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Methodologies to assess human-induced land change processes relevant to land degradation under different scenarios of climate change and socio-economic conditions

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Desertification, Land Degradation and Drought (DLDD), and bio-physical modelling for crop yield estimation in Latin America under a changing climate
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EUROCLIMA facilitates the integration of climate change mitigation and adaptation strategies and measures into Latin American public development policies and plans. The objectives are to contribute to poverty reduction of the Latin American population by reducing their environmental and social vulnerability to climate change and to reinforce resilience of the Latin America region to climate change and promote opportunities for green growth.
Within this programme, the Joint Research Centre (JRC) strengthens and disseminates knowledge on Desertification, Land Degradation and Drought (DLDD) and develops bio-physical and bio-economic models for agricultural systems and policy analysis for Latin America.

Abstract

Land degradation is a complex concept encompassing a variety of processes, natural or human induced, that affect the functioning of the land and the providing of ecosystem services. We propose a methodology to evaluate the impacts of future scenarios of socio-economic pathways and representative forcing pathways on land degradation. We selected a limited set of human induced land change processes that could potentially lead to land degradation and combined them spatially for each scenario. We compared the concurring variables between scenarios and over time to assess the sensitivity of the scenarios to the land change processes relevant for land degradation. With the processes or potential issues and the scenarios used in this study on Latin America end the Caribbean, we found (1) that the differences over time were much larger than those between scenarios and (2) that the effect of climate change was negligible compared to the socio-economic effect. Further investigation with more variables dependent on the climate scenarios is needed to confirm the results.

1 Introduction

Land degradation is a complex concept encompassing a variety of processes, natural or human induced, that affect the functioning of the land and the providing of ecosystem services. Land is considered according to the earth's critical zone concept incorporating the atmosphere, biosphere (including anthropogenic socio-economic issues), pedosphere, and lithosphere interfaces and interactions. Within this land context and given the complexity underlying land degradation, it is now accepted not to be amenable to be represented in a single global map that satisfies all views or needs. Indeed, similar outcomes in one area versus another suggest an equivalence that ignores the physical, biological, social and economic causes that brought about that singular outcome.

In a previous study, we proposed a methodology to interpret and combine maps of the Human-Environment system productivity into dedicated land degradation maps [1]. The objective was to create an indicator that would provide information on how a certain area is affected by a set of potential issues or pressures that can lead to land degradation.

Here, we adapt our methodology to evaluate the impacts of future scenarios of socio-economic pathways and representative concentration pathways on land degradation. Combinations are transparent and without prior assumptions as there is no exact knowledge on the interaction of the land change processes, nor on the impact this might have at various geographic locations. Patterns that are revealed indicate areas where substantial stress on the land resource is to be expected. However, these cannot be interpreted meaningfully without an understanding of the social and economic conditions that brought them about, both locally or globally.

We selected a limited set of biophysical and socio-economic variables relevant to land degradation for which we could make future projections according to the scenarios. We combined them spatially for each scenario over three decades. We compared the variables across scenarios to assess the sensitivity of the human induced land change processes to the proposed scenarios.

2 Methods

2.1 Converging evidence: combining biophysical and socio-economic variables relevant to land degradation

Population increase, low income, land productivity decline, livestock pressure, inadequate farming practices and expansion of agriculture (in marginal areas and/or at the cost of rangeland), water stress, fires, deforestation and drought are a number of pressures that currently affect the land resources. Local impacts are reflected in erosion, soil nutrient depletion, soil carbon losses, water shortage resulting in below average yields, creating "yield gaps". Based on the principle that evidence from independent, unrelated sources can "converge" and lead to strong conclusions, we compile maps in which stratified data are combined. Combinations are transparent and without prior assumptions as there is no exact knowledge on the interaction of the land change processes, nor on the impact this might have at various geographic locations. Patterns that are revealed indicate areas where substantial stress on the land resource is to be expected. However, these cannot be interpreted meaningfully without an understanding of the social and economic conditions that brought them about, both locally or globally. The convergence of evidence relies on two steps. First, the study area is stratified into a number of classes based on the user's interest, for example land use. Second, for each class, the zonal medians of each variable are calculated. The data are then reclassified as being above or below the zonal median, taking into account the expected effect of the pressure on the land (positive or negative). The resulting layers have values of 0 and 1. They are summed to give the number of concomitant issues. The processing is illustrated at Figure 2.1.

2.2 Stratification

In this particular case, the stratification was operated with an unsupervised clustering of the 2010 land cover share of cropland, pasture, forest and urban [2, 3]. Partition around ten medoids was done using `clara` function of R package `cluster`[4]. The algorithm randomly selects 500 sub-datasets of 1000 observations each and partitions them into 10 clusters, which minimize the sum of the dissimilarities of the observations to their closest representative object (medoid). Using the euclidean distance as metric, the dissimilarity between two observations i and j over p variables can be written:

$$d(i,j) = \sqrt{\frac{\sum_{f=1}^{p} (x_{if} - x_{jf})^2}{p}} \tag{2.1}$$

where x_{if} are observations of variable $f \in [1, p]$ [5]. Once the medoids have been found for each sub-dataset, the entire dataset is partitioned by assigning observations to their closest medoid. The mean dissimilarities inside clusters are calculated for each of the 500 sub-datasets. The one for which the dissimilarities between observations and medoids are minimal is kept for the final partition.

2.3 Selecting key variables and scenarios

The proposed methodology consists in combining representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs) scenarios for which spatially distributed projections of a set of land change processes relevant to land degradation are available. The scenarios can then be compared. Projections of population density [6, 7], decadal population change, gross domestic product [8], water stress [9] and land use transitions [2, 3] were used as potential variables and integrated in the analysis. Table 2.1 summarizes information about the datasets.

We chose the scenarios based on the available data from the Aqueduct water stress projections that were developed according to a combination of projected water supply, itself relying on change in climate

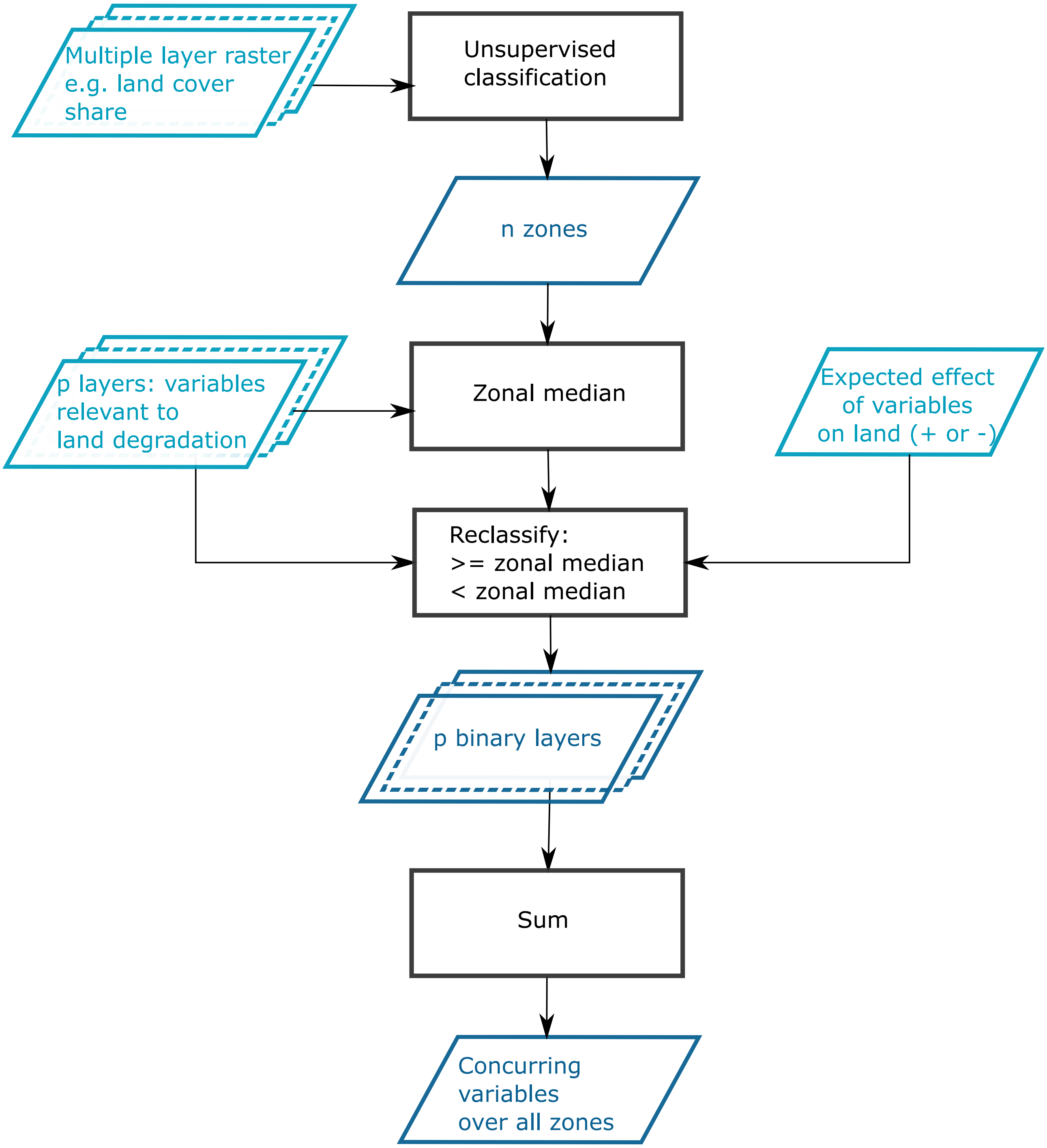

Figure 2.1: Convergence of evidence data processing

factors and water demand underpinned by change in socio-economic drivers" [9].
RCPs are scenarios of the increase in radiative forcing through 2100. They are used to drive the climate factors in the General Circulation Models (GCMs).

- RCP8.5 is a "business-as-usual" scenario of relatively unconstrained emissions with global mean temperature increases of 2.6 to 4.8 °C by 2100 relative to 1986-2005 levels.
- RCP4.5 represents a "cautiously optimistic" scenario with temperatures rising of 1.1 to 2.6 °C by 2100.

SSPs are scenarios of socio-economic drivers.

- SSP2 is the "middle-of-the-road" scenario in which improvements in energy intensity continue at historical levels, technological improvements are medium and there is no marked shift in social acceptance.
- SSP3 is a pessimistic scenario where regional rivalry intensifies with higher population growth in developing countries accompanied by slow GDP growth, and a lower rate of urbanization.

Three combinations of these climate and socio-economic scenarios are used: SSP2/RCP4.5, SSP2/RCP8.5 and SSP3/RCP8.5, centred on the following years: 2020, 2030 and 2040. For each scenario and year, we produce maps of the individual variables relevant to land degradation (binary) and of their sum (concurring potential issues).

2.4 Geographical extent

We harmonized the datasets presented above to raster layers, with a cell size of 0.5 degree, in coordinate reference system EPSG:4326 (WGS 84). Population data were aggregated from 0.125 to 0.5 degree by sum. Water stress, available as a vector layer, was rasterized at 0.5 degree. The Harmonized Land Use is distributed at 0.5 degree. The results in this report focus on Latin America and the Caribbean, delimited according to Sustainable Development Goals (SDGs) reporting region (M49Code1: 419). The country borders are based on the Gridded Population of the World v4 [10]. Nevertheless the land use stratification was done at global level so that the results refer to the global pressure levels.

Table 2.1: Datasets used in this analysis as human induced land change processed relevant to land degradation or potential issues

Abbrev.	Description	Threshold	Source
pop	Population density	above class median	[7]
popDif	Decadal population change	above class median	[7]
gdppc	Gross National Product per capita	below class median	[8]
ws	Water stress	above class median	[9]
gfrstDif	Decadal forest cover change	below class median	[2]
gcropDif	Decadal cropland cover change	above class median	[2]

2.5 Comparing scenarios

For a single scenario, the comparison over time can give a indication on which variable might become predominant in the future and in what part of the globe. For a single year, the scenarios can be compared to suggest what variable would matter most when following a particular pathway.
We compare the scenarios by (1) mapping the differences between the concurring variables or potential issues for two scenarios and (2) calculating the disagreement D between two maps [11, 12]:

$$D = Map2 - \min(Map1, Map2) \tag{2.2}$$

Where the two maps agree, the values of D are 0. Where the values of $Map2$ are greater than those of $Map1$, the values of D are 1, as illustrated at Table **??**. For each variable j, the average disagreement between two scenarios is obtained by adding the individual values and scaling by the land area:

$$D_{avg,j} = \frac{\sum_i d_{i,j} \times a_i}{\sum_i a_i} \tag{2.3}$$

		Map 2	
		0	1
Map 1	0	0	1
	1	0	0

where $d_{i,j}$ ($i \in [1, N]$) are the pixels of image D_j with their associated land area a_i. The overall disagreement is obtained by summing all variables :

$$D_{avg} = \sum_j D_{avg,j} \tag{2.4}$$

The results are presented in a matrix-like graphic. Given the asymmetric character of the disagreement, the upper triangle represents the global increase in potential pressure on land and the lower triangle represents the global decrease in potential pressure, expressed as fractions of the total land area.

3 Results

3.1 Land use based stratification

The partitioning of the land use share into 10 classes on which the following results are based is shown in Figures 3.1 and 3.2. The ternary representation shows the variation inside the classes while the map shows the geographic distribution of the classes. The colours are RGB combinations of the cropland (red), pasture (blue) and forest (green) share of the medoids.

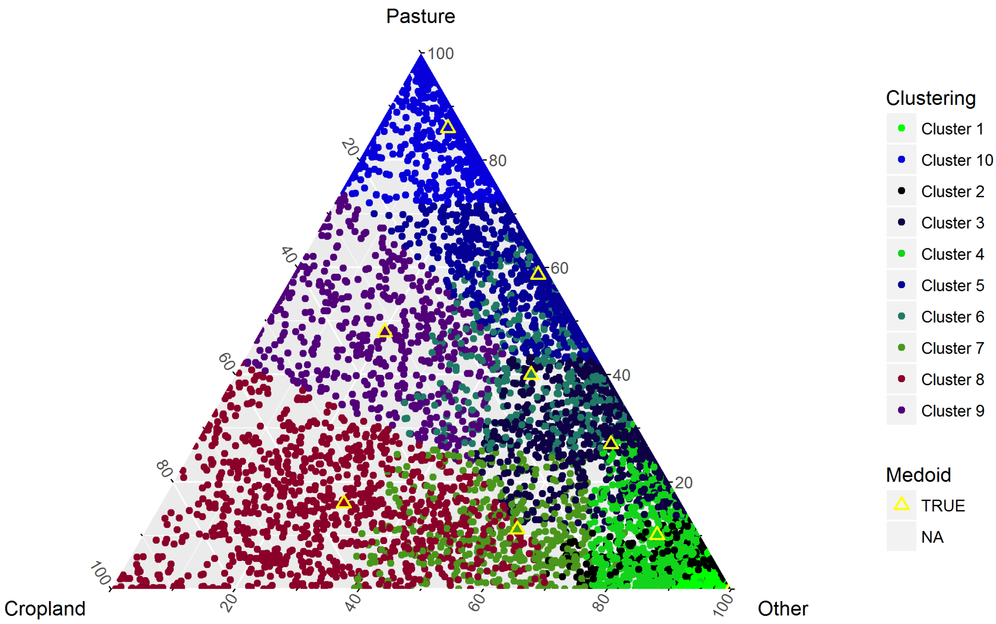

Figure 3.1: Ternary projection of cropland, pasture and other share of land in 2010 for 10000 randomly selected pixels. The colours follow the clusters created by partitioning the data around medoids (yellow triangles) and are constructed as RGB combinations of the the cropland (red), pasture (blue) and forest (green) share of the medoids.

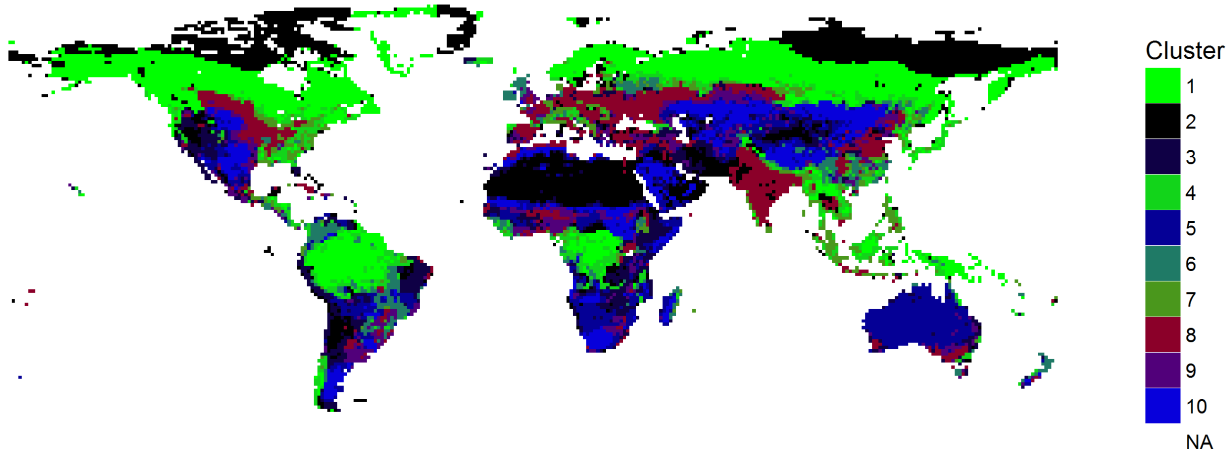

Figure 3.2: Map of the classes obtained by partitioning cropland, pasture, forest and urban share of land in year 2010 [2] around medoids. Colours are RGB combinations of cropland (red), pasture (blue) and forest (green) share of the medoids.

3.2 Concurring variables in 2020

The number of concurring variables in 2020 is similar between the three scenarios (Figures 3.3 and 3.5). We look more in depth in the distribution of potential issues in year 2020 for scenario SSP2/RCP4.5 (Figure 3.4). Half the land mass in Latin America and the Caribbean is concurrently covered by four or more potential issues. The most frequent potential issue is the increase of crop land surface between 2010 and 2020, which is above the global clusters medians on 74 % of the land surface. Next comes the per capita gross domestic product, which is below the median of the global clusters on 64% of the total land area of Latin America and the Caribbean. It is closely followed by population (58 %) and population change between 2010 and 2020 (62 %).
Patagonia and the southern part of the continent seems relatively less threatened than the rest of the continent. Similarly large contiguous areas of central Brazil have no or few issues among the ones studied here. The largest numbers of concurring potential issues are observed in Colombia and Central America. Large contiguous areas of Mexico, Guatemala, Honduras, El Salvador, Costa Rica, Colombia, Peru and around the common borders of Bolivia, Chile and Argentina sustain five of the six potential issues.

3.3 Maps of differences between scenarios

Generally, the differences in time for a same scenario (Figure 3.5) are larger than between scenarios for a same year (Figure 3.6). There are more concurring pressures in 2030 than in 2020, on the East of South America and in Chile, while the pressures ease on the west coast (Peru) and in central Brazil (Fig. 3.5 a, d and g). The changes between 2030 and 2040 are less strong except with SSP3, where a large area of South East Brazil sees an increase in pressure (Fig. 3.5 b, e and h).
The effect of climate (RCP) is very limited in this analysis, even in the future (Figure 3.6 a, b and c). The effect of SSP is stronger. In 2020, there are no notable difference between scenarios. In 2030, a large area of South East Brazil has one issue less in SSP3 than in SSP2 but that difference disappears in 2040. As time goes, there are more and more places with one issue more in SSP3 compared to SSP2. The single issues responsible for the differences can be examined through the disagreement.

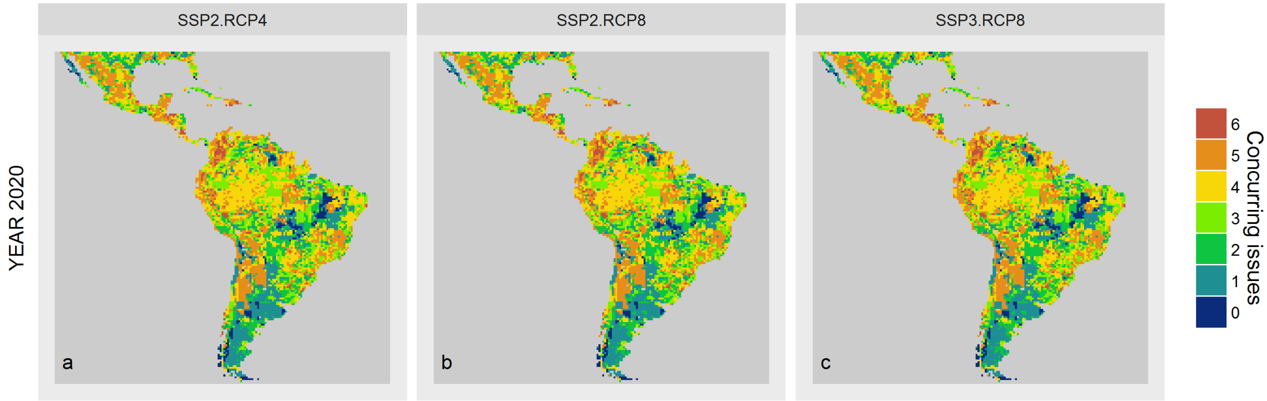

Figure 3.3: Concurring potential issues in year 2020 in the three scenarios. Left: SSP2/RCP4.5, Centre: SSP2/RCP8.5, Right: SSP3/RCP8.5

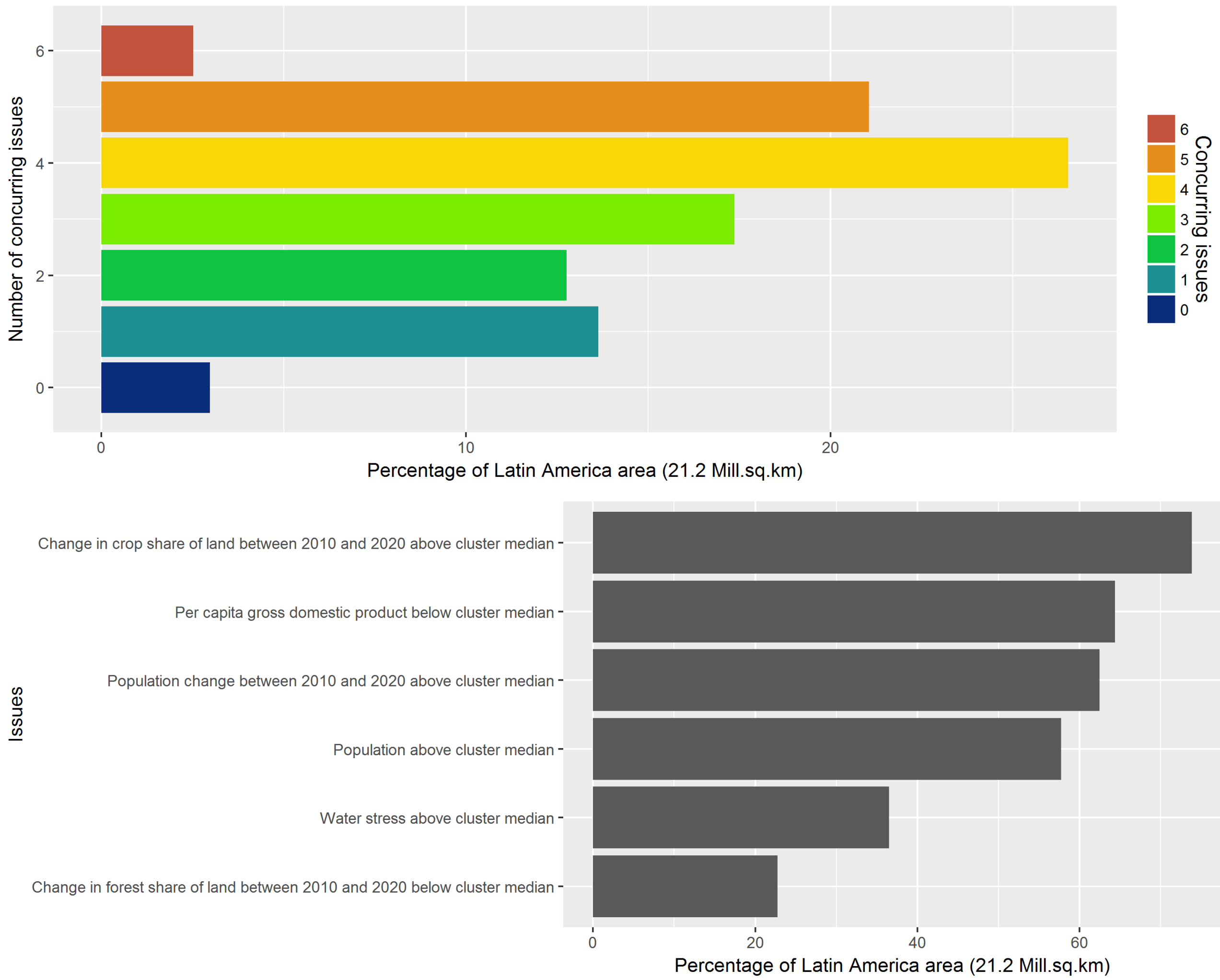

Figure 3.4: Potential issues in year 2020 for scenario SSP2 RCP4.5

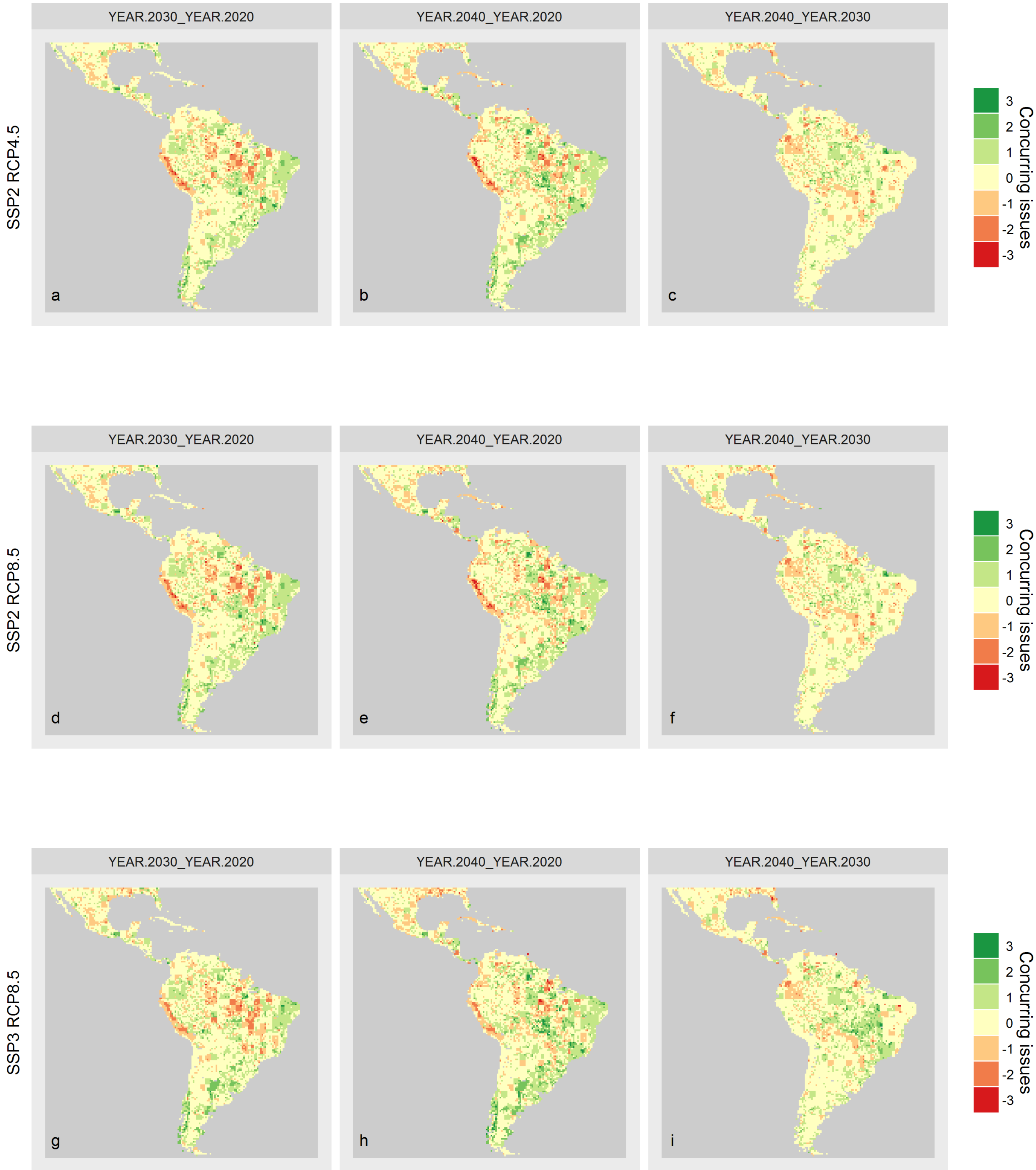

Figure 3.5: Differences in time between concurring potential issues in all three scenarios. Top: SSP2/RCP4.5, Middle: SSP2/RCP8.5, Bottom: SSP3/RCP8.5; Left: Differences between 2030 and 2020, Centre: Differences between 2040 and 2030, Right: Differences between 2040 and 2020.

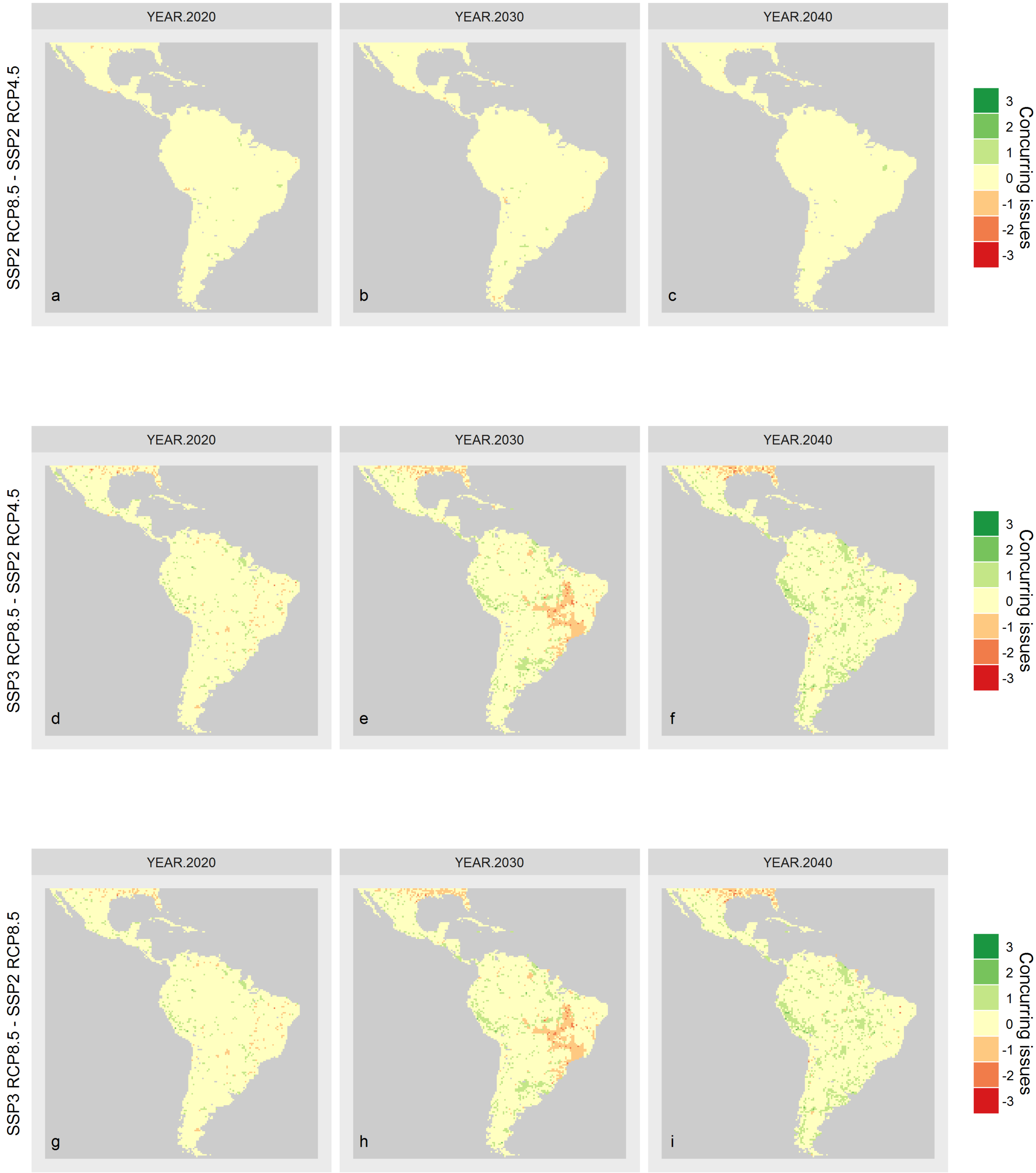

Figure 3.6: Differences between concurring potential issues in all three scenarios over time. Top: Differences between SSP2/RCP8.5 and SSP2/RCP4.5, Middle: Differences between SSP3/RCP8.5 and SSP2/RCP4.5, Bottom: Differences between SSP3/RCP8.5 and SSP2/RCP8.5; Left: year 2020, Centre: year 2030, Right: year 2040.

3.4 Disagreement

The differences between scenarios over time are synthesized by calculating the average disagreement according to Equations 2.2, refeq:Davgj and 2.4. It confirms the observation made on the map that the effect of time is much larger than the effect of scenarios (Figure 3.7). Figure 3.8 allows us to trace the origin of the disagreement back to the individual issues. It appears that the main driver of the increase of pressure over time is the projected GDP per capita (gdppc) that, between 2020 and 2030, becomes lower than the class median in large parts of Brazil. However its effect is differed in time between SSP2, where it happens partly before, and SSP3. The next major contributor is the population change (popDif), with the areas where population change is above the class median larger than those where it is less. This is exacerbated in SSP3 with respect to SSP2. The contribution of population itself (pop) is negligible compared to the other potential issues, suggesting that the population geographic distribution does not change much over time and between scenarios in the datasets used in this analysis. Water stress (ws) differences between scenarios are also small. Over time, there is a larger area that improves than the one that deteriorates. SSP2/RCP8.5 is slightly worse than SSP2/RCP4.5 and SSP3/RCP8.5 is even worse, but the effect is very limited as seen on the map (Fig.3.6 a, b, c). The effect of land use change does not vary between scenarios because the same land use was used for all. Between 2020 and 2030, the surface under forest cover increases or decreases less than in other parts of the world. Then, between 2030 and 2040, it decreases but to a lesser extent. This suggests that between 2020 and 2030, deforestation in Latin America and the Caribbean was less intense than in other forests of the world, while between 2030 and 2040, it was less so. Overall, the total area under crop increases less fast than in other parts of the world with similar starting land use patterns.

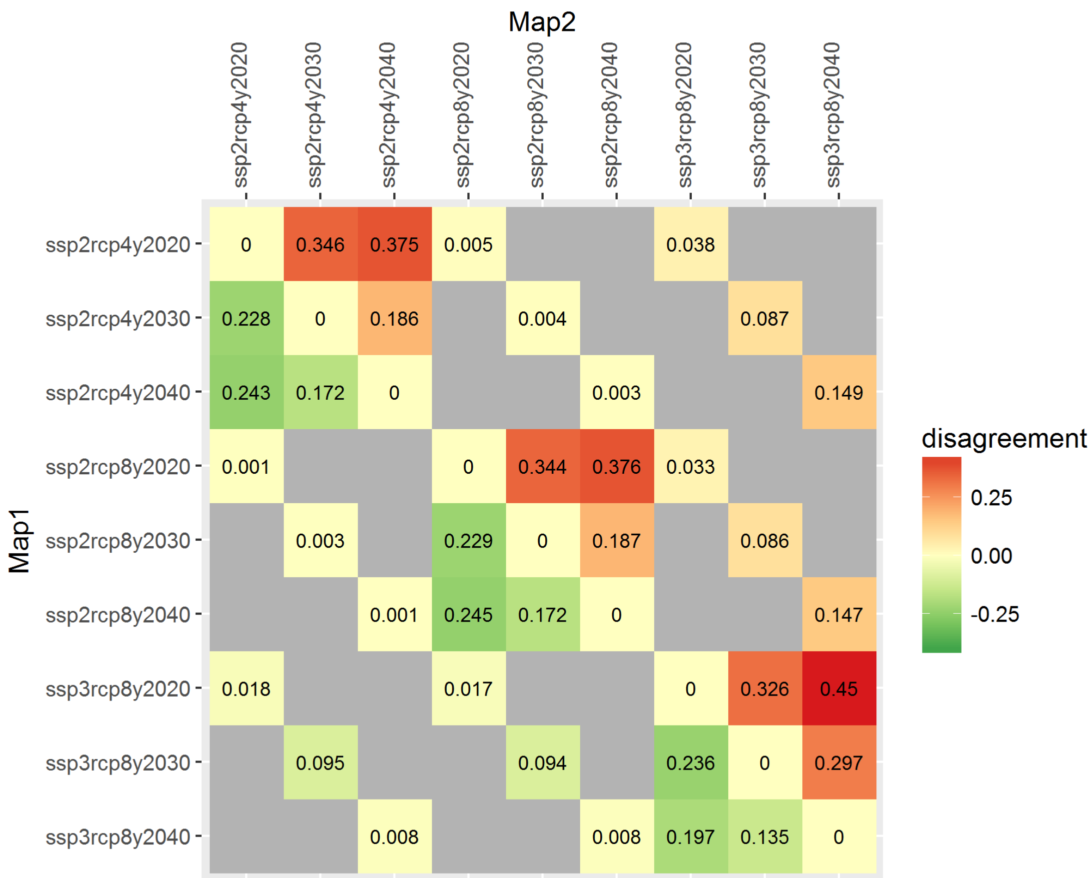

Figure 3.7: Dissimilarities between concurring potential issues in the three scenarios over time.

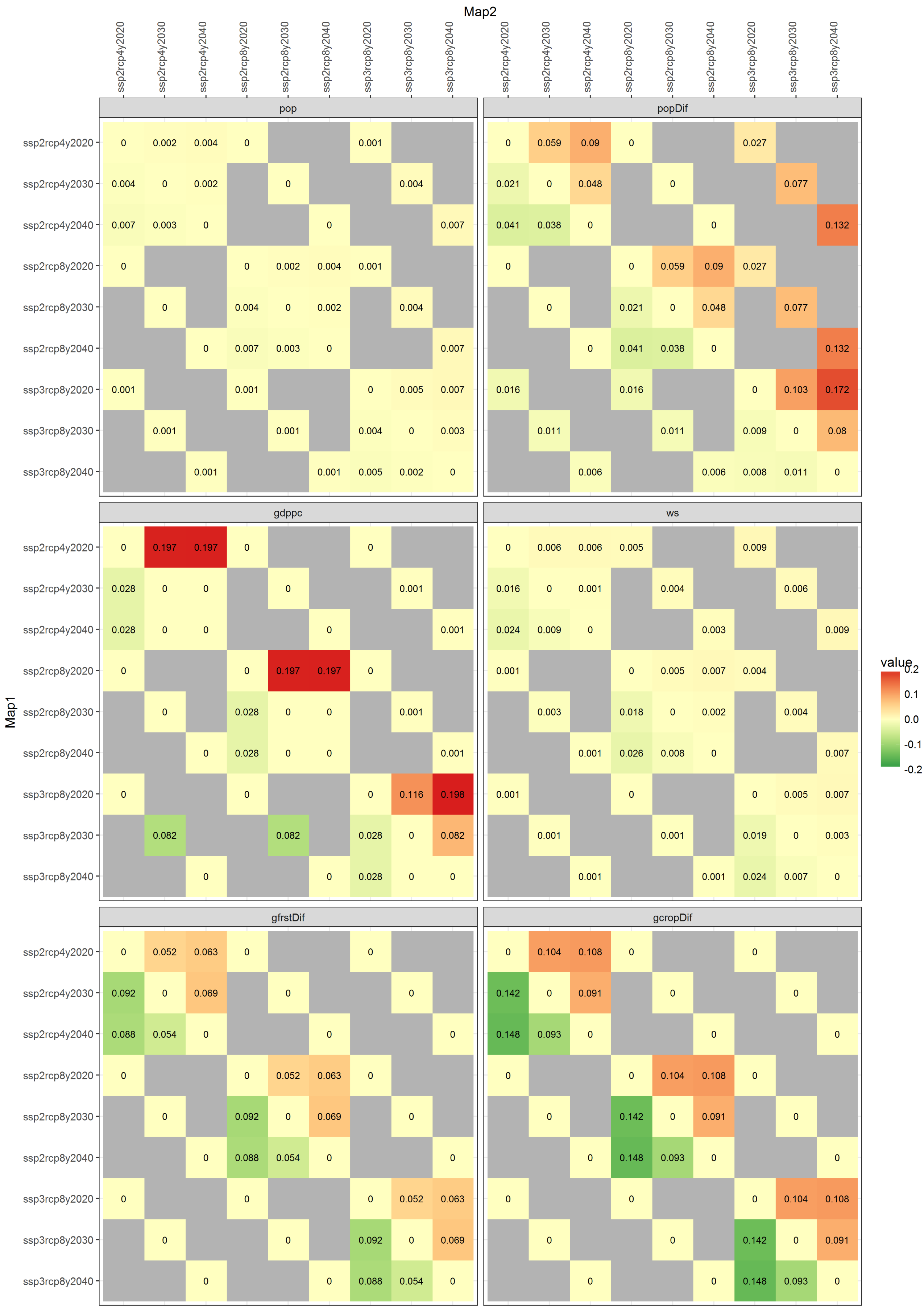

Figure 3.8: Dissimilarities between potential issues in the three scenarios over time. For the variables' description, see table 2.1.

4 Discussion

The differences over time are much greater than the differences between scenarios. On the one hand, a reason for that is that the land use is the same in all three scenarios and only changes over time. On the other hand, the changes in population and the GDP per capita, which depend on the socio-economic scenarios, do also differ more over time than between scenarios. The only variables considered as potential issues relevant to land degradation that have larger differences between scenarios than over time are the population and the water stress but their contribution to the total disagreement is small (Fig. 3.8). The population spatial distribution does vary between scenarios: with SSP3, population growth is high in developing countries and low in industrialized countries and migrations are low in all groups; with SSP2, population growth and migration are medium in all country groups [6, 13]. Water stress also changes from one scenario to another, but not often to the point of crossing the class median threshold. Water stress is the only layer in this exercise that includes the climate change scenarios. From its small contribution to the total disagreement, one could hastily conclude that climate change does not affect land degradation. We would not recommend this conclusion: more information is needed to draw any such conclusion. Also, the variation between the outputs of the climatic models is known to be large. The water supply used to calculate the water stress is based on the weighted mean of the members of an ensemble of six CMIP5 GCMs [9]. However, the water stress dataset used here does not encompass that variability.

The land use segment used in the SSP baseline scenarios elaborated with Integrated Assessment Models (IAMs) should be taken into account to integrate the combined effect of SSPs and RCPs on land degradation. However, the large variations observed among the results of the models [12] would complicate the interpretation of the interactions between potential issues. For a more rigorous integration, all issues should come from the same scenario and the same model. In this study we were limited by the availability of the water stress data that do not follow the combinations of socio-economic and climate scenarios chosen by the modelling community for which the IAMs are run [8]. While the water stress contributes little to the total disagreement (Fig. 3.8), it was considered crucial as potential pressure leading to land degradation and was the only variable included in this study that considered climate change scenarios.

The results suggest that the increase in pressure is often partly compensated by a decrease elsewhere. It is more so with SSP2 than with SSP3, the latter referring to a fragmented world in which international development is pushed to the background.

Information on the evolution of the biomass status or on net primary productivity is notably missing from this analysis. We did not find any dataset relevant to this exercise.
Given the large uncertainties that affect projections in general, the results must be taken with careful consideration. Whenever better projections become available, the model can be run again to provide more reliable results.

5 Conclusions

We propose a methodology to assess the concurrence of human-induced land change processes relevant to land degradation under different scenarios of climate change and socio-economic conditions. With the processes or potential issues and the scenarios used in this study on Latin America end the Caribbean, we found (1) that the differences over time were much larger than those between scenarios and (2) that the effect of climate change was negligible compared to the socio-economic effect. However, only one of the six variables considered as potential issues did include a climatic effect, while three covered the socio-economic conditions. Also, the large uncertainties on projected data limit the robustness of the conclusions. When better and more complete datasets will be available, the exercise can be done again to reinforce the results.

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