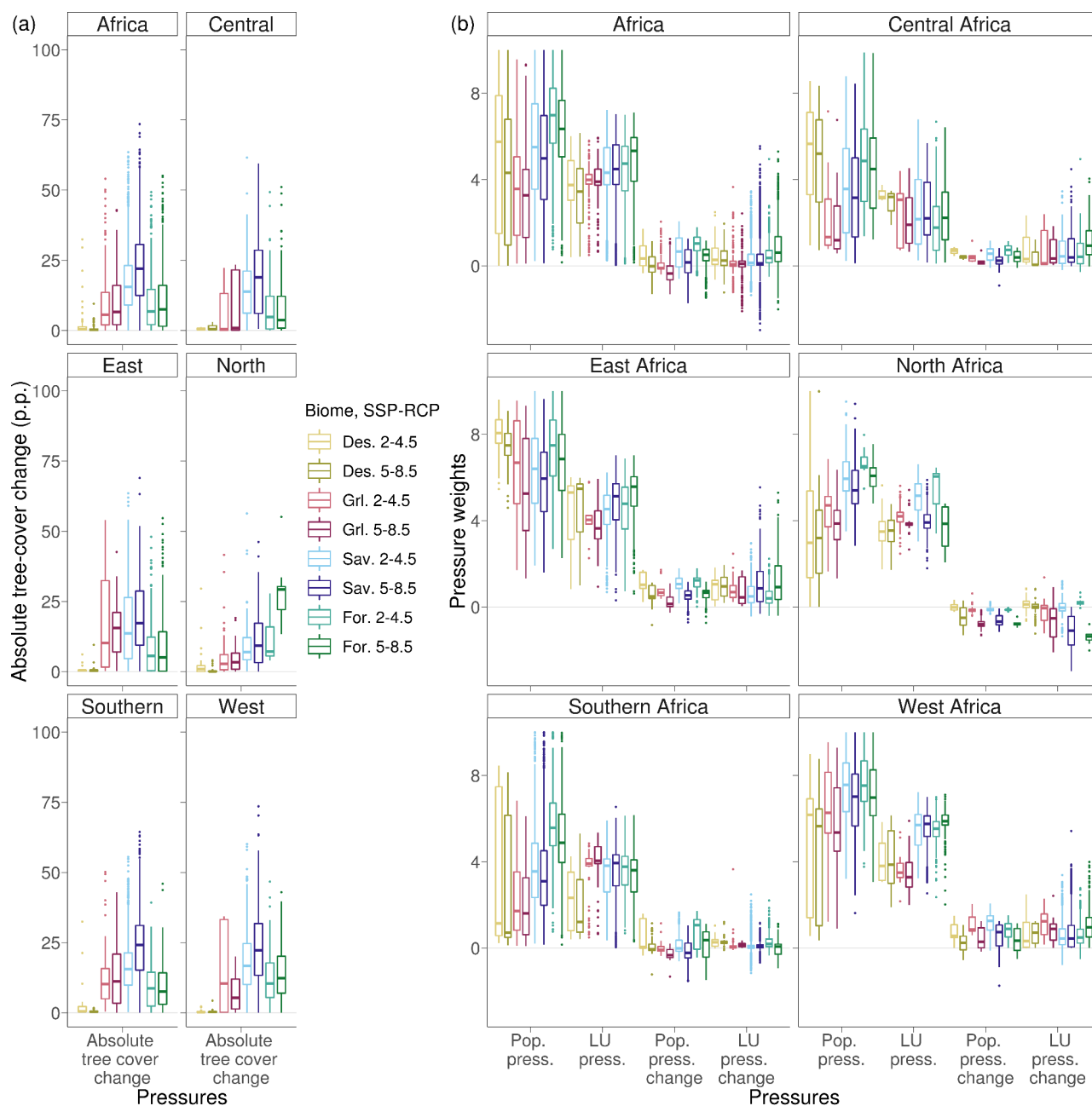
Appendix S7 (a) Climate-driven change in tree cover in protected areas (derived from adaptive dynamic global vegetation model (aDGVM) based on results from Martens et al., [2021]) and (b) socio-economic pressures in 10-km zones around protected areas by biome and region under SSP2-RCP4.5 (SSP, shared socioeconomic pathways; RCP, representative concentration pathways) and SSP5-RCP8.5 scenarios (defined in Table 1 and text) (p.p., percentage points; pop., population; press., pressure; LU, land use; horizontal lines, median; box ends, 25% and 75% quantile; ends of whisker lines, smallest or largest value respectively ≥ or ≤ 1.5 times the interquartile range beyond the box ends of protected areas in each group; Des. - desert; Grl. - grasland; For - forest; Sav. - savanna). Regions are based on regions defined by the African Union (Appendix S6). Absolute values for

tree-cover change from 2000-2019 to 2080-2099 are used because both negative and positive tree-cover changes represent climate-driven vegetation changes. The socio-economic pressures population (based on Gao [2017]) and land use (based on Hurtt et al. [2020]) in 10-km zones around the protected areas were rescaled from 0 to 10 (Appendix S3, Eq. 1) based on Venter et al.'s (2016) scheme. Each protected area's biome is derived from mean state variables simulated by aDGVM.
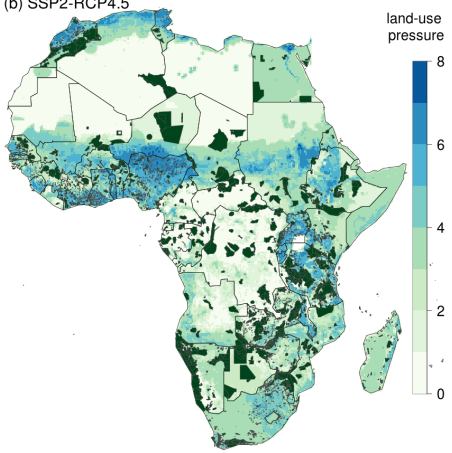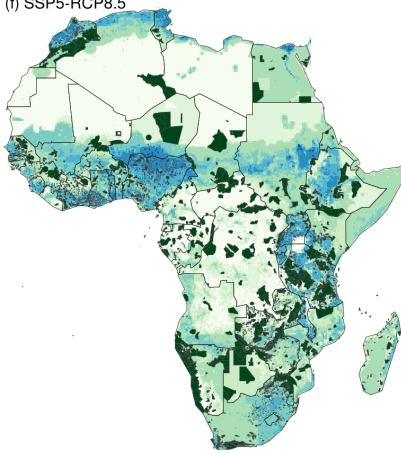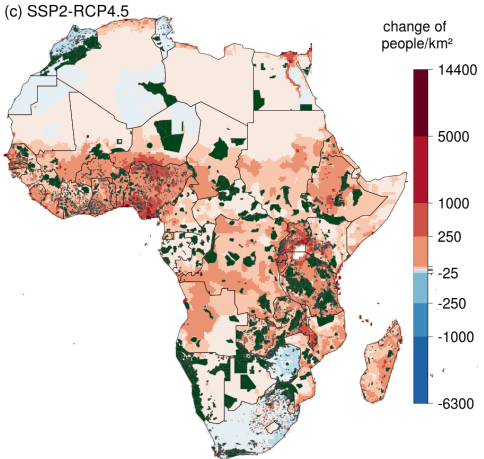
(a) SSP2-RCP4.5

people/km²

(b) SSP2-RCP4.5

land-use
pressure

(c) SSP2-RCP4.5

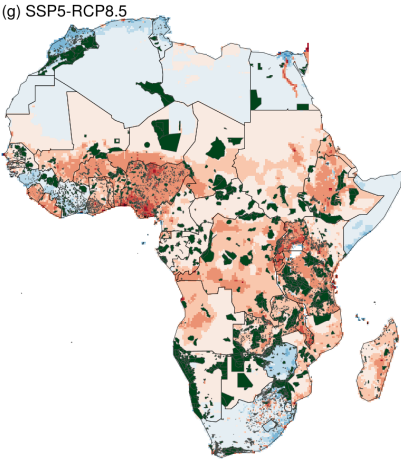change of
people/km²
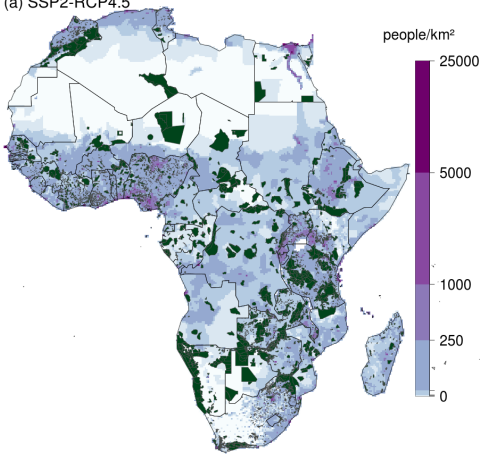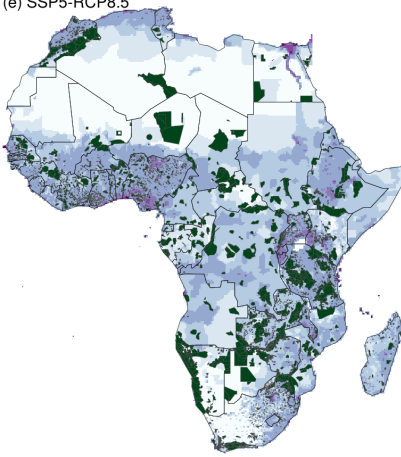
(d) SSP2-RCP4.5

land-use
pressure change
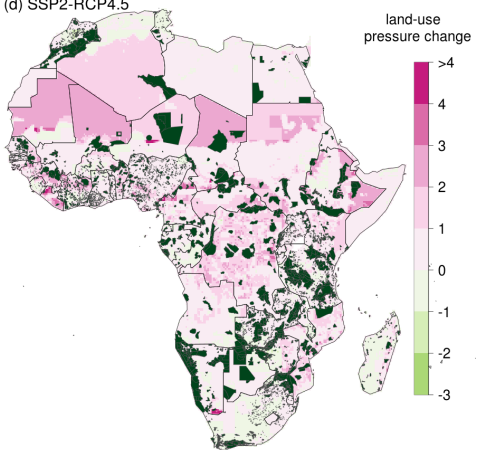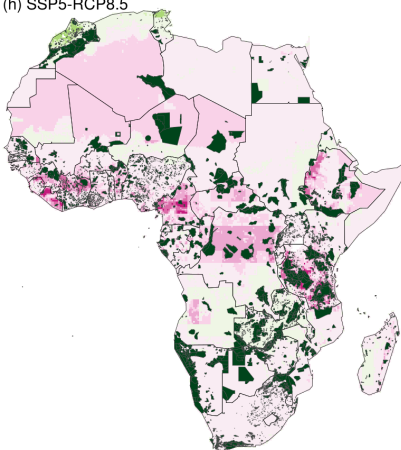
(e) SSP5-RCP8.5

(f) SSP5-RCP8.5
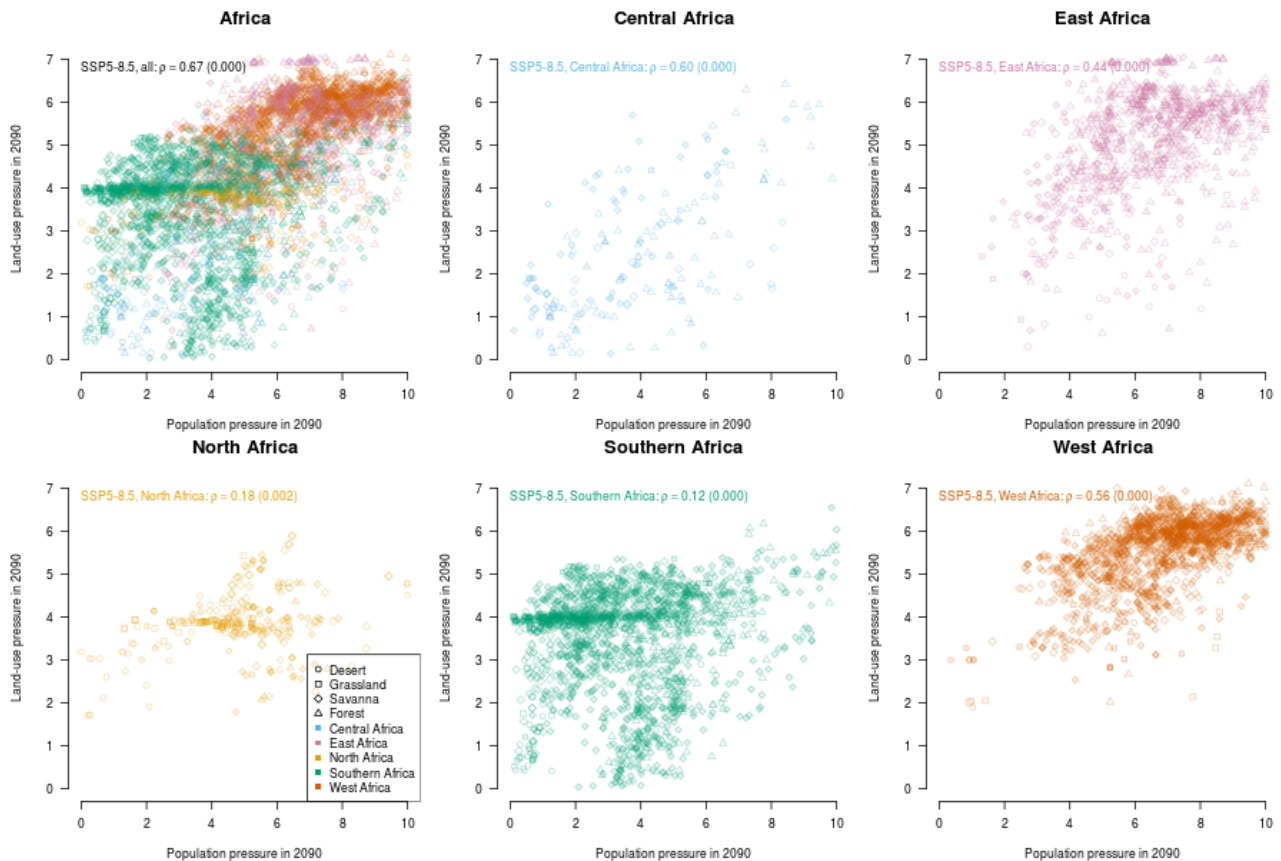
(g) SSP5-RCP8.5

(h) SSP5-RCP8.5

Appendix S8 (a, e) Population density, and (b, f) land-use pressure in 2020 and their change until 2090 ([c, g] population density change; [d, h] land use change) in Africa and protected areas under SSP-RCP scenarios (c, d, left) SSP2-RCP4.5 and (g, h, right) SSP5-RCP8.5 (RCP, representative concentration pathways; SSP, shared socioeconomic pathways). Population projections were derived from Gao (2017). Land use (based on Hurtt et al., 2020) pressure is weighted based on an adapted scheme from Venter et al. (2016) where higher numbers represent higher land-use pressure (see Appendix S3). Protected areas used in this study are mapped on top for each panel.
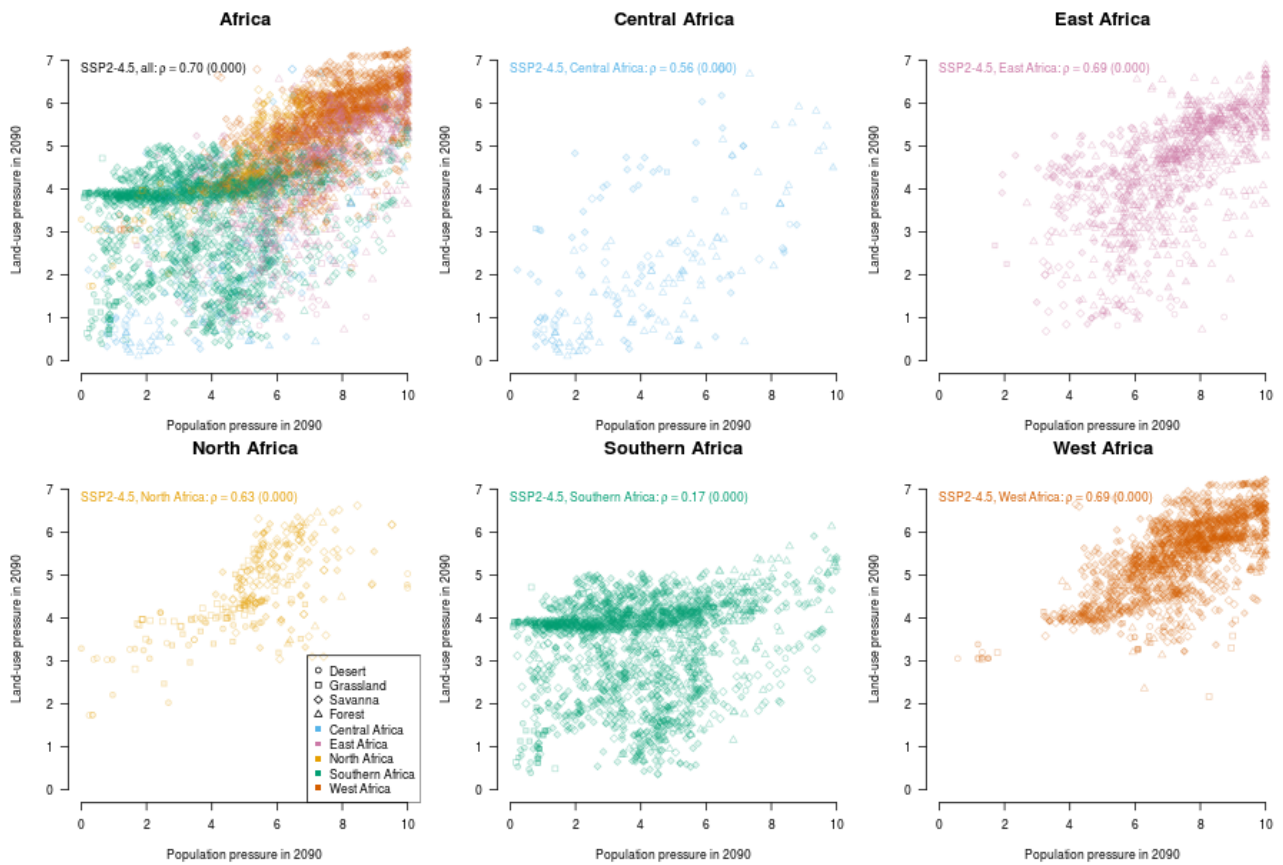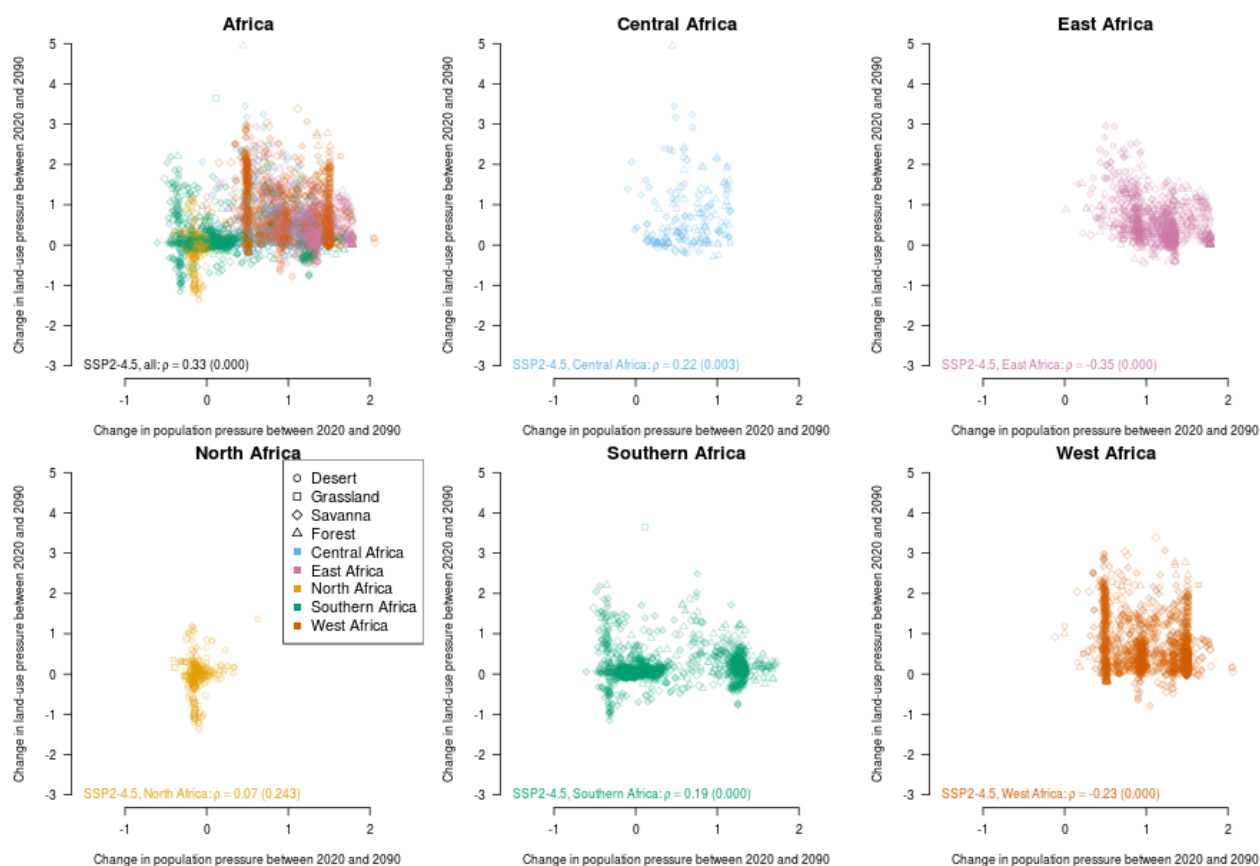
Appendix S9 Population and land-use pressure in 10-km-buffers around protected areas for SSP2-RCP4.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Land use (based on Hurtt et al., 2020) and population (based on Gao, 2017) pressures were weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all
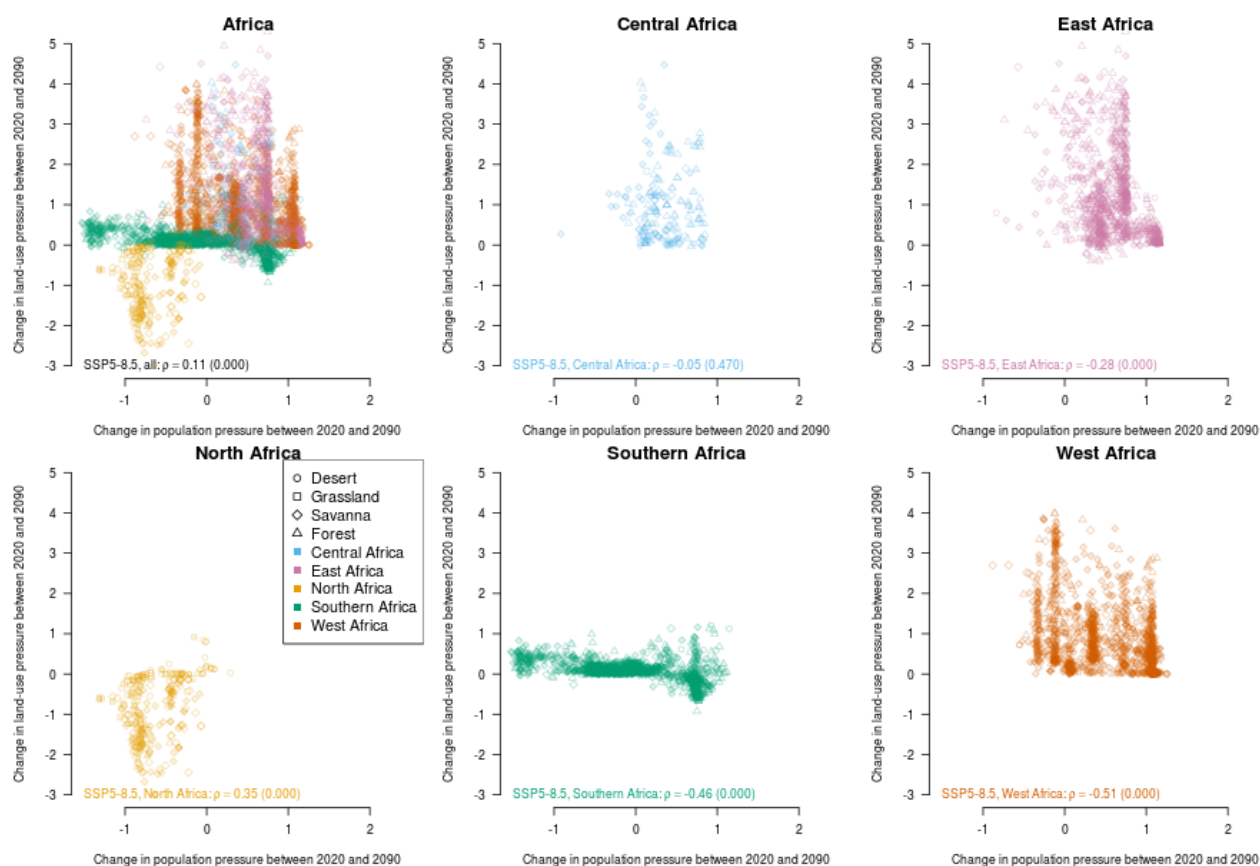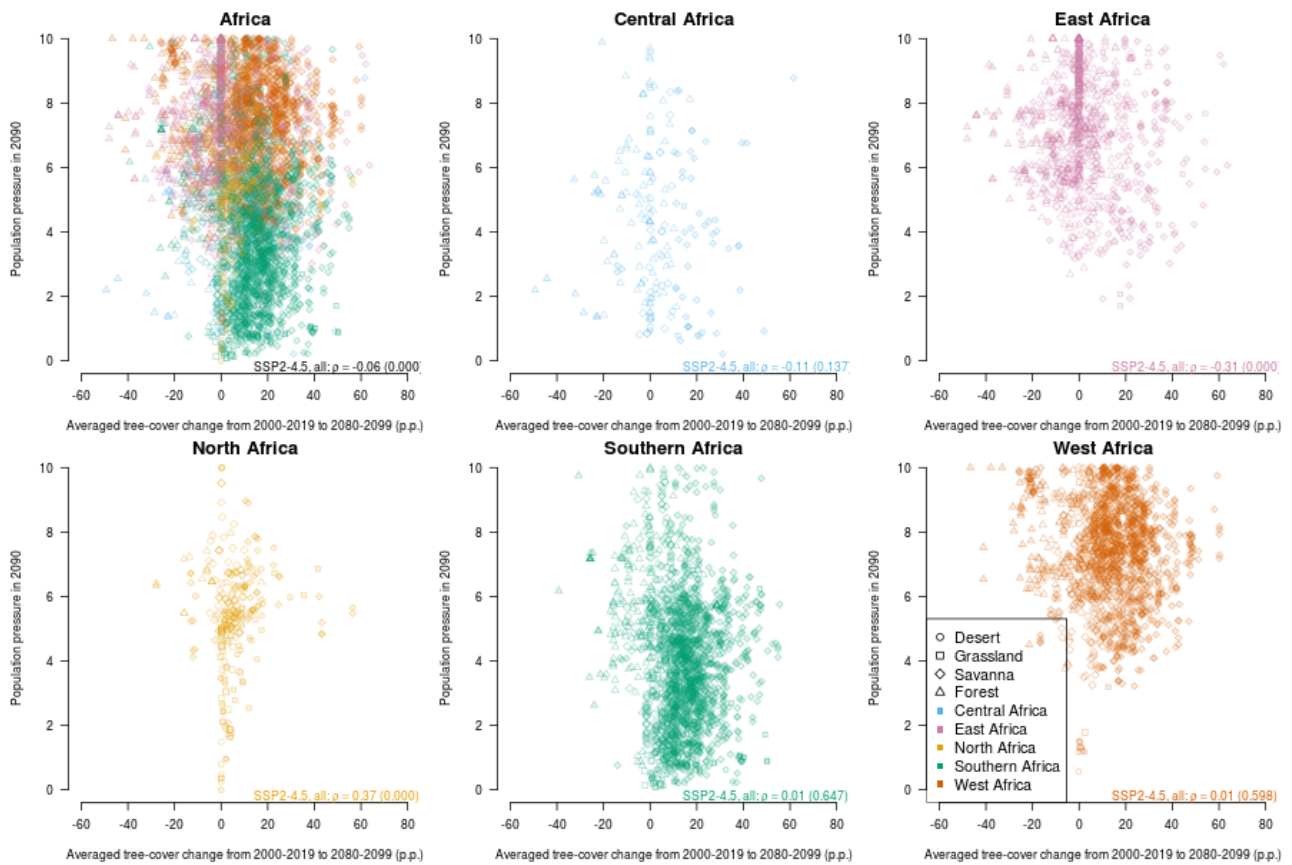
panels of the figure.

Appendix S10 Population and land-use pressure in 10-km-buffers around protected areas for SSP5-RCP8.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Land use (based on Hurtt et al., 2020) and population (based on Gao, 2017) pressures were weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.

Appendix S11 Change in population and land-use pressure in 10-km-buffers around protected areas for SSP2-RCP4.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Change in land use (based on Hurtt et al., 2020) and population (based on Gao, 2017) pressures were weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.
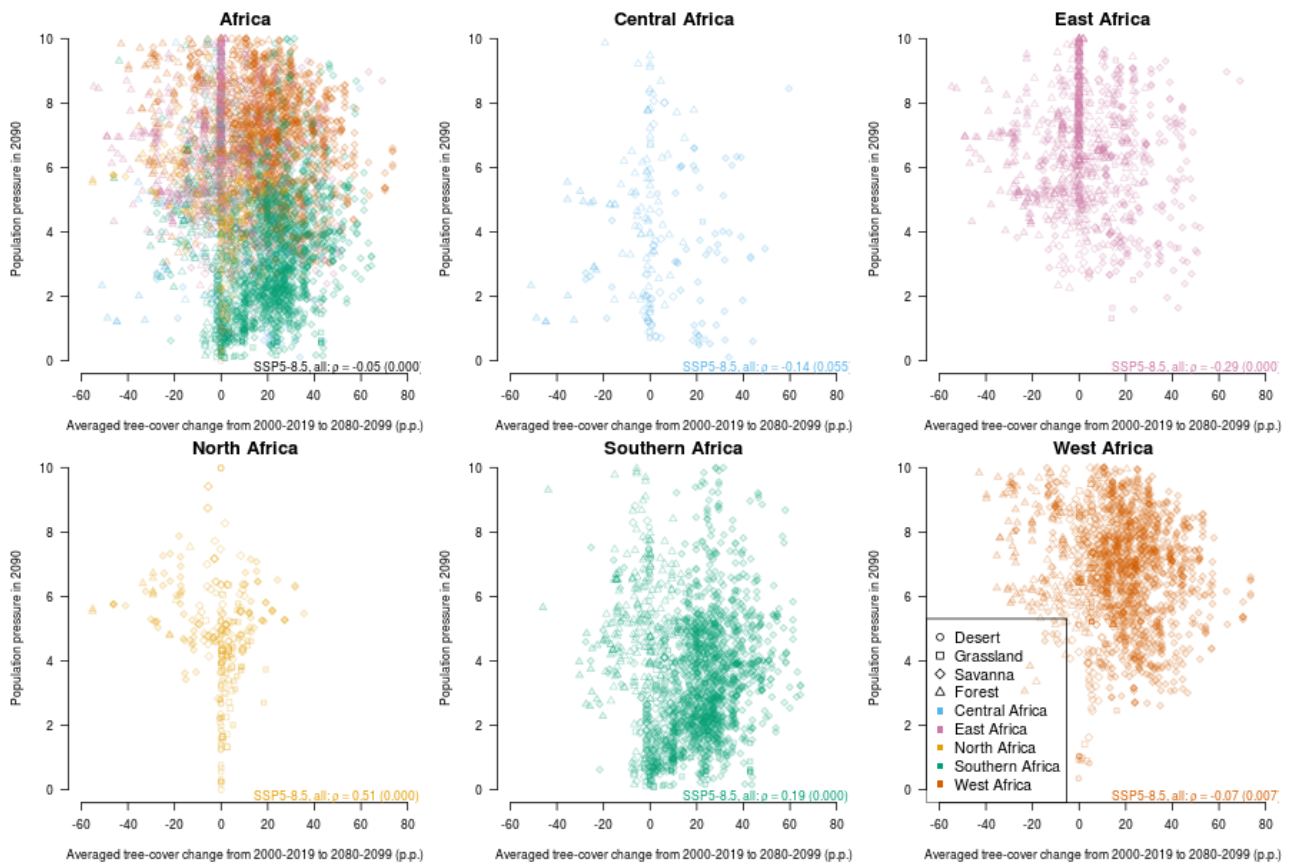
Appendix S12 Change in population and land-use pressure in 10-km-buffers around protected areas for SSP5-RCP8.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Change in land use (based on Hurtt et al., 2020) and population (based on Gao, 2017) pressures were weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.

Appendix S13 Tree-cover change in protected areas and population pressure in 10-km-buffers for SSP2-RCP4.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Population (based on Gao, 2017) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.
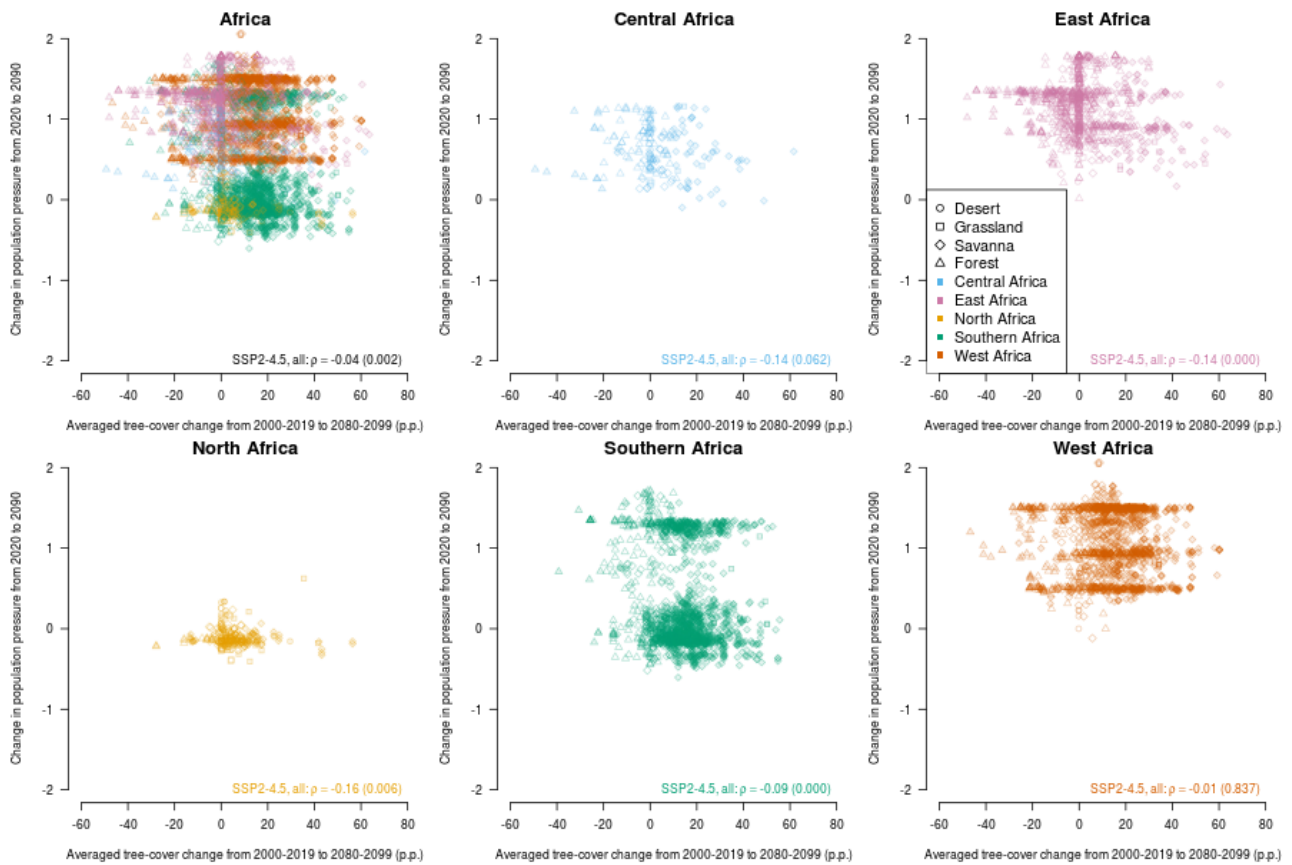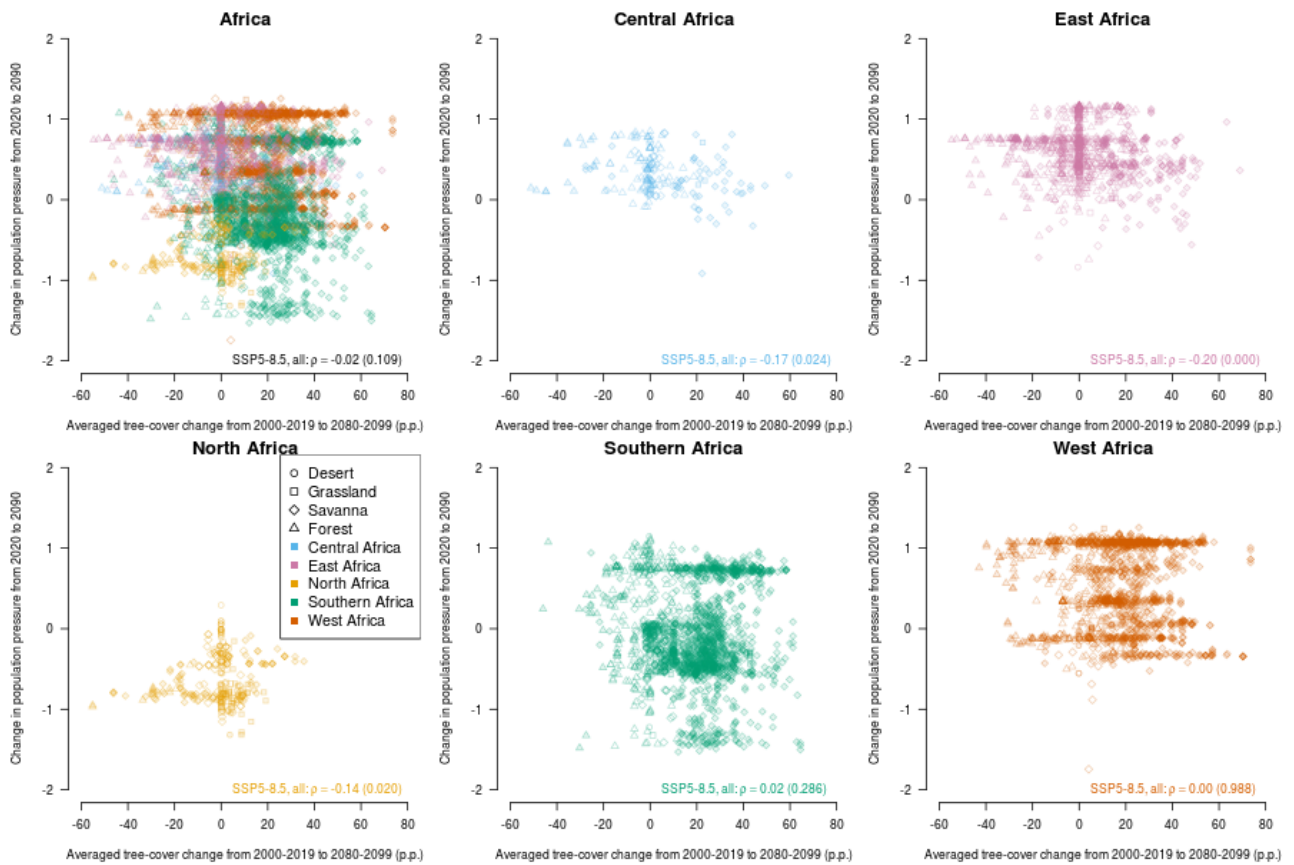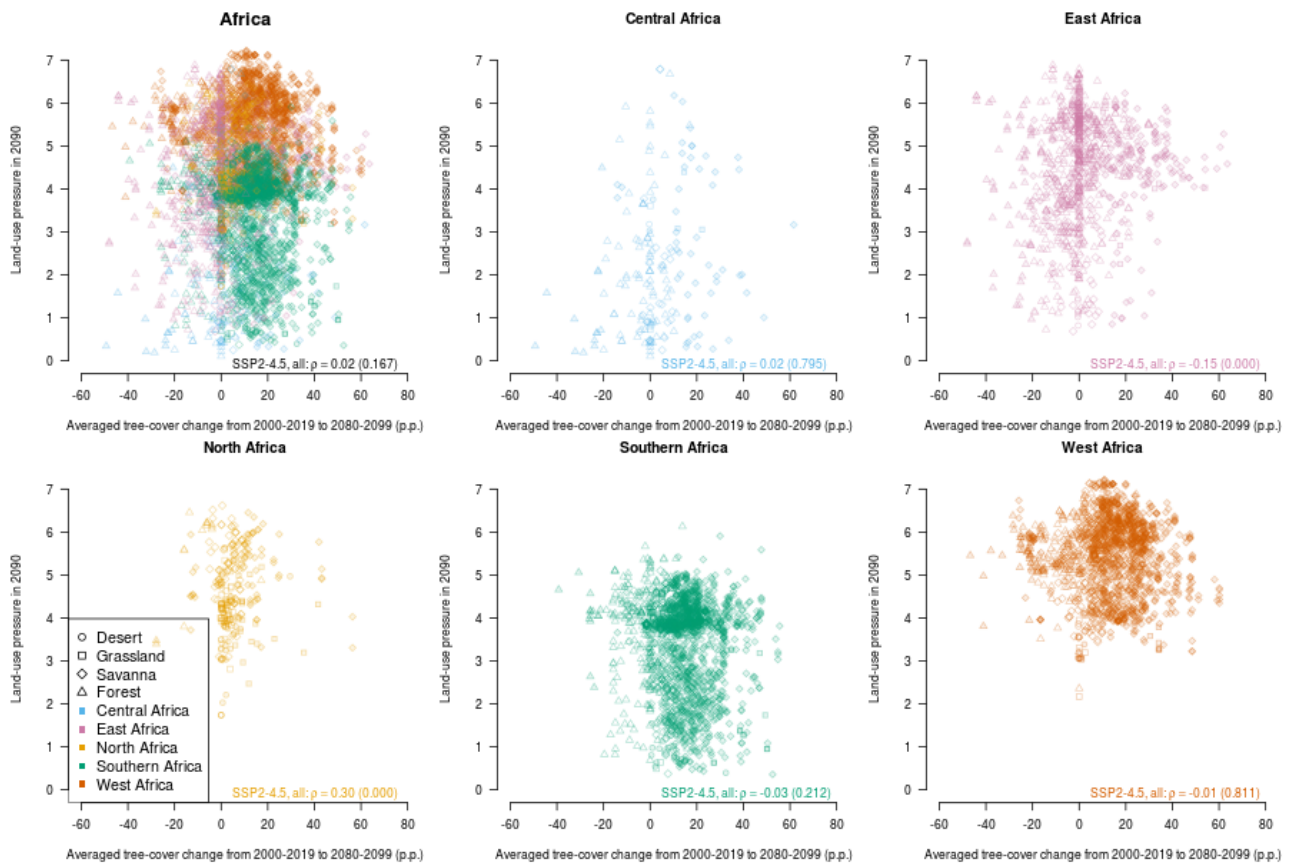
Appendix S14 Tree-cover change in protected areas and population pressure in 10-km-buffers for SSP5-RCP8.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Population (based on Gao, 2017) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.

Appendix S15 Tree-cover change in protected areas and population pressure change in 10-km-buffers for SSP2-RCP4.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Population (based on Gao, 2017) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.
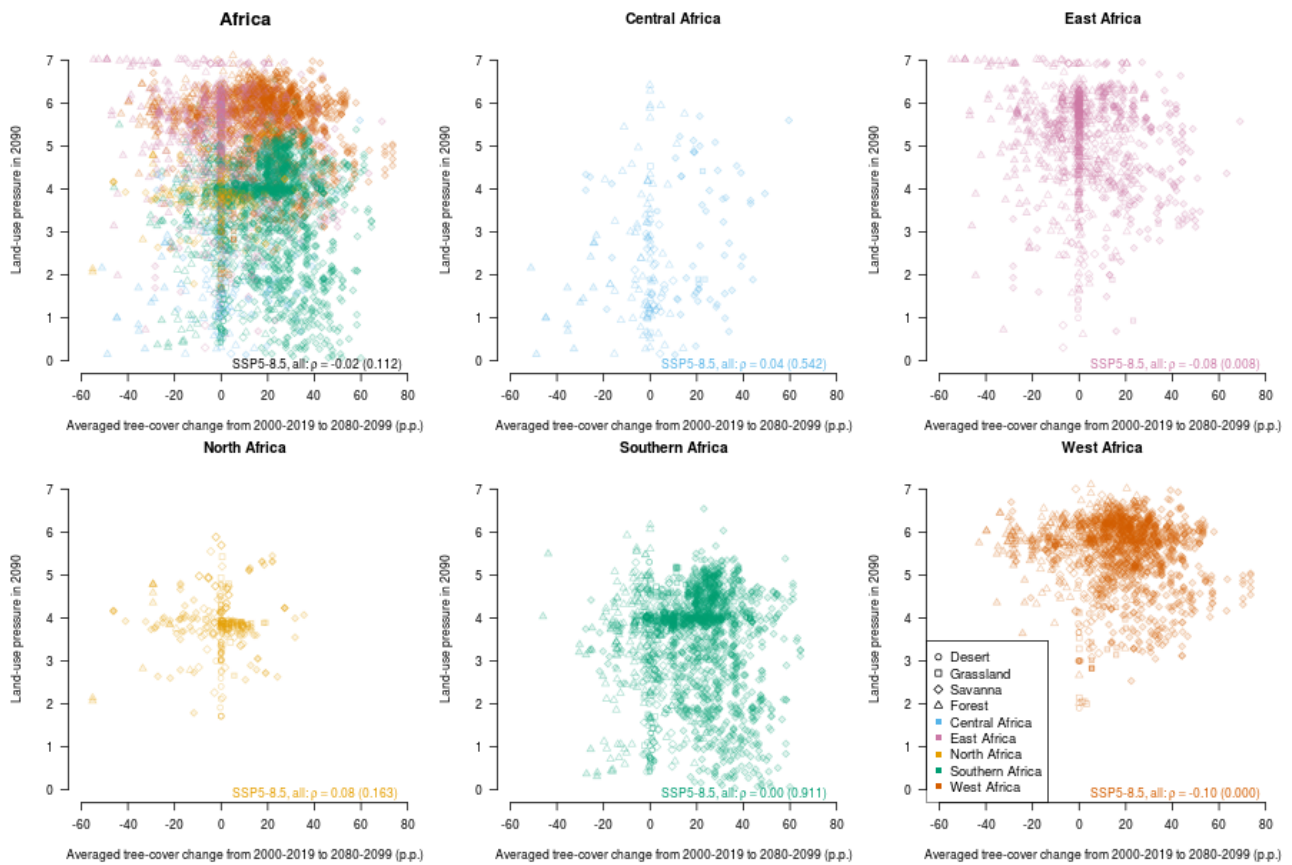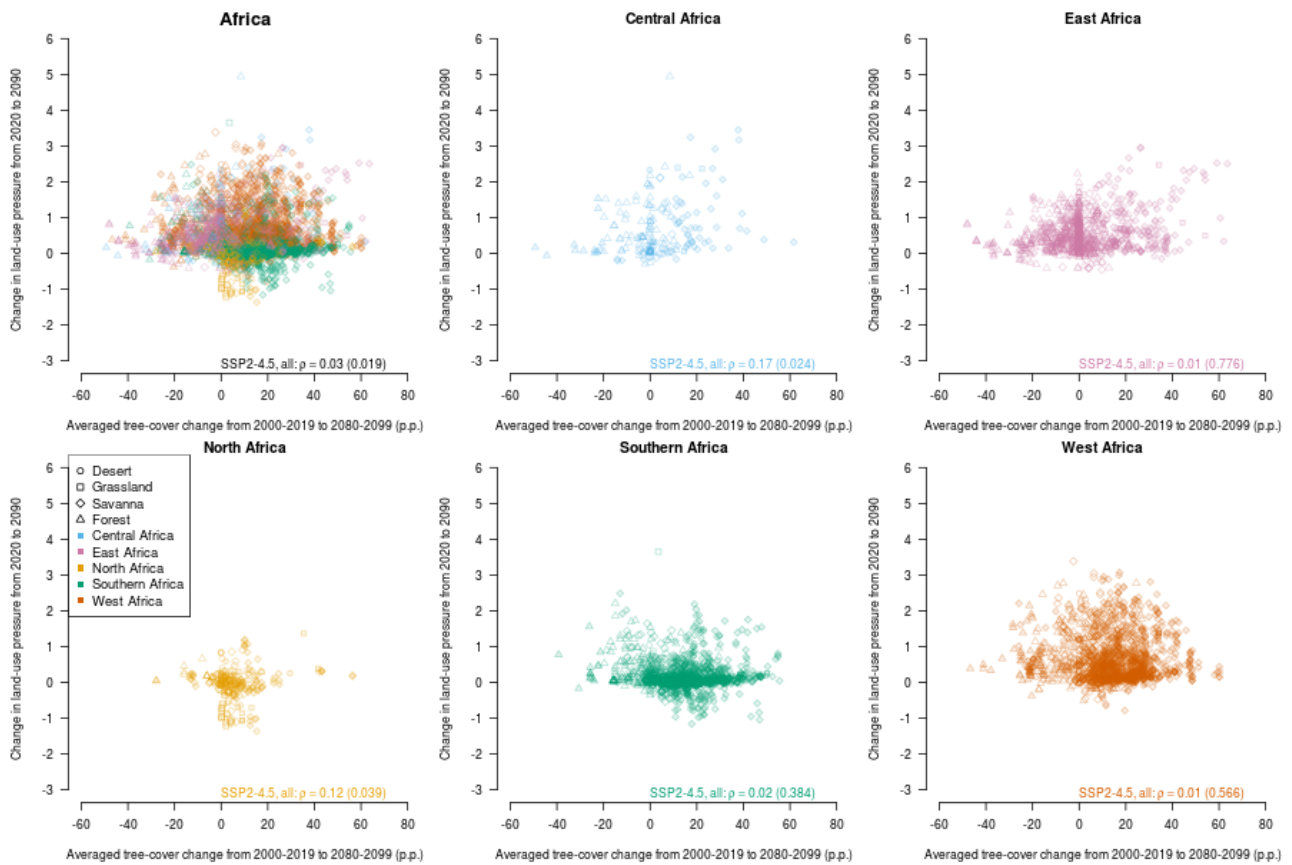
Appendix S16 Tree-cover change in protected areas and population pressure change in 10-km-buffers for SSP5-RCP8.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Population (based on Gao, 2017) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.
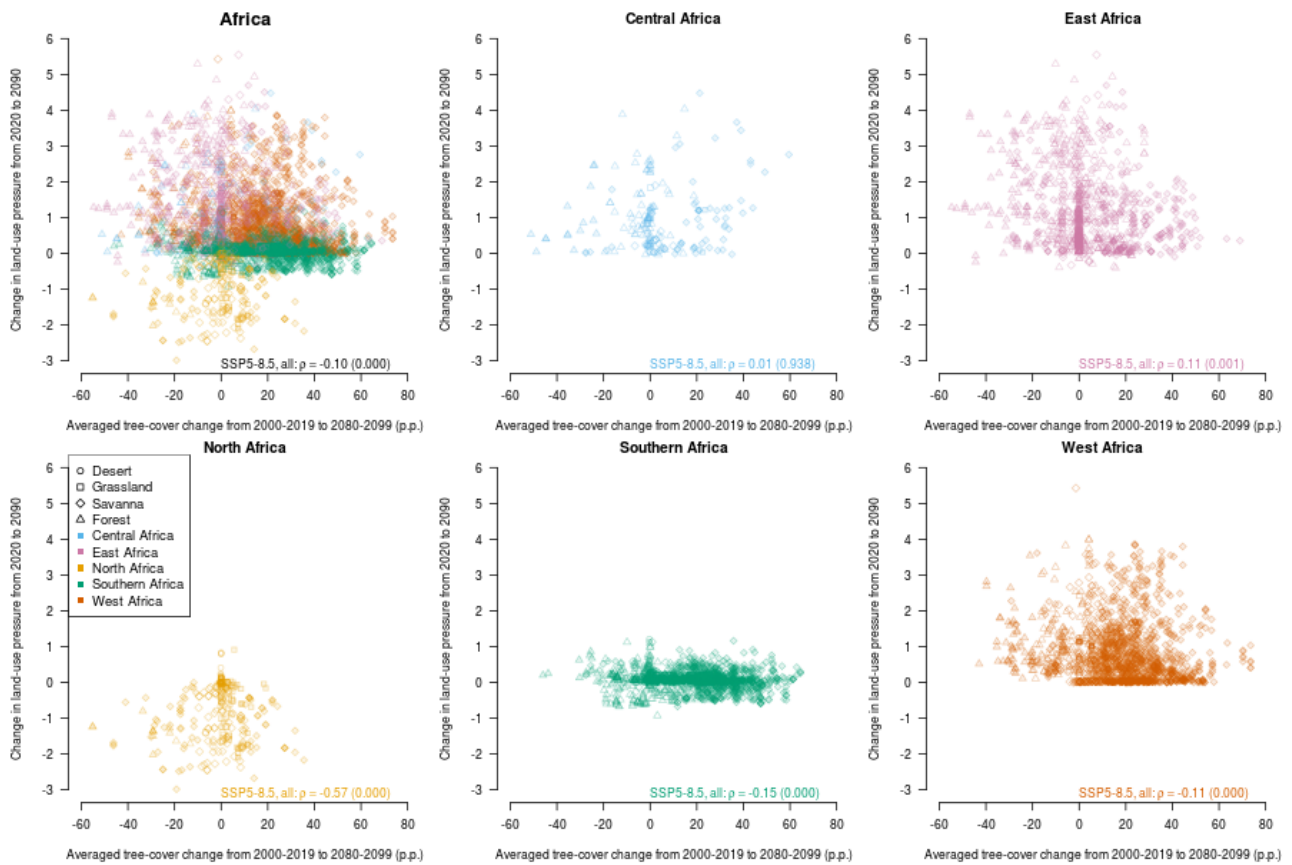
Appendix S17 Tree-cover change in protected areas and land-use pressure in 10-km-buffers for SSP2-RCP4.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Land use (based on Hurtt et al., 2020) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.
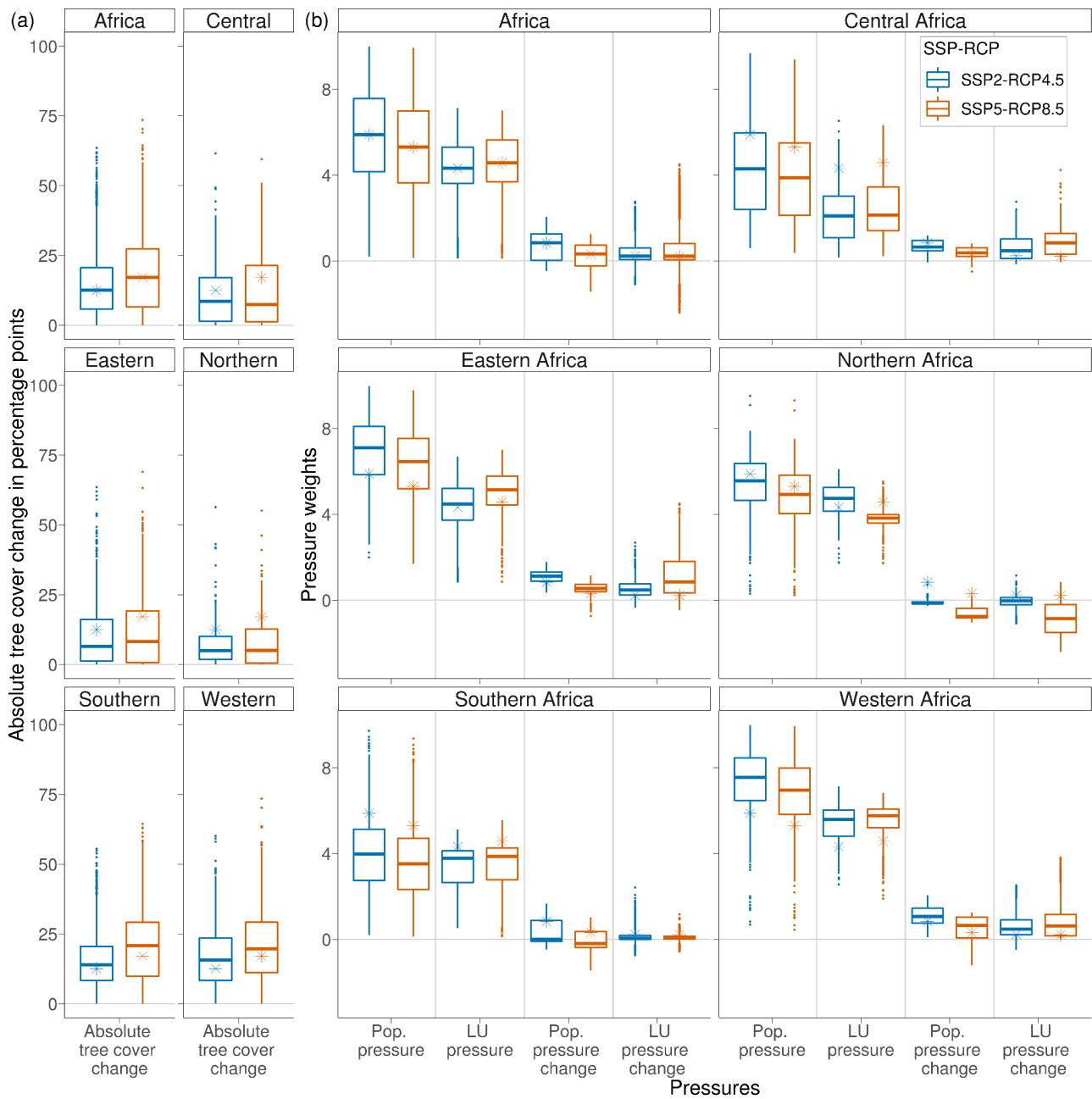
Appendix S18 Tree-cover change in protected areas and land-use pressure in 10-km-buffers for SSP5-RCP8.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Land use (based on Hurtt et al., 2020) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.

Appendix S19 Tree-cover change in protected areas and change in land-use pressure in 10-km-buffers for SSP2-RCP4.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Land use (based on Hurtt et al., 2020) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.

Appendix S20 Tree-cover change in protected areas and change in land-use pressure in 10-km-buffers for SSP5-RCP8.5 grouped by region and biome with habitat loss. Each protected area is represented by a point. Colours represent the regions that the protected areas are in (Appendix S6). The shape of a point represents the mean biome in the protected area as classified using the scheme in Appendix S4. Filled points represent protected areas projected to show habitat loss following the classification in Appendix S5. Tree-cover change was derived from simulations with the adaptive Dynamic Global Vegetation Model (aDGVM, Martens et al., 2021). Land use (based on Hurtt et al., 2020) pressure was weighted based on an adapted scheme from Venter et al. (2016). The shown legend applies to all panels of the figure.

Appendix S21 Climate-driven tree-cover changes on protected areas (a) and socio-economic pressures in 50-km buffers around protected (b) areas by region under SSP2-RCP4.5 and SSP5-RCP8.5. See Fig. 2 for the same figure with the 10-km buffer used in the study. The box plots are based on median, 25% and 75% quantile, and smallest (largest) value greater (less) than or equal to 1.5 times the interquartile range of protected areas in each group. Asterisks are the respective continental scale medians from the 'Africa' panel for each pressure and scenario combination. Regions are based on regions defined by the African Union (Appendix S6). Tree-cover change in percentage points (a) is derived from the adaptive dynamic global vegetation model (aDGVM, based on results from Martens et al., 2021). Absolute values for tree-cover change values from 2000-2019 to 2080-2099

are used because both negative and positive tree-cover changes represent climate-driven vegetation changes. For (b), the socio-economic pressures population (based on Gao, 2017) and land use (based on Hurtt et al., 2020) in 50-km buffers around the protected areas were rescaled to 0-10 (Appendix S3, Equ. 1) using a scheme from Venter et al. (2016). Grey vertical lines separate each socio-economic pressure and their changes. See Appendix S7 for pressures on protected areas by biome and region under both scenarios. See Appendix S7 for pressures on protected areas by biome and region under both scenarios. aDGVM - adaptive Dynamic Global Vegetation Model; LU - land use; Pop. - Population; RCP - representative concentration pathway; SSP - shared socio-economic pathways.