**Documentation PLACES code for dynamically simulating ecosystem services responses to land use scenarios**

Lines in calculation.R

1) Creation of land use map – from line 62

The raster with the selectable hexagons (each has their own id) is read into R and reclassified based on the allocation of land use types on the individual hexagons. The resulting land use scenario map is exported for potential later use.

For each land use type and ecosystem service consequence, a numerical ID is selected. No numerical ID should be 1 to avoid errors in the calculation later.

Based on the extent of the land use map, two useful maps that function as masks are created, one with all values being 0 and one with all values being NA.

2) Ecosystem service consequence mapping

2.1 Human Health and NH3 deposition from line 90

First, all non-agricultural land use is set to NA in a new raster. Then, the available patches of all agricultural land uses are calculated with a function from the landscapemetrics package.

In the next steps, for each agriculture type, an if-statement checks whether the agriculture type was present in the landscape, and a distance raster from this agriculture type is calculated. The distance raster is used to calculate a distance decay process for PM2.5 transport and NH3 deposition. The initial emission/deposition value of PM2.5 and NH3 from each farm type is multiplied with the distance from the farm type and an exponential decay variable.

To account for accumulated emissions, the patch areas of the farm type patches are calculated and for patches larger than 350m², the emissions/depositions are calculated once again for these patches. In turn, the calculation accounts for overlapping emission sources through counting large patches of the same agricultural land use twice. Lastly, the if-statement is closed with else-statements to ensure that the values are set to 0 if the respective agriculture type is not present in the land use map.

Finally, all PM2.5 emissions from each agriculture type are summed up and masked for the study area. The values for PM2.5 concentration are masked out for all land uses except for urban areas, where they show up. After a sensitivity analysis of the respective best on worst case for this ecosystem service, the current scenario is normalized between the lowest and highest encountered concentration values from this sensitivity analysis.

The same procedure is taken for the NH3 deposition. All deposition rasters from each agriculture type are summed up, masked to the study area and masked to show only on nature areas. The resulting raster is normalized with values from the previous sensitivity analysis.

2.2 Surface water eutrophication – from line 281

For water eutrophication in surface water bodies, a soil map is loaded that shows which soil is predominant in each hexagon. Then, the leaching raster is prepared as a raster of value 0 everywhere. Step by step, the leaching mass of each agriculture type on each soil type (sand or clay) is assigned to the leaching raster at the location of the agriculture type on the respective soil. Next, a csv table is loaded that includes the ID numbers of each sub-watershed in the study area, as well as a raster with each sub-watershed and another raster that was calculated to show the distance in each sub-watershed to the surface water entry point of the watershed.

Next, the leaching raster and the distance weight raster are used to calculate what share of leaching mass arrives in the water body entry point. The sum of this mass is written into each watershed in a dataframe. The land use map is checked to count if additional natural land use was placed in the watersheds. The share of this additional nature is multiplied with its retention capacity (here 70%). The final leaching mass is reduced by the retained mass.

The watershed entry points are loaded as a raster and the final leaching mass is attached to the respective point. To smooth out the visualization, a focal mean over all water area is calculated. The produced raster is masked to the study area and to only show water. Finally, the leaching mass in surface water bodies is normalized by best and wors case values attained by a previous sensitivity analysis.

2.3 Water stress in nature – from line 328

First, a groundwater map is loaded that shows the predominant category of groundwater levels per hexagon. A new raster is created into which groundwater extraction ID are assigned to locations with a combination of agriculture type and groundwater level category. For each ID, an if-statement creates a new extraction raster and a distance raster for this agriculture type at this groundwater level category. The extraction value for this case is multiplied with the distance and an exponential decay function. If the case does not exist in the land use scenario at hand, the extraction values in the raster are set to zero. This procedure is repeated for each extraction case.

All extraction rasters are summed up, and clipped to the study area. A raster with relative sensitivity zones in the study area is loaded and multiplied with the extraction raster. The final extraction values are masked to show up only in nature and are finally normalized according to wors and best case values from the sensitivity analysis.

2.4 Habitat fragmentation – from line 490

From previous analyses, several rasters are loaded, including the patches of fixed natural land use, the habitat fragmentation scores of fixed land uses, and the rasters for best and worst scenarios. Then, the number of patches of nature is retrieved and the naturalness of each land use is assigned in a dataframe. Also, the buffers around each fixed land use are loaded.

In a for-loop, the area around each patch is defined and the amount of each land use within this buffer area is calculated and the subsequent area-weighted score of naturalness within the surrounding buffer of the patch is calculated. All scores are masked to the natural land uses and the scores from the fixed land uses are added. The final value is normalized using the previously loaded best and worst case scenario.

2.5 Loss of recreational value – from line 527

First, the in-situ recreational quality values are assigned to each land use in the map. Then, an if-statement check if Agroparks are in the land use map and creates a 2.5km buffer around them. The loss of recreational value from noise or smell or industrial buildings is simulated as a distance decay function, with increasing loss values closer o the Agropark. A similar function is executed for all intensive livestock farms. For additional nature areas, a positive effect on the recreational value in its surroundings is calculated.

Then, all spatial recreational changes are summed together and added to the in-situ recreational map. The final map is masked to show values on agricultural land and nature and is normalized by worst and best case values.

3. Scores – from line 577

The final ecosystem service consequence values are turned into scores between 0 and 100 based on the average raster value for all cell that encounter the consequence. The worst case scenarios are used to calculate the worst case average scores to correctly calculate the scores of the current round.

Next, a dataframe is created for the score and the name of the consequence. The dataframe is then used to create a spider plot that shows how the ecosystem service consequences performed compared to the worst and best case. Labels are added for each consequence. The plot is saved and uploaded into the tool interface.