Land Gained and Lost: A Fermi Estimate

Climate change affects the amount of land usable by humans in at least three different ways. Land is lost through sea level rise. Land may be lost because it becomes too hot for human use. Land is gained because it becomes warm enough for human use. Exact calculations of the size of all three effects, if possible at all, would require much more expertise and effort than I am bringing to the problem; what I offer in this chapter are Fermi estimates, numbers based on very crude approximations. My conclusions could easily be wrong by a factor of two but are, I believe, unlikely to be wrong by a factor of ten.

For all three estimates I will be assuming warming of 3°C above current temperatures and sea level rise of .6 meters above present sea level, roughly what the latest IPCC report projects for the end of the century under SSP3-7.0.

Land Lost to Sea-level Rise

The amount of land lost equals the length of coastline times the amount by which it shifts in. For the total length of the world's coastline I found a figure of 356,000 km. I came across a figure of a hundred feet of shift for every foot of sea level rise in a book discussing the situation on the U.S. Atlantic coast; since I do not have figures for every coast in the world, I will use that.

60 m of coastline shift x 356,000 km of coastline = 21,436 km^2

That is my very approximate estimate of land lost to sea level rise.

Land Lost to Rising Temperature

How much does temperature rise in hot parts of the world with 3° more of global warming? Figure SPM.5b of the latest IPCC report[1] shows a map of projected average temperature change due to a 4° increase relative to 1850-1900 in average global temperature, roughly 3° relative to current temperature; areas that are both hot and densely populated appear to warm by a little less than the global average. Table 11.SM.2 shows the effect of different levels of global warming in different regions on maximum temperatures. It looks from that as though 3° of global warming would raise the maximum temperature of the relevant regions[2] by about 3°. So if we knew at what temperature, average or maximum, the Earth's surface becomes too hot for human habitation, we could conclude that any area currently within three degrees of that would, with our assumed level of global warming, become too hot for humans.

The simplest approach to doing this is to compare a map of global temperature (Figure 1) to a map of population density (Figure 2) and see at what temperature population density goes to close to zero. Comparing the two maps we observe that while the coldest areas of the globe are essentially empty, the hottest are not; some, such as the Philippines, Senegal, and Malaysia, are densely populated. If there is a temperature at which the Earth's surface becomes unlivable, these maps do not show it. Our estimate of the amount of land lost by the direct effect of heating, calculated in this way, is zero.

Arguably what habitability depends on is not average but maximum temperature; if it gets unendurably hot during a summer day, the fact that winter nights are cold is little compensation.

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[1] This and other references to IPCC figures in this chapter are to IPCC AR6 WGI Full Report.
[2] SAS, EAS, SEA, and CAF in the table.

Figure 3 is the equivalent of Figure 1 for maximum temperatures. The highest temperature regions it shows include densely populated parts of India as well as more sparsely populated parts of Africa and Arabia. Insofar as one can tell from that map, there are no places large enough to show on the map where maximum temperatures are too high for human habitation. It is possible that some would be that hot after an additional three degrees of warning but the combined evidence of Figures 2 and 3 suggests not, since some of the hottest regions are densely populated.

I have been defining usable land as land humans can live on. It might make more sense to define usable land as land suitable for growing crops. Is there any significant amount of land that is too hot to grow crops?

So far as I can tell, there is not. Maps showing yield of various crops can be found online; some regions with high average and maximum temperatures show substantial yields. The yields shown are averaged over countries, but a map of agriculture in India shows crops being grown across areas within India of both high average and high maximum temperature.

My conclusion is that there is probably no substantial amount of land area that will become either uninhabitable or unable to grow crops solely because of temperature with global warming of 3°C.

This does not mean that there is no area that will become either uninhabitable or unable to grow crops as a result of global warming, only that there is no area where it will happen solely because of temperature. Looking at Figure 2, one observes a wide region of northern Africa with almost nobody living there — the Sahara. It is less hot than some populated regions, so temperature is not the entire reason it is empty, but it can be, almost surely is, part of the reason, so increased temperature might expand it.

On the other hand, the latest IPCC report suggests that climate change might have the opposite effect:

> Some climate model simulations suggest that under future high-emissions scenarios, CO_2 radiative forcing causes rapid greening in the Sahel and Sahara regions via precipitation change (Claussen et al., 2003; Drijfhout et al., 2015). For example, in the BNU-ESM RCP8.5 simulation, the change is abrupt with the percentage of bare soil dropping from 45% to 15%, and percentage of tree cover rising from 50% to 75%, within 10 years (2050-2060) (Drijfhout et al., 2015). However, other modelling results suggest that this may be a short-lived response to CO_2 fertilization (Bathiany et al., 2014).

Land Gained Due to Rising Temperature

Human land use at present is limited by cold, not heat, as shown on Figure 2 above — the equator is populated, the polar regions are not. It follows that global warming, by shifting temperature contours towards the poles, should increase the amount of land warm enough for human habitation. Melting the icecap over Antarctica would require considerably more than three degrees of global warming and the southernmost land masses north of it are already inhabited, so significant land gains from warming will be in the northern hemisphere.

It seems likely that habitability depends more on minimal temperature than on average temperature. Figure 11.SM.1 of the sixth IPCC report shows minimum temperature of areas such as North America and Northern Asa going up by between 2 and 3.4 degrees per degree of global warming. Since warming is greater in colder climates, I take 3 degrees per degree as a reasonable guess for the increase in minimum temperature in the northern part of those zones. It follows that three degrees of global warming will increase the minimum temperature in the colder parts of those zones by about nine degrees. To estimate how much land that will shift from not quite habitable to at least barely habitable we need two numbers — what the length over land of the contour dividing barely habitable from not quite habitable is and how far a nine degree increase in temperature will shift it.

Figure 4 shows temperatures in January, which in the northern hemisphere should be close to the minimum, with contours every five degrees — much more precise information than Figure 1 provides for average temperatures. Combining the temperature information on Figure 4 with the population density information on Figure 2, the border of habitability appears to be at about -15°C. Nine degrees of warming will raise the January temperature of land currently at -24° to -15°, shifting land between those two contours from not quite habitable to at least barely habitable. From Figure 4 I estimate the distance between the -15° and -25° contours to average about 800 km, making the distance between -15° and -24° about 720 km. I estimate the length over land of those contours to be about 15,000 km. Hence the area between them is about 10,800,000 km^2.

While land at the northern edge of the zone is being warmed to barely habitable, from a population density of less than two per square km to a population density of more than two but less than ten, land a little farther south is being warmed from barely habitable to more than barely habitable, and the land south of that … . Combining those effects, 10.8 million square km is a rough estimate of the increase in fully usable land.

The analysis so far has used population density as the measure of habitability. As I suggested earlier, it might make more sense to use the ability to grow crops. Crop production maps for Canada and Russia show crops growing in about the same areas that appear habitable by population density.

Conclusion

On the basis of these calculations I find, for the effect of climate change by the end of the century under SSP3-7.0:

Loss of usable land by flooding due to sea level rise: 21,436 km^2

Loss of usable land due to the direct effect of warming: Probably close to zero.

Increase of usable land due to the direct effect of warming: 10.8 million km^2.

All of these numbers are very approximate, but they imply an increase in the amount of land warm enough to be usable by humans by more than twice the area of the United States. They also imply that nearly five hundred times as much land is gained through warming as is lost through sea level rise.

Previous Estimates

"Climate change impacts on global agricultural land availability" by Xiao Zhang and Ximing Cai 2011 *Environ. Res. Lett.* 6 014014 is a more elaborate analysis, focusing on the amount of arable land and taking account of a wider range of constraints including soil quality and humidity. It reaches a less optimistic conclusion, finding increases in some regions, decreases in others, with the net effect[3] ranging from -.8 million km^2 to +1.2 million km^2.

Ramankutty, N. et al 2002, "The global distribution of cultivable lands: current patterns and sensitivity to possible climate change," *Global Ecol. Biogeogr.* 11 377–92, gets result more similar to mine. The authors conclude "In the GCM-simulated climate of 2070–99, we estimate an increase in suitable cropland area of 6.6 million km^2." Since I am estimating land warm enough for human use and they are estimating land suitable for cultivation taking account of a variety of constraints, it is not surprising that their figure is lower than mine. The Sahara, for example, is warm enough for human use — there are densely populated regions that are warmer — but not currently suitable for cultivation.

One other difference between the two papers is that the former did not and the latter did take account of the reduction in water requirements for plants due to CO2 fertilization;[4] that might help explain the difference in their results. My calculation also did not take account of the effects of CO_2 fertilization since I was looking only at temperature, not water availability, which makes it puzzling that it is the second paper that gets results close to mine. A possible explanation is that the first article's model eliminated land that became insufficiently humid for agriculture due to climate change and the second article's model did not, since it took account of the reduced water requirements due to increased CO_2, but that is only a guess. There may have been other important differences.

Both models are more sophisticated than mine, since they include constraints on agriculture other than temperature. The advantage of mine is that it is simple enough so a lay reader can, with a little effort, check it, convince himself that the results are at least approximately correct. To do the same with either of the other two would require more expertise than anyone not in the field is likely to have and, even for someone with the relevant expertise, quite a lot of time and effort.

That is important for two reasons. The first is that the problem is complicated enough so that two different teams of professional authors can get very different answers, hence the reader, provided only with the answer, has no way of knowing which to believe. The second is that the effects of climate change are a subject that many people feel strongly about. In such an environment, the reader has good reason to put more weight on a crude analysis that he can test for himself than on a more sophisticated analysis that he cannot test.

I have tried to make all of the arguments in this section depend only on facts that an intelligent reader with access to the internet can check for himself. Trust but verify. If you cannot verify be reluctant to trust.

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[3] Not including land not available because of population increase.

[4] Ramankutty et. al. says they included CO2 fertilization. Zhang and Cai does not mention the issue, but one of the authors informs me that they did not.