The global impacts of climate change under a 1.5°C pathway: supplement to assessment of impacts under 2, 3 and 4°C pathways

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Summary

This report presents an initial assessment of the global-scale impacts of climate change in 2100 with an increase in global mean surface temperature of 1.5°C above pre-industrial levels. It supplements an earlier report on impacts under pathways which reach 2°C, 3°C and 4°C above pre-industrial values by 2100. Impacts are represented by indicators covering the water resources, river flooding, coastal flooding, agricultural, environmental and health (heat) sectors, and population and economic growth are assumed to develop along the same 'middle of the road' trajectory under each climate futures.

For most indicators, impacts are (as expected) less under at 1.5°C than at 2°C, but are still substantial. There is little difference in impact between 1.5°C and 2°C for the areas exposed to a decline in crop suitability, and exposure to extreme heat stress (Wet Bulb Globe Temperature>32) is already eliminated at 2°C. Sea dike costs are similar in 2100 under the 1.5°C and 2°C pathways, but in early years are considerably lower under the 1.5°C pathways.

Key caveats to the initial assessment are presented in the report. The spatial and seasonal patterns of change in climate are defined by CMIP3 climate models. The impact indicators are calculated using one impact model only, so the range in estimated impacts is likely to be underestimated. Interpolation between different levels of impact to estimate impacts at 1.5°C assumes a smooth relationship between amount of forcing and impact. Step changes are possible, not only at higher rates of temperature change where climate regimes may be pushed into uncharted territory (not relevant here) but also for very low rates of change. The magnitude of impacts in the coastal zone are influenced by the assumed pathway of temperature towards 1.5°C, and the stylised scenarios used here may not span the full range of possibilities.

Contents

1. Introduction

The Paris Agreement reached at COP 21 in Paris in December 2015 commits countries to aim for a maximum increase in global mean temperature of 1.5^{o}C (implicitly) above pre-industrial levels and (again implicitly) by 2100 (United Nations, 2015). A previous report for the Committee on Climate Change (Arnell et al., 2015) summarised global-scale impacts under pathways which reach 2, 3 and 4^{o}C above pre-industrial levels by 2100. This report supplements that previous report with a preliminary assessment of impacts for the same indicators at 1.5^{o}C by 2100.

The previous report used scenarios describing pathways of change through the 21st century that reached specific increases in temperature by 2100, based on plausible projections of future emissions. However, there are currently very few published plausible pathways which limit the increase in temperature to 1.5^{o}C by 2100 (Rogelj et al., 2015), and those that do assume low emissions early in the 21st century. The impacts in the first half of the 21st century under these trajectories are therefore considerably lower than under the trajectories considered in the previous report. The indicators which are a result of the integration of change over time are also substantially affected by assumed temperature changes in the first decades of the 21st century. This report therefore focuses on impacts only in 2100, when the increase in global mean surface temperature is assumed to be exactly 1.5^{o}C above pre-industrial. Two different approaches are used, as explained in more detail in the Methodology section. For most indicators, impacts are simply calculated using changes in climate scaled to correspond to an increase in temperature of 1.5^{o}C. For the coastal indicators, which are partly determined by the rate of temperature change through the 21st century, three different plausible trajectories of change in temperature (not emissions) towards 1.5^{o}C in 2100 are used to construct sea level rise scenarios. Considering a range of temperature profiles is important as there is a time lag between surface warming and oceanic response. This is known as the commitment to sea level rise.

Full results are presented in the accompanying spreadsheet.

2. Methodology: indicators and scenarios

Table 1 summarises the indicators that have been calculated for a global increase in temperature of 1.5°C in this supplementary analysis. The indicators are described in more detail in Arnell et al. (2015). As before, socio-economic scenario SSP2 is used to represent future population and GDP.

Table 1: Indicators of impact

Sector	**Indicator**
Water	Numbers of people living in water-stressed watersheds (<1000m^3/capita/year)
	Numbers of people living in water-stressed watersheds exposed to a change (increase or decrease) in water stress
	Average annual number of people exposed to droughts
River floods[1]	Average annual flood risk
	Average annual number of people exposed to river floods
Coastal floods[2]	Expected annual number of people flooded, with different levels of adaptation (no additional adaptation since 1995, evolving adaptation taking into account socio-economic change only, and enhanced adaptation incorporating the effect of sea level rise).
	Average annual capital cost of coastal flood protection from dike building
Agriculture	Area of cropland with change (increase or decrease) in suitability for cropping
	Average annual area of cropland exposed to droughts
Environment	Area becoming climatically unsuitable for more than 75% of plant/animal species ("areas of concern")
	Proportion of species losing more than 50% of their habitat area due to climate change
Health	Average annual population exposed to heatwaves
	Average annual population exposed to increased heat stress (with two different thresholds)
	Change in labour capacity
	Number of frost-days

1 River flood indicators under all temperature pathways have been corrected due to an error in an input file, and the results for the 2°C, 3°C and 4°C scenarios are different to those in Arnell et al. (2015)

2 Sea-level rise scenario and impact metrics for 2°C, 3°C and 4°C have been updated from Arnell et al. (2015) to take account of new sea-level rise scenarios which better reflect the latest science (see text for details).

For all except the coastal indicators, impacts with a 1.5°C rise in temperature in 2100 are estimated by interpolation between impacts estimated at different levels of global mean surface temperature change using damage functions. The impacts of climate change under a given change in global mean temperature depend on the associated spatial and seasonal distribution of change in relevant climatic variables, and this varies between different climate models. Damage functions are therefore constructed separately for scenarios constructed from each climate model, as shown in Figure 1: this report uses scenarios constructed from CMIP3 climate models, for comparison with impacts presented in Arnell et al. (2015). Note that damage functions for the ecosystem indicators are only available for the minimum, median and maximum across the climate model patterns, rather than the individual climate models.

The use of damage functions to interpolate to estimate impacts at different levels of temperature change assumes that the rate and historical evolution of temperature change does not influence the magnitude of impacts. The ecosystem indicators used here assume realistic rates of dispersal in response to climate change, so time is relevant for these indicators. Plants, amphibians and reptiles have limited dispersal rates so interpolating to estimate impacts at 1.5^{o}C is reasonable, although if temperatures rise above 1.5^{o}C before declining then the overshoot temperature will determine the magnitude of impacts. Birds and mammals have higher dispersal rates than plants, amphibians and reptiles, so the amount of overshoot will be more important. However, as shown in Figure 1, the range between minimum and maximum impact for a given temperature change is large. Perhaps more significant, however, is assumption that there are no barriers to dispersal and habitats remain connected. If achieving a 1.5^{o}C temperature limit involves substantial land use change – specifically for BioEnergy with Carbon Capture and Storage (BECCS) – then barriers to dispersal may be increased and the impacts of climate change increased.

The damage functions in Figure 1 show the effect on impacts of different spatial and seasonal changes in climate associated with a given global temperature change. Some important impacts – particularly on crop productivity - are also affected by CO_2 concentration. In principle it is possible to construct damage functions showing impacts for a given temperature change (and associated change in other relevant variables) for specified CO_2 concentrations. However, such calculations have not been done in practice, so in this supplementary report – unlike in Arnell et al. (2015) - no impacts on crop productivity at 1.5^{o}C have been estimated.

The coastal zone indicators are affected by the rate of change in temperature over time in two ways. First, the rate of temperature change determines the rate of sea level rise. Second, the rate of sea level rise influences the timing of the construction of adaptation measures, in this case sea dikes. For these reasons, it is not feasible to construct damage functions relating coastal zone impacts to temperature change. Coastal zone impacts were therefore estimated by constructing three stylised temperature pathways, each reaching 1.5^{o}C above pre-industrial levels in 2100, and translating these pathways into sea level rise using a physically-based emulator based on the relationships between temperature and sea level rise in the IPCC AR5 report (Church et al., 2013). The three temperature pathways (i) increase gradually to reach 1.5^{o}C in 2100, (ii) reach a peak of 1.7^{o}C in 2050 before declining gradually to 1.5^{o}C in 2100, and (iii) peak at 1.6^{o}C in 2075 before declining to 1.5^{o}C in 2100.

Figure 2 shows the projected sea level rise under these three pathways: there is a difference of around 8cm between them in 2100.

The method used to project sea level rise from temperature used here is different to that used in Arnell et al. (2015), and produces a higher sea level rise for the same temperature change than previously. This is because a different set of assumptions were used to generate the latest scenario following sea-level science present in the IPCC AR5 report (Church et al. 2013), compared with the science presented in the IPCC AR4 report used in the previous report (Meehl et al. 2007). Around the time of AR4, it was unclear whether the higher rates of ice melt recorded from the land based ice sheet of Antarctica and Greenland would continue, and therefore this was not considered in the scenarios and scenario methodology presented in the report. Between 2007 and 2015, advances were made in the understanding of land based ice melt, including an improved inventory of glaciers and rates of change, plus new simulations, feedbacks and dynamics of ice sheet melt. This meant a higher contribution from land based ice melt to projected sea-level rise. Additionally, new science between 2007 and 2015 indicated a slightly higher rate of thermal expansion / steric change (the increase in ocean volume as the ocean warms), thus again contributing to a higher level of sea-level rise. However, relatively, this change was less than ice melt. Figure 2 therefore also shows the rise in sea level under the previous 2, 3 and 4^{o}C pathways. Note that for these pathways, the range shown is the range between the 10th and 90th percentiles representing uncertainty in thermal expansion and ice melt contributions, whilst for the 1.5^{o}C pathways the range is between the different trajectory shapes (based on differing rates of temperature rise to achieve the 1.5^{o}C value in 2100).

There are, of course, a number of key caveats with the approaches used in this supplementary report, in addition to those outlined in Arnell et al. (2015). Most significantly:

- The spatial and seasonal patterns of change in climate are defined by CMIP3 climate models. Patterns based on the CMIP5 generation of climate models will be quantitatively different, although the differences between the different pathways are similar.
- The impact indicators are calculated using one impact model only, so the range in estimated impacts is likely to be underestimated.
- Interpolation between different levels of impact to estimate impacts at 1.5^{o}C assumes a smooth relationship between amount of forcing and impact. Step changes are possible, not only at higher rates of temperature change where climate regimes may be pushed into uncharted territory (not relevant here) but also for very low rates of change.
- The magnitude of impacts in the coastal zone are influenced by the assumed pathway of temperature towards 1.5^{o}C, and the stylised scenarios used here may not span the full range of possibilities.

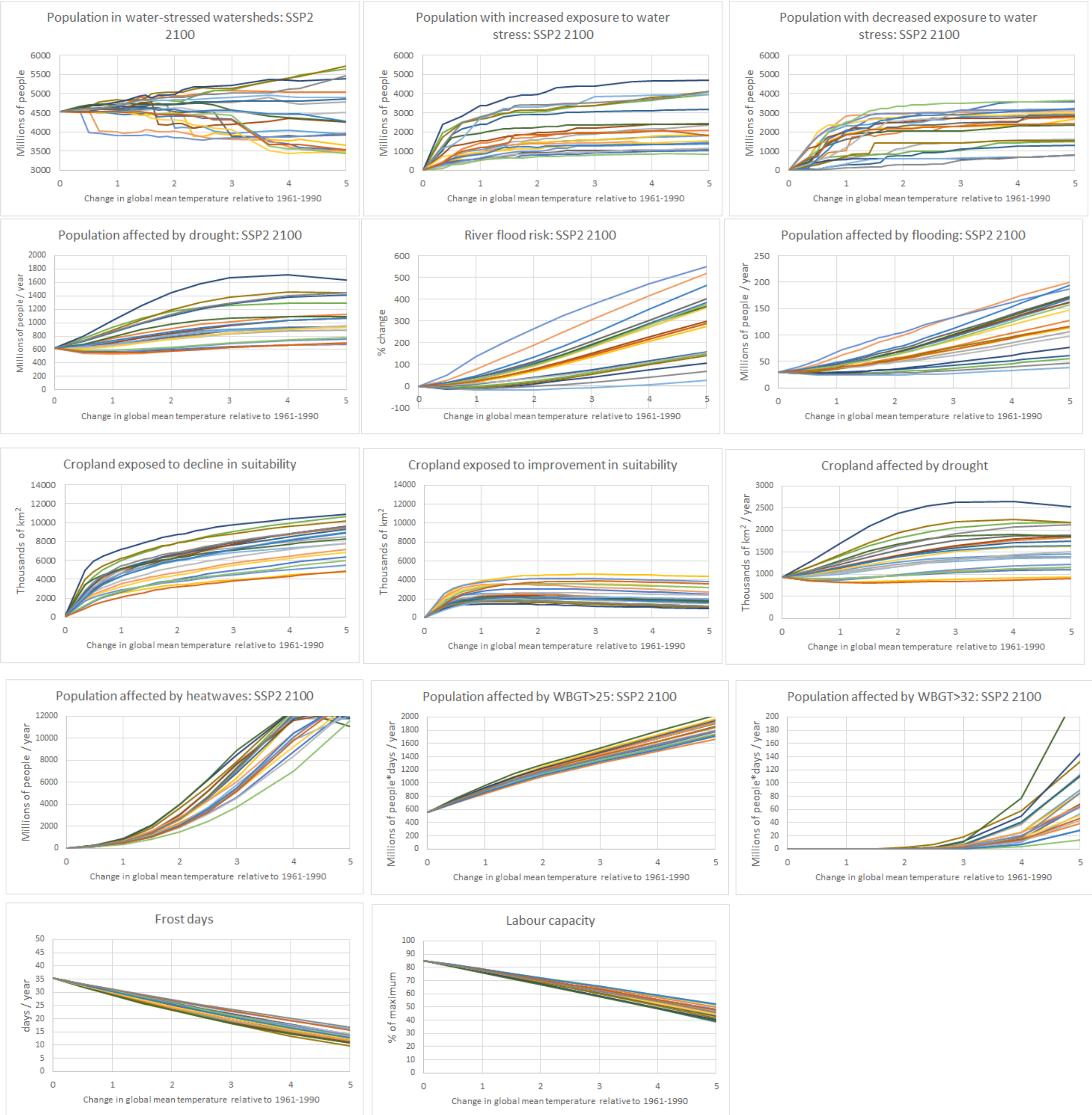
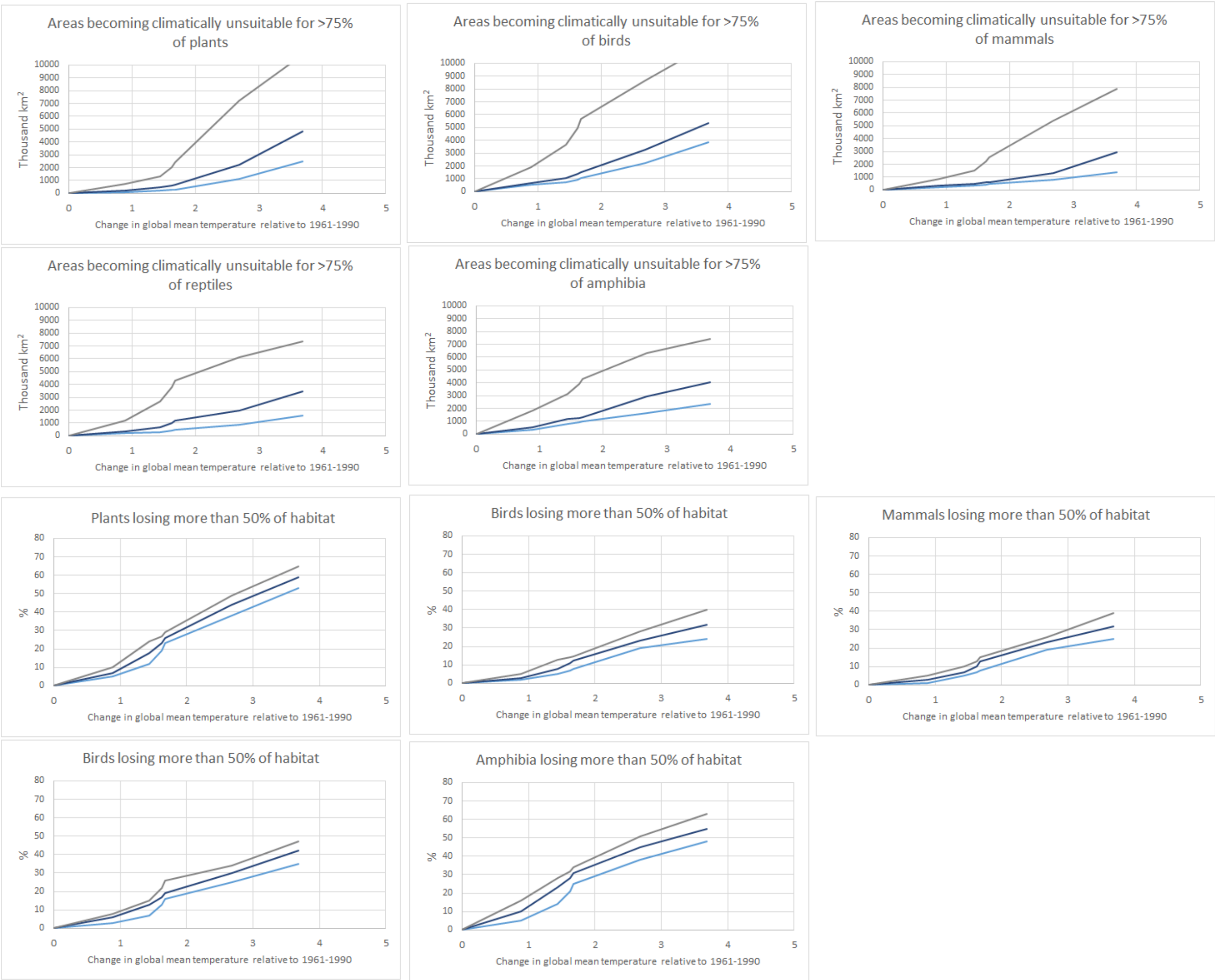


Figure 1: Damage functions used to estimate impacts at 1.5oC above pre-industrial levels. The different lines represent damage functions constructed from different CMIP3 climate model patterns. For the ecosystem indicators, functions were only constructed for the minimum, median and maximum impact. For the socio-economic indicators, impacts are calculated assuming socio-economic scenario SSP2 in 2100.



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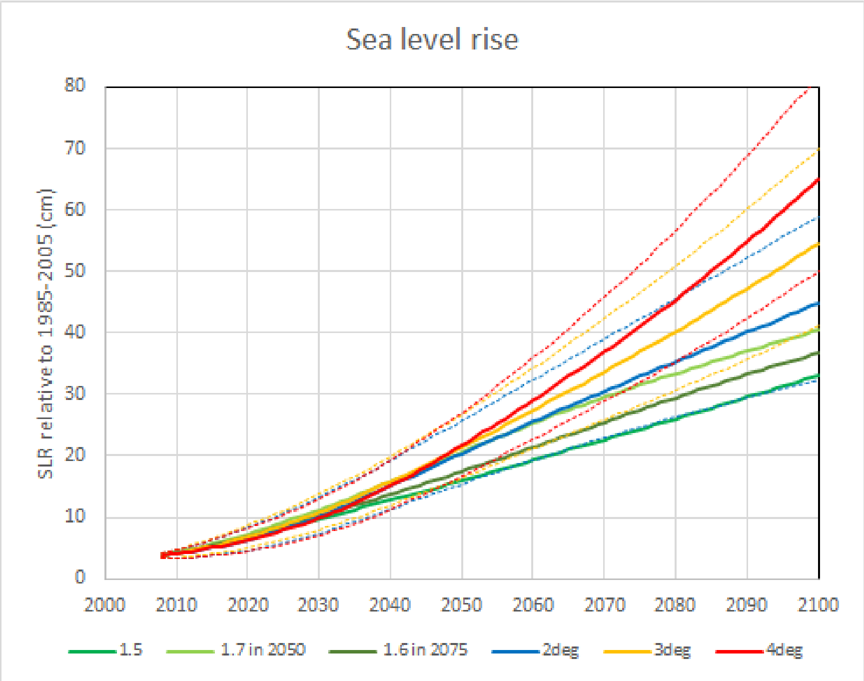


Figure 2: Change in global mean sea level. For the 2, 3 and 4°C scenarios, the plot shows the median estimate (solid lines) together with the 10th and 90th percentiles of the uncertainty distribution (dotted lines)

3. Summary of results

Figure 3 shows the impacts in 2100 for each indicator, and Figure 4 shows the proportion of impacts avoided relative to the 4^{o}C pathway. Note that there are no estimated impacts under the 1.5^{o}C pathway for the crop productivity indicators, and avoided impacts under the 1.5^{o}C pathway for the coastal zone are not calculated because the pathways are conceptually different as outlined above.

For most indicators, impacts are (as expected) less under at 1.5^{o}C than at 2^{o}C, but are still substantial. There is little difference in impact between 1.5^{o}C and 2^{o}C for the areas exposed to a decline in crop suitability, and exposure to extreme heat stress (WBGT>32) is already eliminated at 2^{o}C. Sea dike costs are similar in 2100 under the 1.5^{o}C and 2^{o}C pathways, but are considerably lower under 1.5^{o}C in earlier years (particularly compared against the 90th percentile of uncertainty of the 2°C scenario).

The proportion of impacts avoided varies between indicators, as does the relative effect of the 1.5 and 2^{o}C pathways. For some indicators – for example exposure to increased water resources stress – there is a big difference between the two, but for others there is a smaller difference. The range in the proportion of impacts avoided is large for some indicators, due to large variations in the shape of the damage functions (Figure 1): this is particularly apparent for the drought indicators.

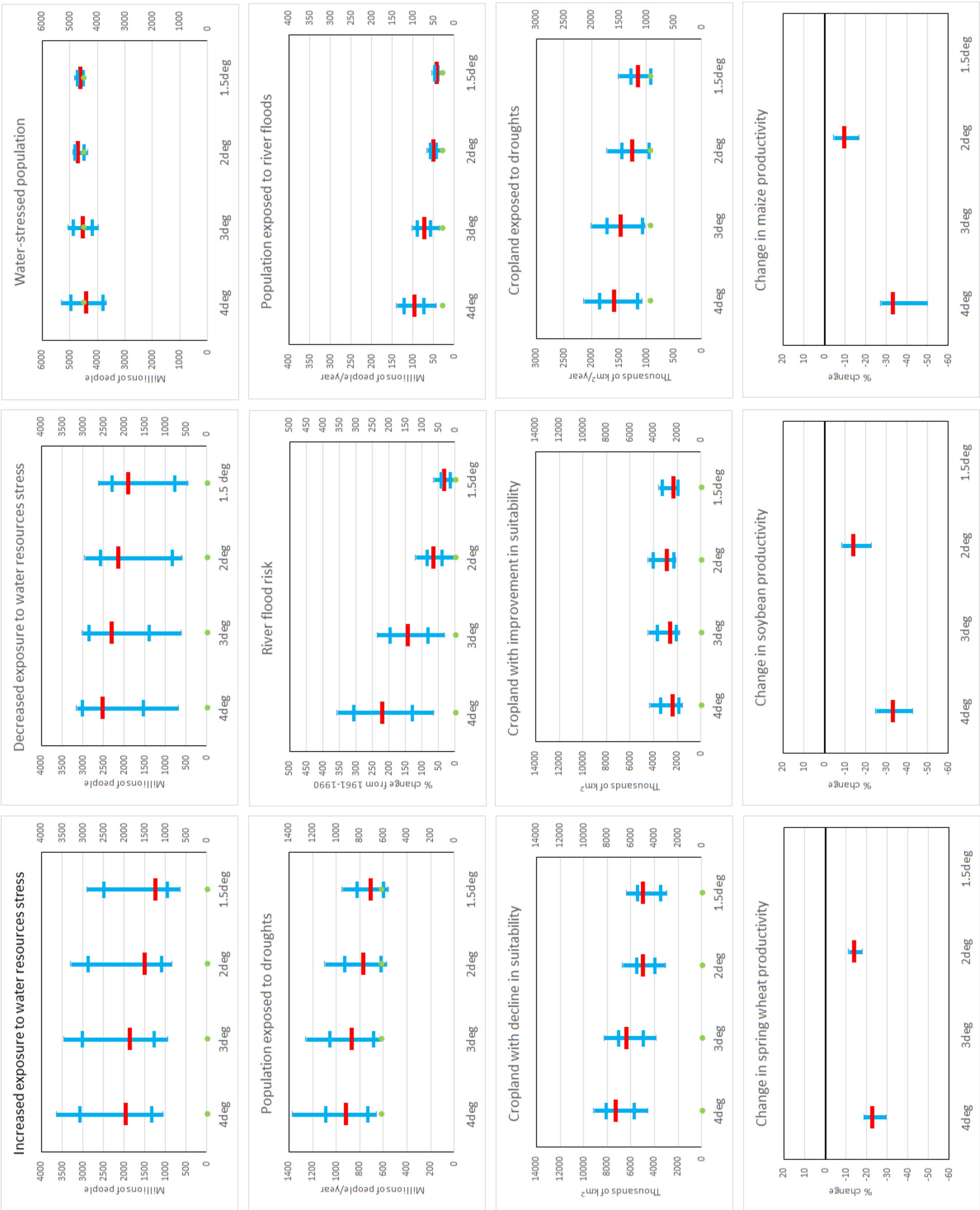
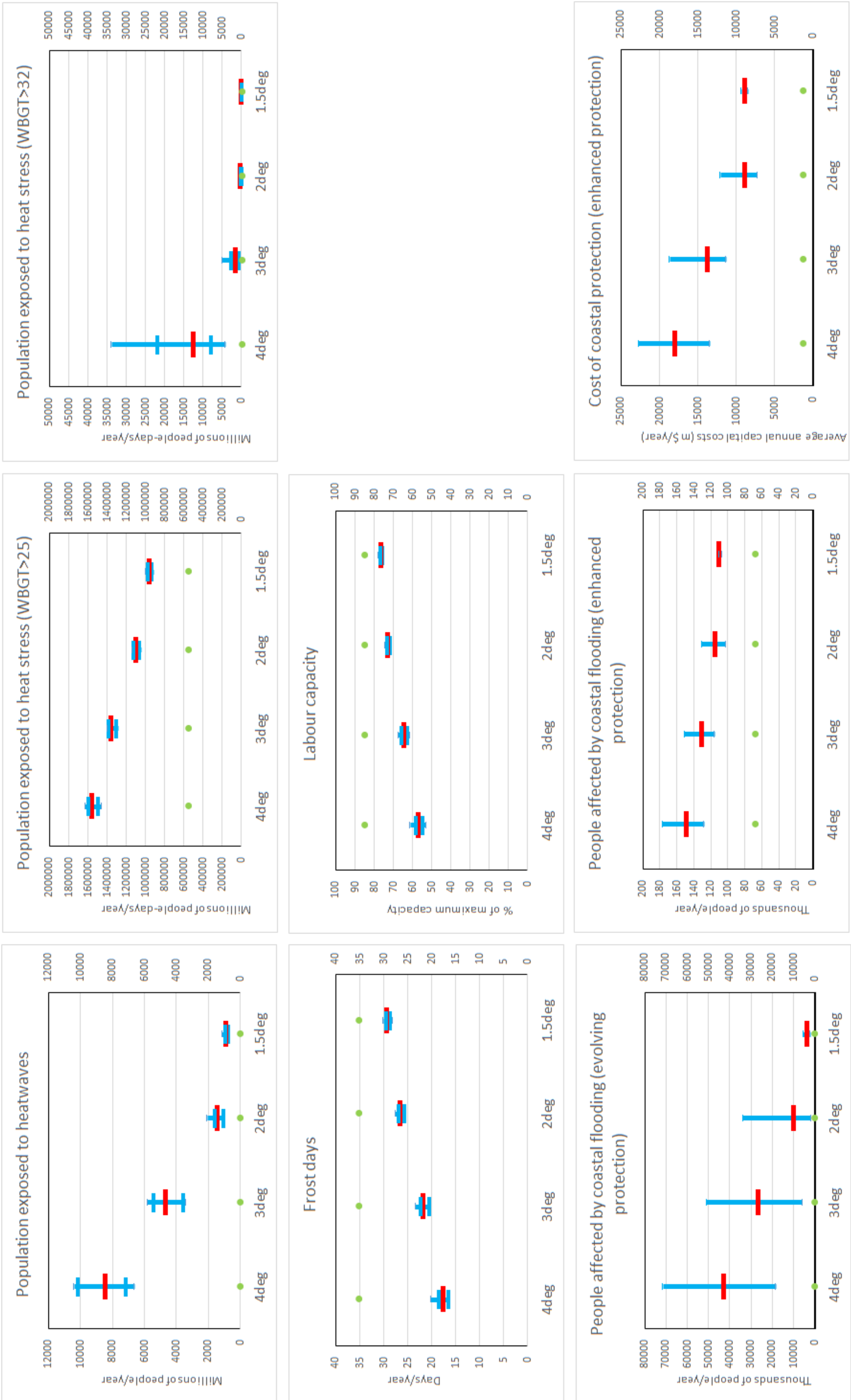


Figure 3: Global-scale impacts in 2100. The red line shows the median impact, and the blue bar the range between the 10th and 90th percentiles. The green dot shows the impact in the absence of climate change. For the coastal indicators, the impacts under the 1.5°C pathway represent the range across the three different temperature trajectories.



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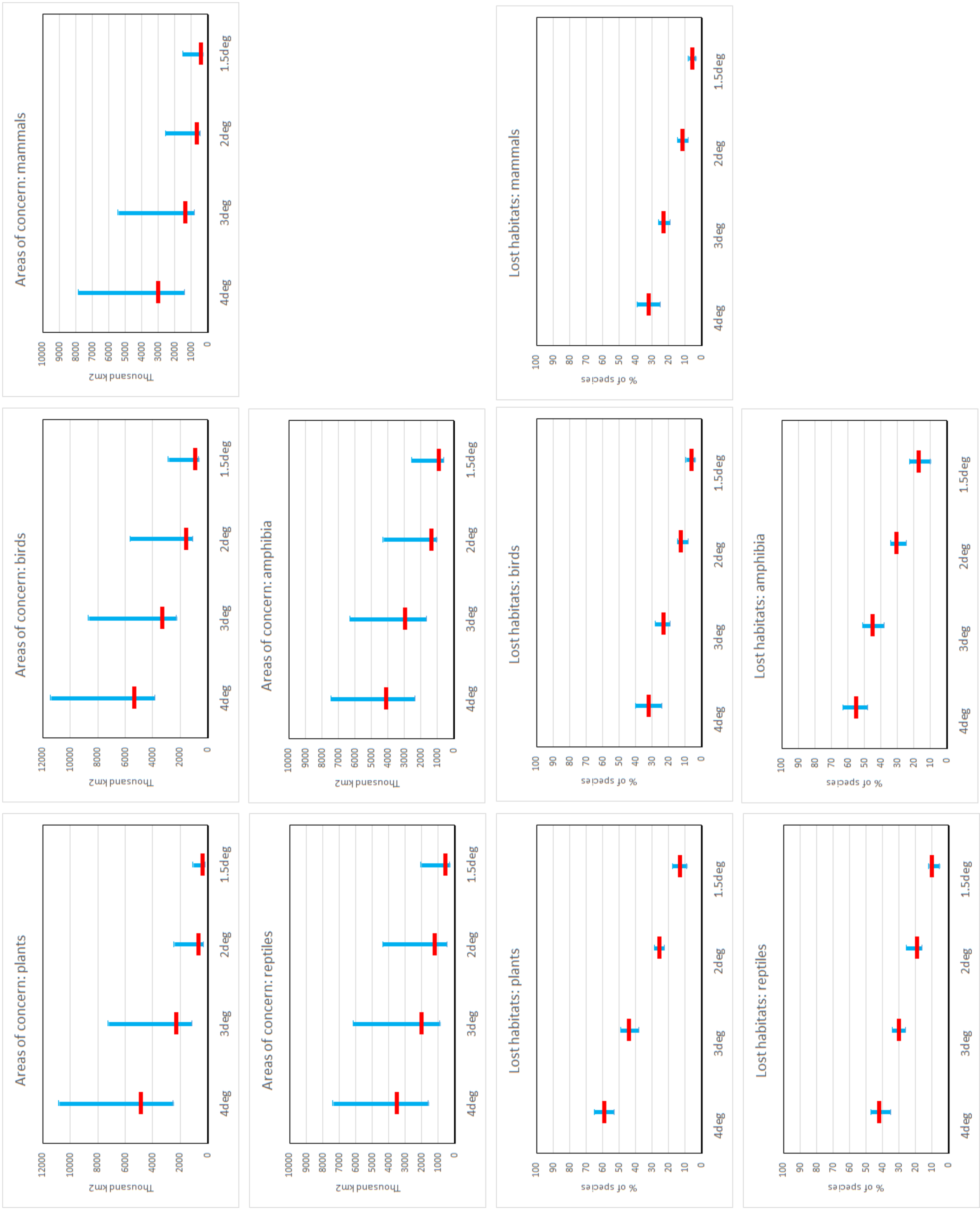

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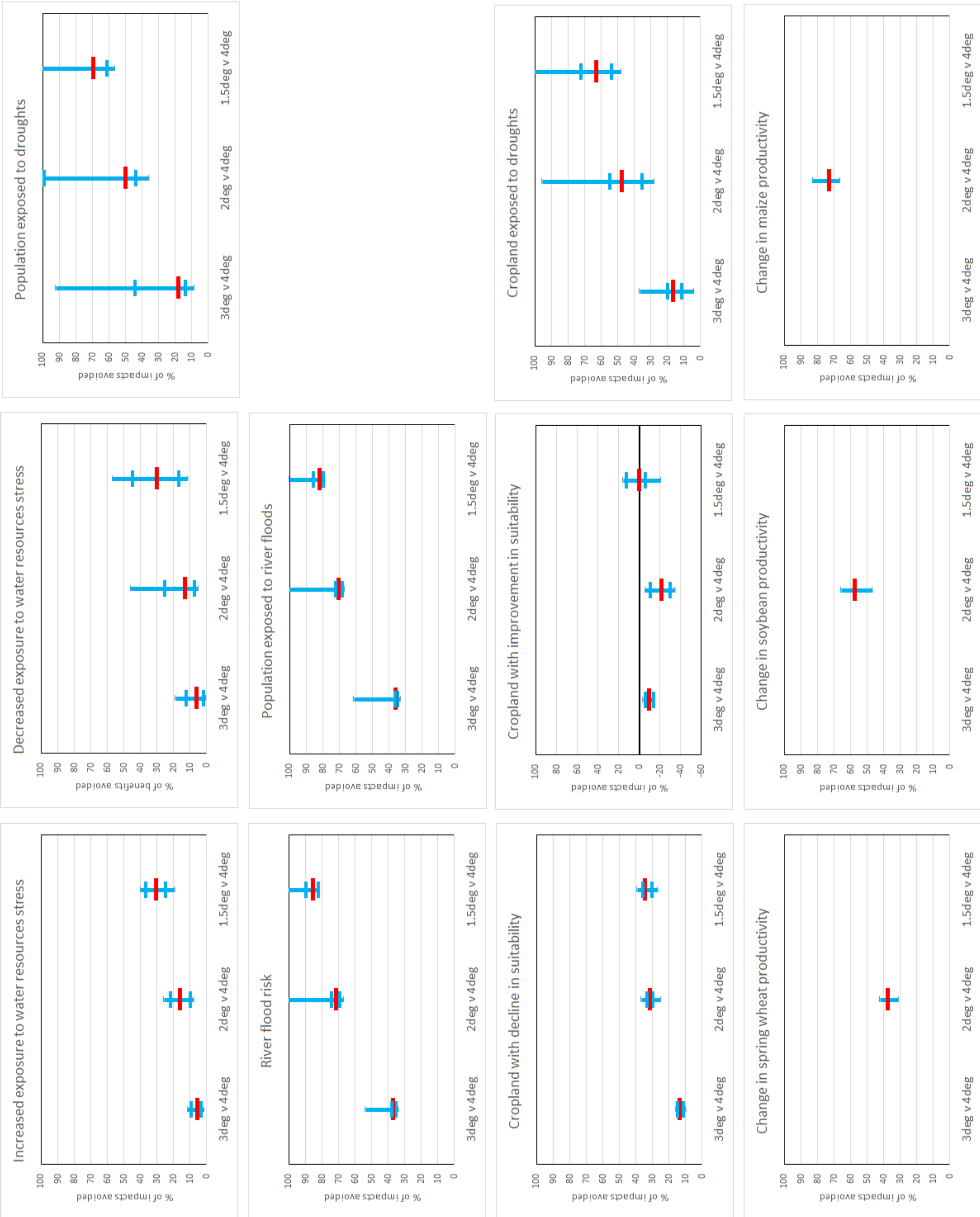
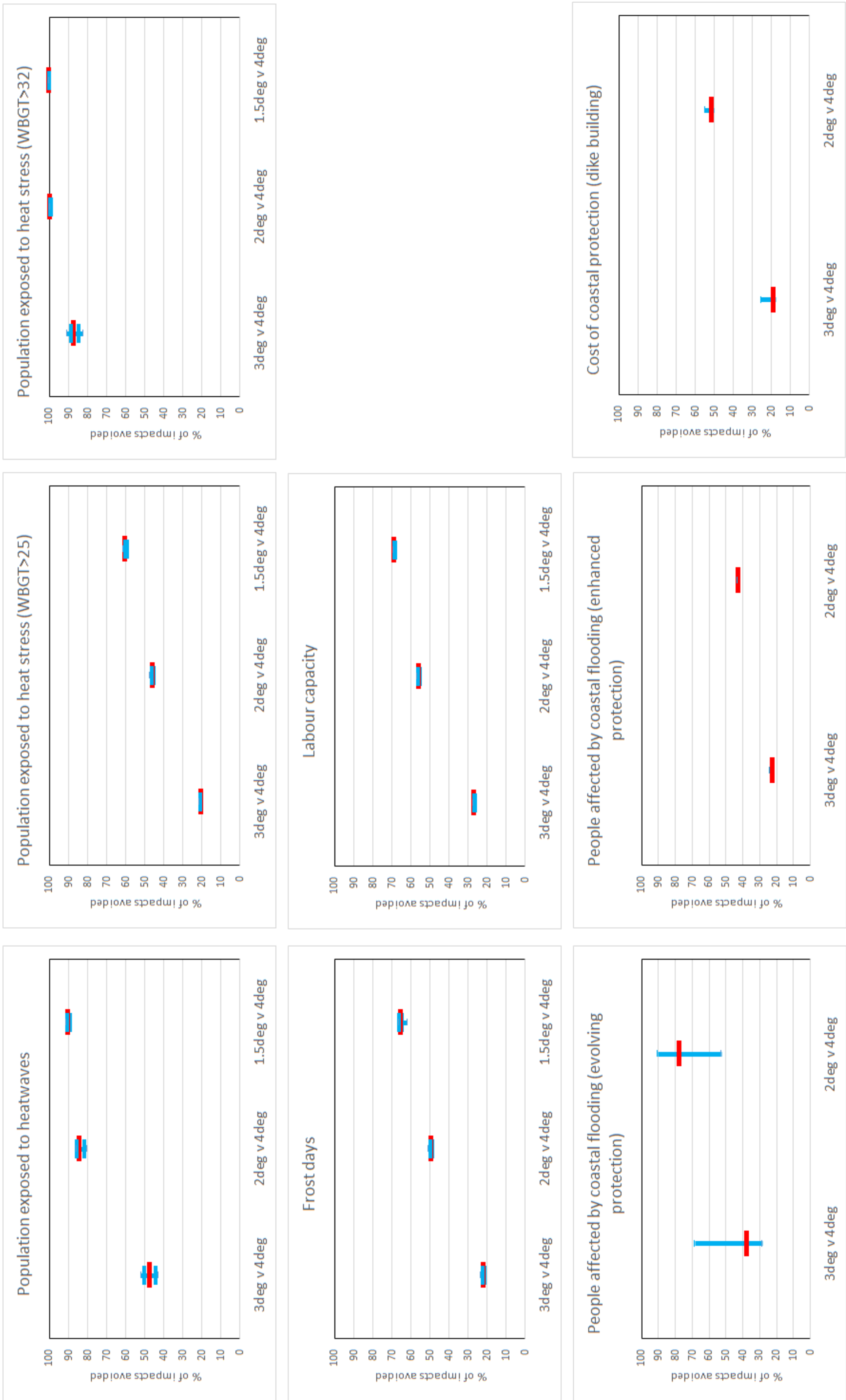


Figure 4: Proportion of global-scale impacts that are avoided by the 3, 2 and 1.5^{o}C pathways relative to the 4^{o}C pathway.



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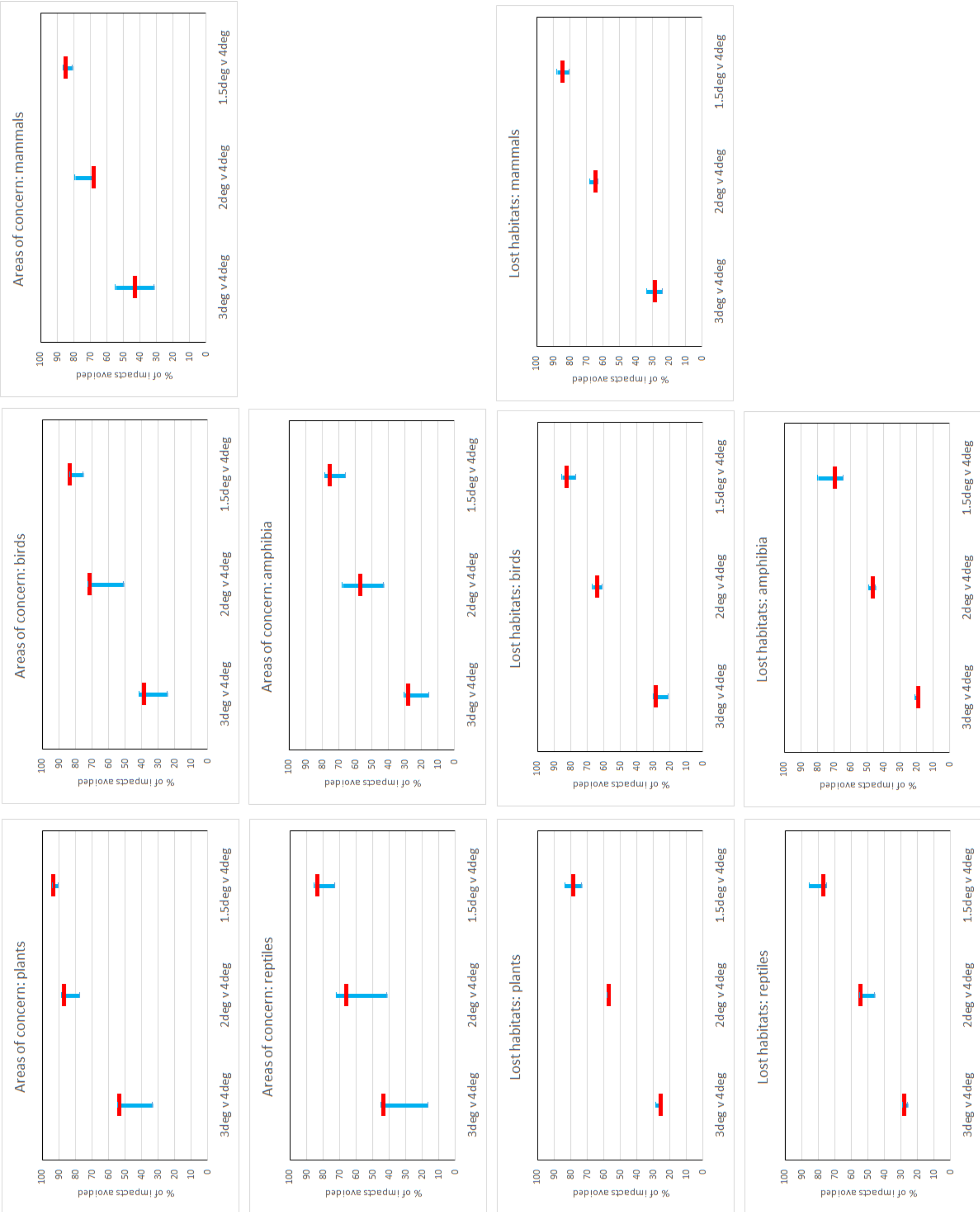

Figure 4 (continued)

4. Comparison with other studies

So far, only one other published study has assessed impacts with a 1.5°C warming in 2100. Schleussner et al. (2015) used a range of approaches to estimate global and regional impacts for indicators of high temperatures, extreme rainfall, river runoff, crop productivity (for four crops), sea level and coral reef bleaching, comparing impacts at 1.5°C with those at 2°C. The heat and rainfall indicators were calculated directly from 11 and 14 CMIP5 climate modes respectively by extracting 20-year periods with mean temperature increases 1.5 and 2°C above pre-industrial levels. The runoff and crop productivity indicators were taken from ISI-MIP results using the same 'time-slicing' method, using five CMIP5 climate models and 11 and 6-7 impact models respectively. The crop productivity indicators were also estimated assuming different amounts of CO_2 fertilisation. For all of these indicators, Schleussner et al. (2015) presented median impacts across space, along with the range in impacts across a region, rather than regional aggregations. Sea level rise was estimated using temperature trajectories taken from two simulations using the MESSAGE integrated assessment model (Rogelj et al., 2013) which had 50% likelihoods of achieving the 1.5 and 2°C targets[1], together with an empirical relationship between temperature and sea level rise. They estimated coral bleaching risk by constructing damage functions relating bleaching and sea surface temperature using a coral bleaching model and output from climate models, and used these functions with the same temperature pathways as used to estimate sea level rise.

Figure 5 reproduces Schleussner et al.'s (2016) summary of their assessment of impacts with the 1.5 and 2°C targets. Their estimates of change in wheat, maize and soybean productivity under the 2°C target (median changes of 0, -6% and +1% over 50% of cropped area respectively) are different to estimates in Arnell et al. (2015) (median changes in average productivity of -14%, -10% and -14% respectively), but the indicator is defined differently so direct comparisons are difficult. Schleussner et al. (2016) estimate that sea level would be 10cm lower in 2100 under a 1.5°C target than a 2°C target: our estimate here is a reduction of 5 to 12cm.

[1] Note that they did not estimate impacts under trajectories with larger temperature increases

	1.5 °C	2 °C	
Heat wave (warm spell) duration [month]			
Global	**1.1** [1;1.3]	**1.5** [1.4;1.8]	Tropical regions up to 2 months at 1.5 °C or up to 3 months at 2 °C
Reduction in annual water availability [%]			
Mediterranean	**9** [5;16]	**17** [8;28]	Other dry subtropical regions like Central America and South Africa also at risk
Increase in heavy precipitation intensity [%]			
Global	**5** [4;6]	**7** [5;7]	Global increase in intensity due to warming; high latitudes (>45 °N) and monsoon regions affected most.
South Asia	**7** [4;8]	**10** [7;14]	
Global sea-level rise			
in 2100 [cm]	**40** [30;55]	**50** [35;65]	1.5 °C end-of-century rate about 30 % lower than for 2 °C reducing long-term SLR commitment.
2081–2100 rate [mm/yr]	**4** [3;5.5]	**5.5** [4;8]	
Fraction of global coral reefs at risk of annual bleaching [Constant case, %]			
2050	**90** [50;99]	**98** [86;100]	Only limiting warming to 1.5 °C may leave window open for some ecosystem adaptation.
2100	**70** [14;98]	**99** [85;100]	
Changes in local crop yields over global and tropical present day agricultural areas including the effects of CO_2-fertilization [%]			
Wheat – Global	**2** [-6;17]	**0** [-8;21]	Projected yield reductions are largest for tropical regions, while high-latitude regions may see an increase. Projections not including highly uncertain positive effects of CO_2-fertilization project reductions for all crop types of about 10 % globally already at 1.5 °C and further reductions at 2 °C.
Wheat – Tropics	**-9** [-25;12]	**-16** [-42;14]	
Maize – Global	**-1** [-26;8]	**-6** [-38;2]	
Maize – Tropics	**-3** [-16;2]	**-6** [-19;2]	
Soy – Global	**7** [-3;28]	**1** [-12;34]	
Soy – Tropics	**6** [-3;23]	**7** [-5;27]	
Rice – Global	**7** [-17;24]	**7** [-14;27]	
Rice – Tropics	**6** [0;20]	**6** [0;24]	

Figure 5: Summary of differences in impacts between 1.5°C and 2°C targets (Schleussner et al., 2016). For the heat, rainfall, water and crop indicators the figure shows the median impact occurring across 50% of the land area. The square brackets show the 33 and 66th percentiles.

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