# Thinking about habitability through the exploration of thresholds and tipping points in climate migration

Maria Franco Gavonel, PhD

Lecturer in Global Social Policy and International Development
University of York
maria.francogavonel@york.ac.uk

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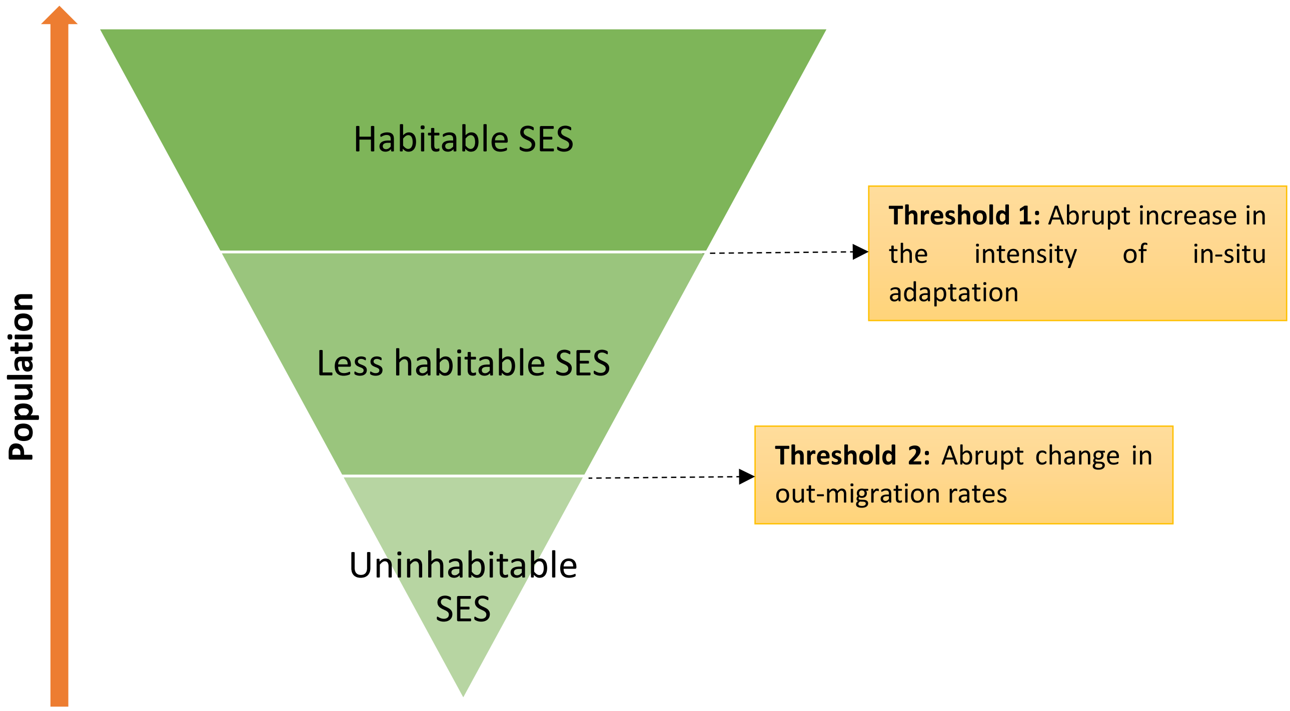
Climate change has brought to the front the discussion on whether a place is deemed liveable or not. However, this is not a discrete change of state, but a very fluid one that can be amenable to different factors that may accelerate or delay reaching certain thresholds in a social-ecological system (SES). As part of the HABITABLE project, we aim to advance the understanding of the relationship between the concepts of habitability and social tipping points – namely, tipping points in climate migration, or a point in a SES at which a small quantitative change in climate variability triggers a nonlinear change in out-migration rates (Adger et al., 2022). We do this by following a bottom-up approach, in which place-based physical systems and social contexts are taken into account in order to provide a more granular insight of this process (Horton et al., 2021).

Habitability can be defined as the capacity of a SES to sustain the lives and livelihoods of the human population that forms part of it (Gemenne et al., 2021). By defining habitability as a property of a SES, emphasis is put on the fact that it is the interaction among the *specific* elements of that SES, which results in a given capacity to support its inhabitants. For example, if members of a village adapted well to changes in environmental conditions *in that village*, it is not given that they will also adapt well if they were relocated to a different village. This is not trivial because it implies that even if the two places have similar characteristics, the relationship between the social and ecological elements of the SES may differ. People develop emotional bonds to places that represent a collection of meanings, values, and feelings associated with a locality (Szaboova et al., 2022). Thus, place attachment can foster a particular relationship within the SES that may contribute to its resilience (Adams, 2015).

The proposed definition of habitability also refers to the lives and livelihoods of the SES's inhabitants in order to highlight that this concept accounts for the possibility that environmental change could be life-threatening directly (for instance, if the survival of a population is affected by severe floods) or indirectly (for example, if their livelihoods were affected by a drought, so that their subsistence would be endangered by food insecurity).

Habitability can be seen as a latent variable, namely, one that cannot be directly observed, but that can be inferred through the observation of other variables (Greene, 2003). Habitability should then be understood as a continuum where in the upper end there is a SES that allows its population to thrive and in the lower end, one that prevents its inhabitants from doing so. In the context of climate migration (Adger et al., 2009; McLeman, 2018), two key thresholds can be considered as indicators that define three levels of habitability. Figure 1 illustrates this process. At the top of the inverted triangle, a habitable SES is characterised by the ability to allow its population to live and thrive without too much reliance on adaptation measures, either in the form of in-situ adaptation or in the form of out-migration. It is important to highlight, though, that even in these cases, *some* adaptation will still be needed since regular interaction of its inhabitants with the environment usually requires some degree of response to their surroundings. Thus, at this level of habitability, it is likely to observe households in which both in-situ adaptation and out-migration (of one or more household members) coexist in the same household – as they constitute different risk diversification strategies (Stark & Bloom, 1985). This implies that migration in itself does not constitute a tipping point since it already happens even when the SES is habitable. Moreover, there is a 'natural' rate of migration at which all voluntary migration takes place. At this point, a potential policy recommendation would be to enhance migration in order to facilitate mobility of those who are willing to move.

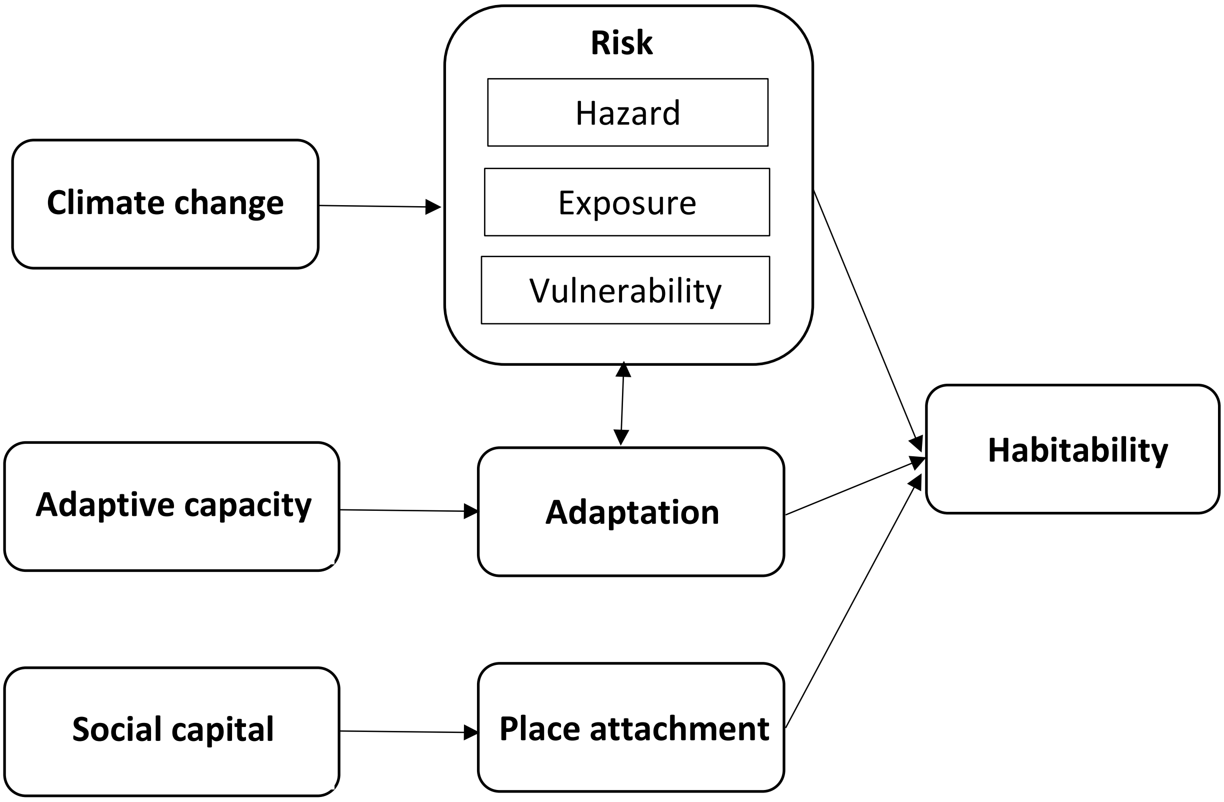
**Figure 1: Habitability and its thresholds**




As environmental conditions deteriorate and this SES becomes less habitable (i.e., a point located in the middle part of the inverted triangle), demand for adaptive measures in the locality rises and we observe a nonlinear increase in the intensity of in-situ adaptation (i.e., number of in-situ adaptation responses carried out by the household). For instance, in order to reduce the impact of more frequent and intense droughts, people may not only invest in water reservoirs, but they may also change cropping patterns and replace their crops with more resistant species (Sam et al., 2020). In this example, the household would increase its in-situ adaptation intensity from 1 to 3. If, on average, households exhibit a discontinuous increase in the intensity of in-situ adaptation, the SES would be reaching its first threshold. At this level, it is also likely that out-migration rates will increase, although just incrementally and not yet in an abrupt (i.e., discontinuous) manner. In Figure 1, there is a positive relationship between population and habitability: as more people out-migrate, population levels decrease. At this point, a potential policy recommendation would be to promote investment in adaptation responses in order to reduce the pressure that households face at this stage.

When this SES becomes uninhabitable (i.e., a point located at the bottom of the inverted triangle), the costs of in-situ adaptation outweigh its benefits and a decision on whether to have more household members as migrants (or even the full household) must be made. Furthermore, some people won't have the freedom to make this choice, but they will be forced to either leave or stay. At this point, we will observe an abrupt (i.e., discontinuous) change in out-migration rates, signalling that the SES is crossing its second threshold. However, this change could take place in either direction. On the one hand, if people are willing and/or capable of moving, out-migration rates will increase as a result of more voluntary and involuntary migration. On the other hand, if people are not willing to move and/or do not have the resources to do so, out-migration rates will decrease – and this population could end up trapped in their SES (Foresight: Migration and Environmental Change, 2011). In the latter case, it is likely that death rates or the frequency of illnesses (due to food insecurity, for example) will increase. Therefore, at this level of habitability, we will observe further shrinking of the population. Given these two potential mechanisms (i.e., out-migration and death/morbidity), population levels could be considered an indicator of habitability, namely the latter would be a sufficient (albeit not necessary) condition for the former. At this point, a potential policy recommendation would be to promote planned relocation of those who stayed in the locality due to resource constraints rather than due to willingness to stay.

**Figure 2: Drivers of habitability**




As alluded before, habitability depends on *both* physical and social conditions that affect a SES. In particular, habitability is a function of three variables: risk, adaptation responses, and place attachment (see Figure 2). Risk here refers to the probability of a loss, which depends on hazard (i.e., frequency and severity of an event), exposure (i.e., the accumulated value and proximity to potential damage), and vulnerability (i.e., susceptibility to damage) (Adger et al., 2022). It should be emphasised that vulnerability is determined by a set of individual characteristics (e.g., age, gender, ethnicity), household characteristics (e.g., wealth, size), and community characteristics (e.g., rurality, provision of basic services, social cohesion) that affect the extent to which people could be affected by a hazard. This goes in line with the notion that habitability is a situated concept that involves power relations that come into play through different factors affecting vulnerability (Farbotko & Campbell, 2022). Climate change affects the three elements of risk: it increases the frequency and intensity of climatic events (Seneviratne et al., 2021); it increases exposure by reducing the distance to damages (e.g., if a river changes course as a result of excess rain (Arnell & Gosling, 2014)); and it exacerbates vulnerability (e.g., if climate change affects gender relations within the household (Cattaneo et al., 2019)). The rise in risk increases the need for adaptation responses. The extent to which the latter will be implemented depends, in turn, on adaptive capacity. If effective, adaptation responses can reduce risk by lowering exposure (for example, by building river flood defences) and/or vulnerability (for instance, by increasing household income through remittances). The third element affecting the habitability of a SES is place attachment. As mentioned before, place attachment reinforces bonds within the elements of the SES, which in turn strengthen community resilience (Berkes & Ross, 2013). Place attachment is a function of social capital, defined here as the number of networks a person has built in their locality that can provide them benefits if necessary (adapted from (Paldam, 2008)). The resulting interplay between risk, adaptation responses, and place attachment will affect the SES's habitability.

In sum, climate change is likely to raise the risks for affected populations, reducing the level of habitability of a SES up to a point at which a small perturbation (for example, a marginal increase in temperature variability) could trigger a social tipping point. If adaptation responses are effective and they manage to reduce risk, then a SES could be more habitable and, therefore, less prone to exhibit social tipping points. Finally, if place attachment is strong within inhabitants of a SES, it could work as a deterrent of out-migration, thus delaying the occurrence of a social tipping point.

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