Supporting Information

Dispersal and Connectivity in Increasingly Extreme Climatic Conditions

David D. Hofmann[1,2,§] Dominik M. Behr[1,2] John W. McNutt[2]
Arpat Ozgul[1,2] Gabriele Cozzi[1,2]

April 27, 2024

[1] Department of Evolutionary Biology and Environmental Studies, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland.

[2] Botswana Predator Conservation Program, Wild Entrust, Private Bag 13, Maun, Botswana.

[§] Corresponding author: david.hofmann2@uzh.ch

Running Title: Dispersal in a Changing Climate

Keywords: climate change, conservation, dispersal, flood extremes, individual-based simulations, landscape connectivity, movement ecology, step-selection functions

S1 Dispersal Model

The model employed to simulate dispersal was based on an integrated step selection function (iSSF). In (integrated) step selection functions (iSSFs, Fortin et al., 2005; Avgar et al., 2016), observed GPS locations are converted into steps (the straight-line traveled between two GPS recordings (Turchin, 1998)) and compared to a set of *random* steps in a conditional logistic regression framework (Fortin et al., 2005; Thurfjell et al., 2014; Muff et al., 2020; Fieberg et al., 2021). The model presented in (Hofmann et al., 2023) used dispersal data collected on 16 dispersing AWDs from a free-ranging wild dog population in northern Botswana. GPS data during dispersal was collected at 4-hourly intervals and translated into steps of similar duration. Observed steps were then paired step with 24 random steps that were generated using a uniform distribution for turning angles $(-\pi, +\pi)$ and step lengths from a gamma distribution fitted to observed steps (scale θ = 6'308 and shape k = 0.37). It was then assumed that animals assigned to each observed and random step a selection score of the form (Fortin et al., 2005):

$$w(x) = exp(\beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n) \qquad \text{(Equation S1)}$$

Where $(x_1, x_2, ..., x_n)$ represent the covariate values along each of the steps and the $(\beta_1, \beta_2, ..., \beta_n)$ are the animal's relative selection strengths (Avgar et al., 2017) towards these covariates. The benefit of *integrated* SSFs over regular SSFs is that they provide a means to render two complementary "kernels". A *movement* kernel that describes general movement behavior of dispersing AWDs and a *habitat* kernel that describes preferences of AWDs with regards to environmental conditions (Fieberg et al., 2021). iSSFs also allow interactions among the two kernels and are thus suitable to render that movement behavior may change depending on habitat conditions. A fitted iSSF model can be used as an individual-based movement model to simulate dispersal (Signer et al., 2017; Hofmann et al., 2023).

S2 Dispersal Model Estimates

Figure S1 depicts estimates from the model developed by Hofmann et al. (2023) that we used to simulate dispersal trajectories in the present.

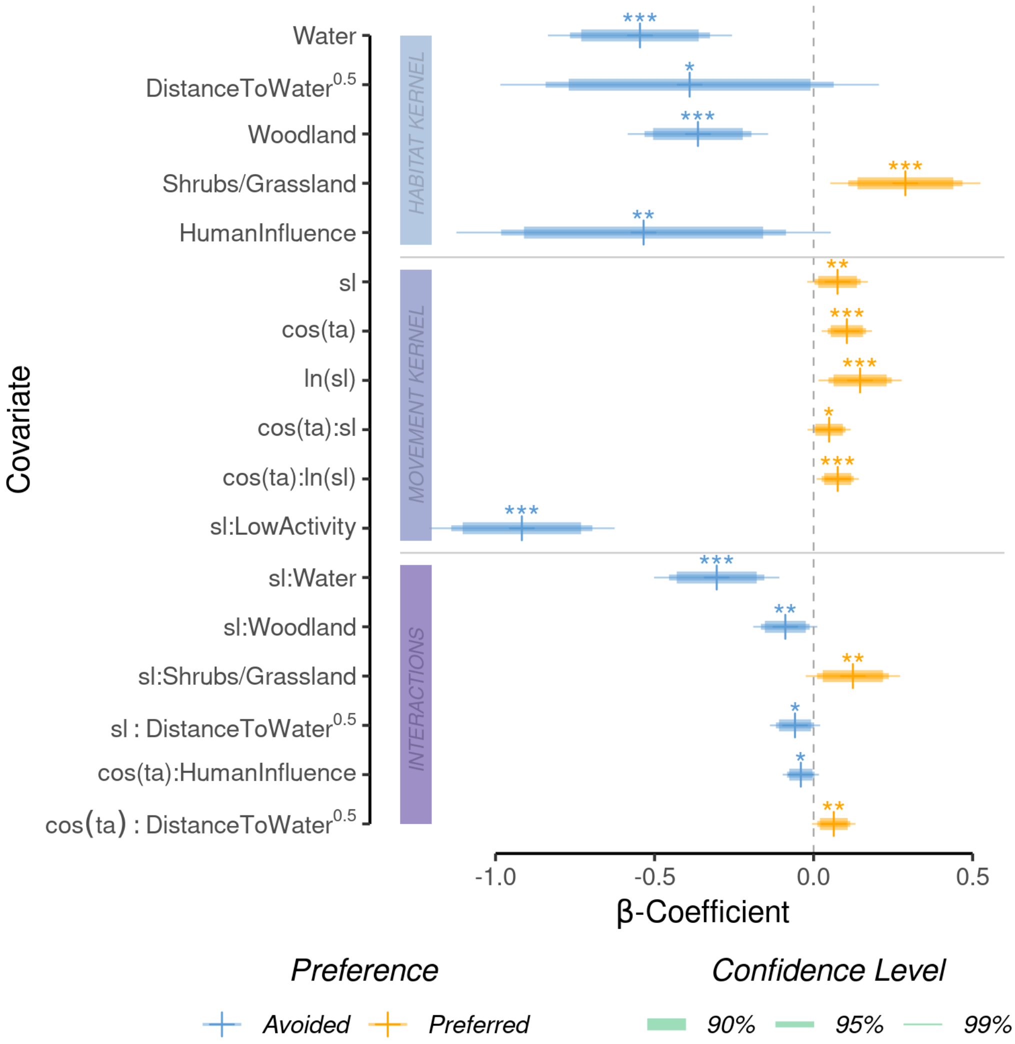

Figure S1: Model parameters from the step-selection model implemented by Hofmann et al. (2023). The model was fit to GPS data of dispersing African wild dogs and comprises of a habitat kernel (light blue band), a movement kernel (dark blue band), and their interactions (purple band). Abbreviations are as follows: sl = step-length, ln(sl) = natural logarithm of the step-length, cos(ta) = cosine of the relative turning angle.

S3 Immigration & Emigration by Source Area

Figure S2: Number of individuals emigrating from, or immigrating into a specific source area (focal area). Colors indicate into which other areas emigrants moved or from which other areas immigrants originate. For instance, the most left plot in the upper panel shows the number of individuals moving from source area 1 into the six other source areas during minimum and maximum flood, respectively.

S4 Source-Specific Inter-Patch Connectivity

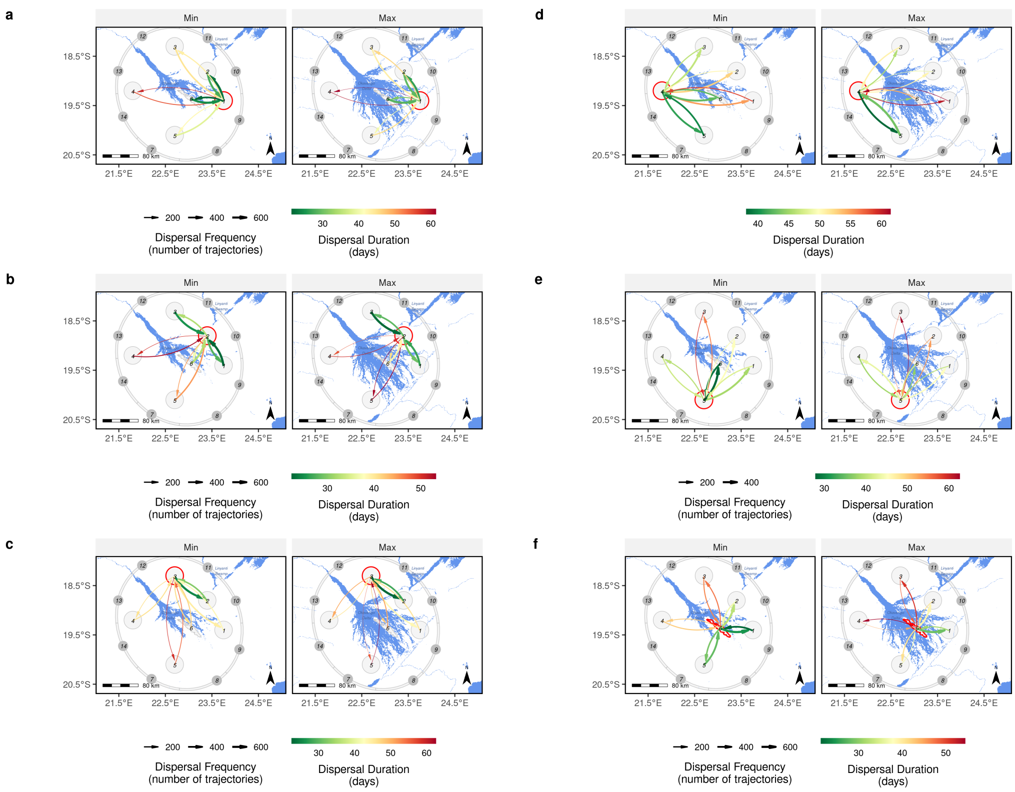

Figure S3: Spatial representation of inter-patch connectivity derived for each source area separately across the two extreme flood-scenarios. The focal source area of each subfigure is highlighted by a red circle. Subfigure (a), for instance, depicts inter-patch connectivity for source area 1.

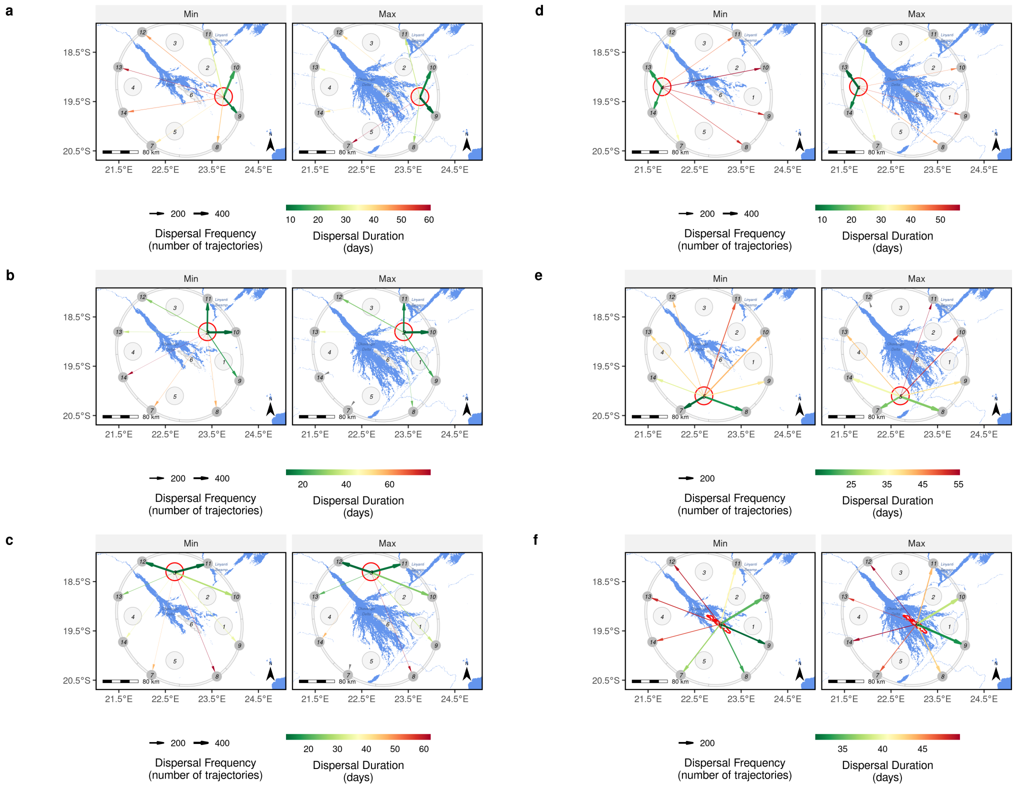

Figure S4: Spatial representation of egression patterns derived for each source area separately across the two extreme flood-scenarios. The focal source area of each subfigure is highlighted by a red circle. Subfigure (a), for instance, depicts the number of individuals egressing from source area 1.

S5 Dispersal into Egression Zones

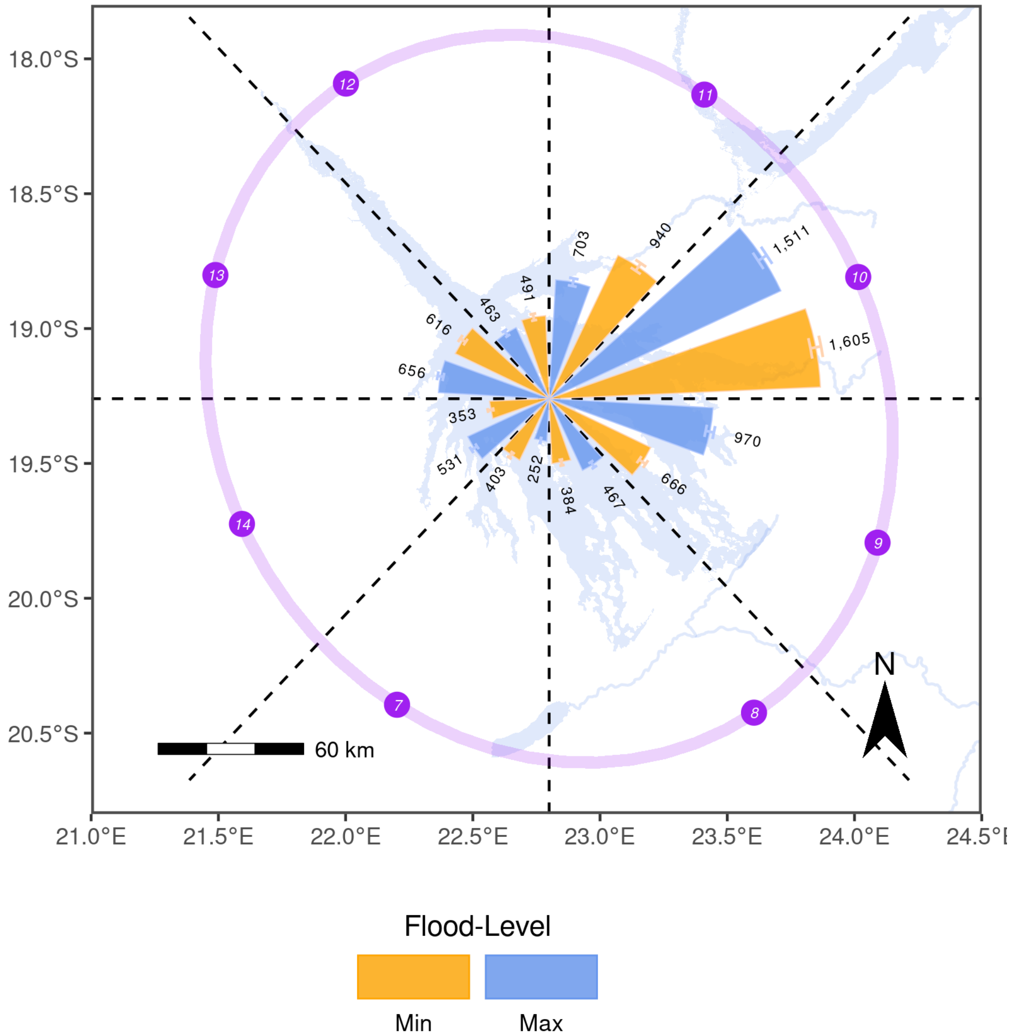

Figure S5: Absolute number of simulated trajectories running into each of the designated egression zones (purple) during minimum and maximum flood.

S6 Source-Specific Intensity of Use

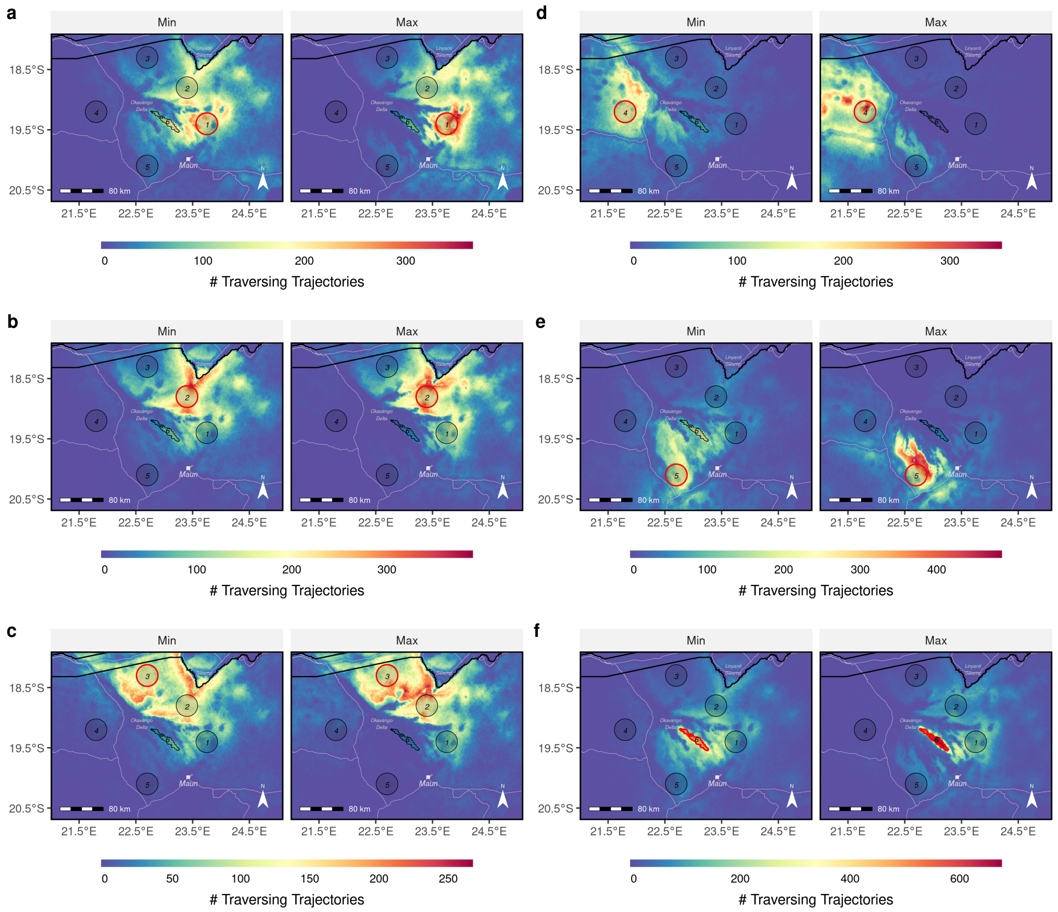

Figure S6: Heatmaps showing the intensity of use for each source area separately across the two extreme flood-scenarios. The focal source area of each subfigure is highlighted by a red circle. Subfigure (a), for instance, depicts the heatmaps for source area 1.

S7 Source-Specific Betweenness

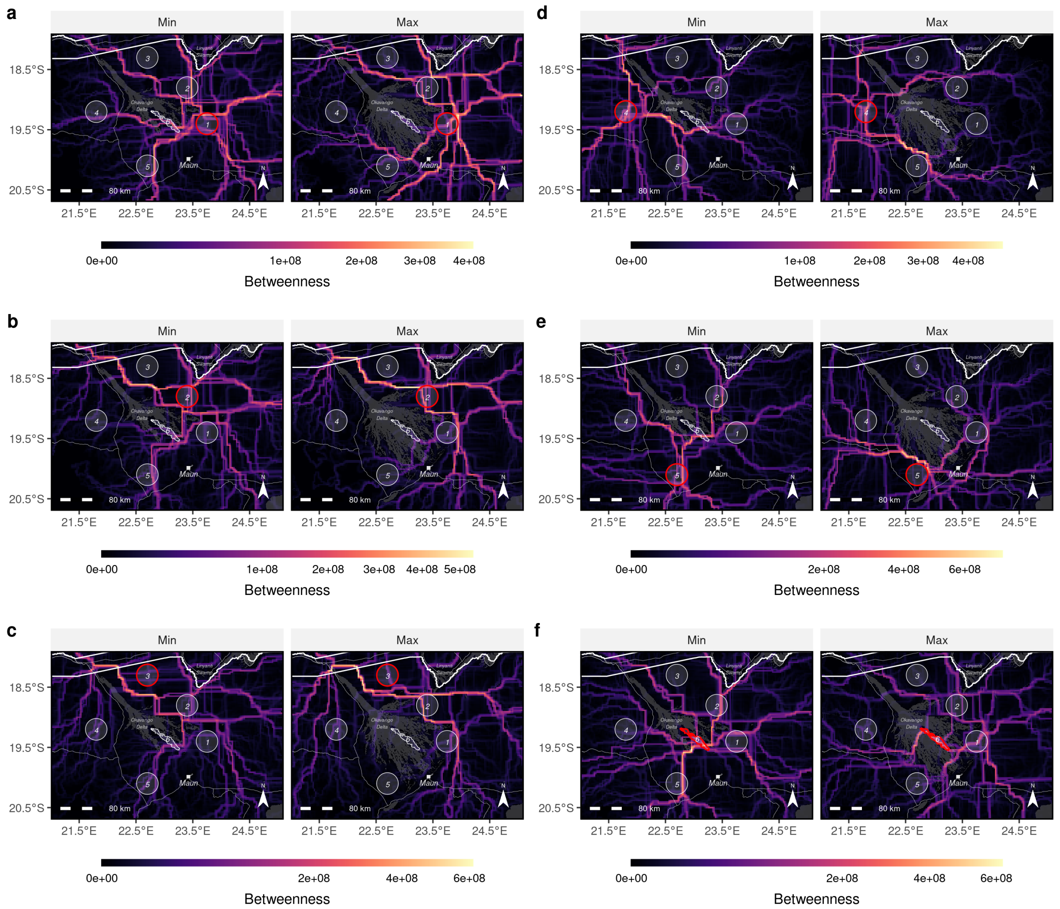

Figure S7: Betweenness maps prepared for each source area separately across the two extreme flood-scenarios. The focal source area of each subfigure is highlighted by a red circle. Subfigure (a), for instance, depicts the betweenness maps for source area 1.

S8 Source-Specific Human-Wildlife Conflict

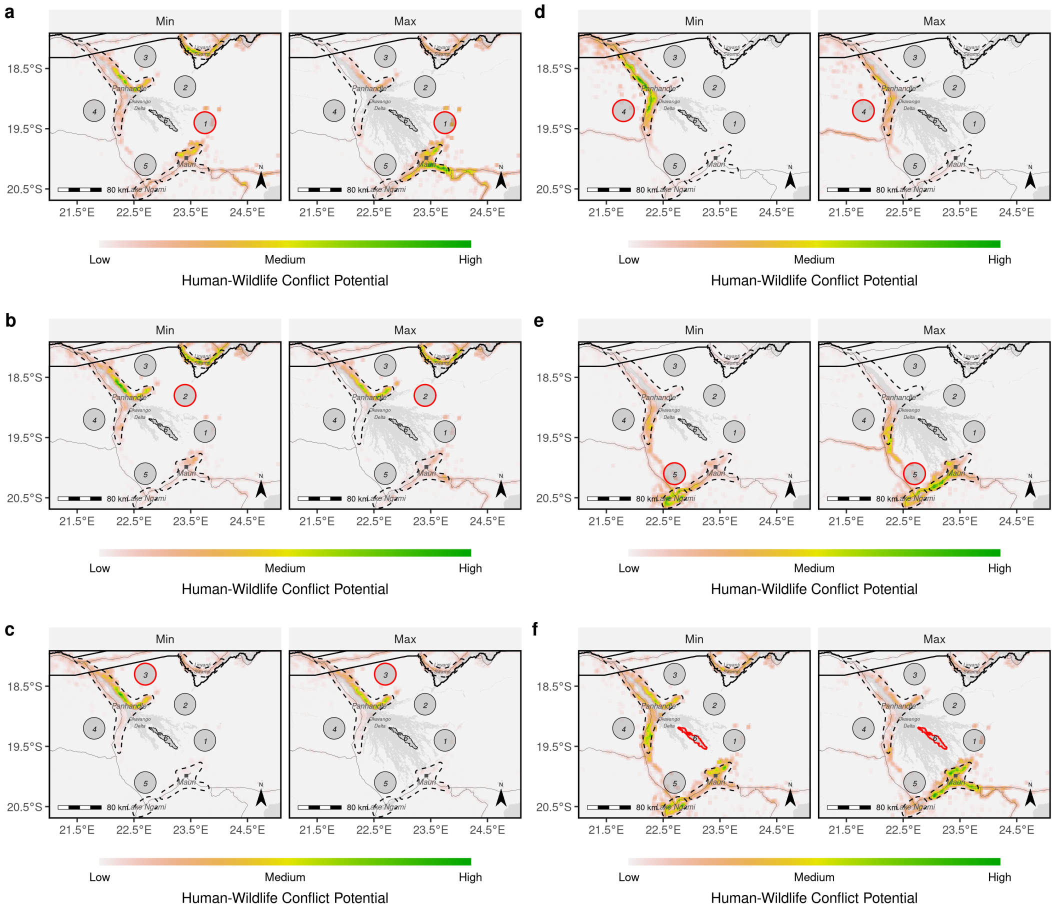

Figure S8: Human wildlife conflict maps prepared for each source area separately across the two extreme flood-scenarios. The focal source area of each subfigure is highlighted by a red circle. Subfigure (a), for instance, depicts the human wildlife-conflict maps for source area 1. Dotted shapes were used to compare human-wildlife conflict within specific areas (see also Figure S9).

S9 Changes in Potential for Human-Wildlife Interactions

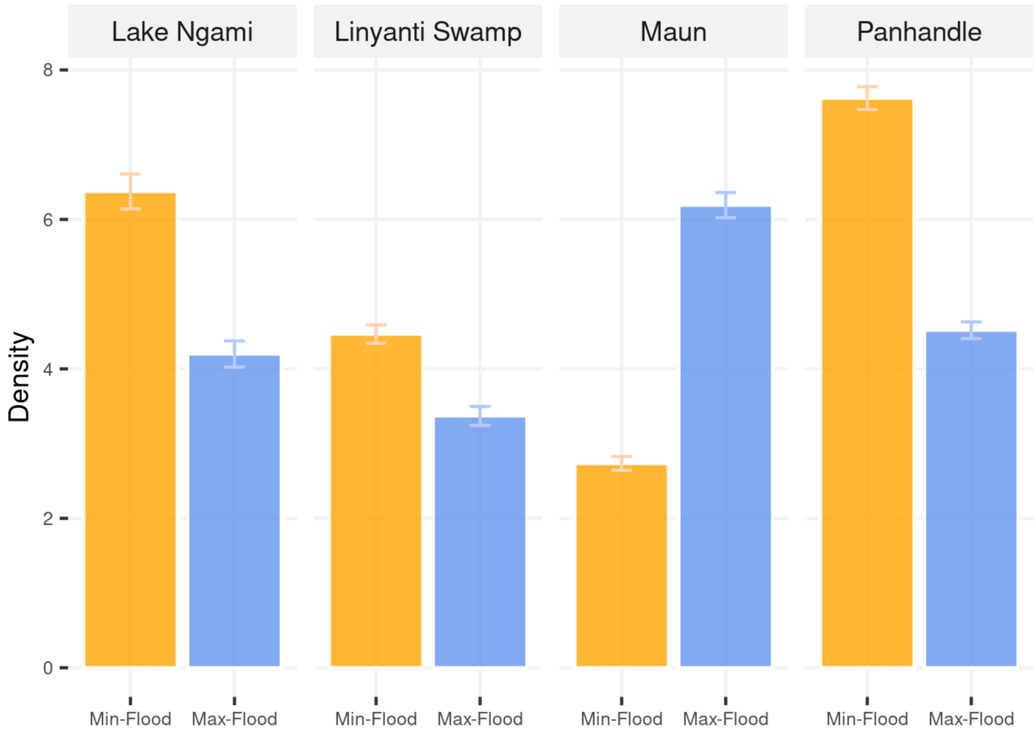

Figure S9: Number of simulated trajectories within the vicinity of human-dominated landcapes in different areas of interest across the minimum and maximum flood scenarios. The areas are represented by the black dotted shapes in Figure S8

S10 Alternative Approach to Map Potential Human-Wildlife Interactions

To identify potential hotspots for human-wildlife conflict and generate Figure 6c, we isolated all simulated animal locations within 500 meters to a human-influenced grid-cell (Figure 6c in the main manuscript). To compute the needed distances, we assumed human-influence to be binary (influence = 1, no influence = 0), thus ignoring potential impacts of human density. We argue that the severity of human-wildlife conflict is not necessarily related to human density, yet humans' attitude towards wildlife. Attitude often correlates negatively with habitat suitability for the species of interest (Behr et al., 2017), and so conflict is often pronounced in peripheral areas (McNutt et al., 2017). Since we lacked detailed information of anthropogenic resistance (Ghoddousi et al., 2021) across the study area, we deemed a binary representation of human impacts as appropriate. Alternatively, one can also compute a compound score by multiplying the human-influence layer with the heatmaps derived from simulated dispersal. This is presented in Figure S10, where we multiplied the heatmaps (Figure S10a) with the human-influence layer (Figure S10b) and produced maps showing potential for human-wildlife conflict. Qualitatively, the maps in Figure S10 are very similar to the ones presented in Figure 6c.

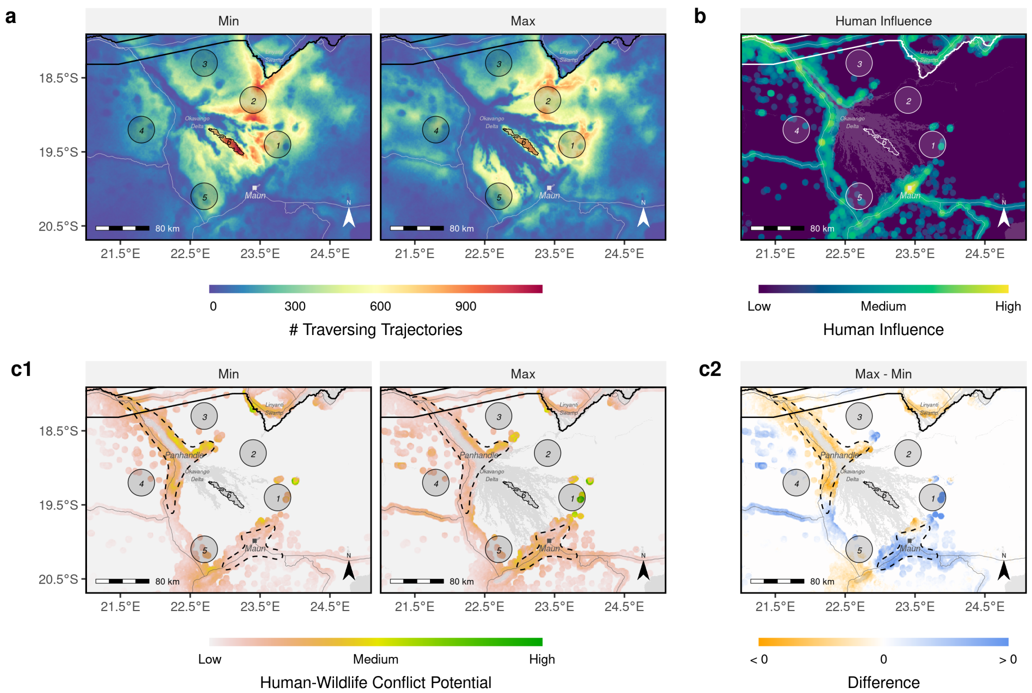

Figure S10: Alternative approach to quantifying the potential for human-wildlife conflict. Here, we multiplied the heatmaps (a) with the human-influence layers (b) to obtain human-wildlife conflict maps (c1). We also computed a difference map (c2) for the layers shown in (c1).

References

Avgar, T., Lele, S. R., Keim, J. L., & Boyce, M. S. (2017). Relative Selection Strength: Quantifying Effect Size in Habitat- and Step-Selection Inference. *Ecology and Evolution*, *7*(14), 5322–5330. https://doi.org/10.1002/ece3.3122

Avgar, T., Potts, J. R., Lewis, M. A., & Boyce, M. S. (2016). Integrated Step Selection Analysis: Bridging the Gap Between Resource Selection and Animal Movement. *Methods in Ecology and Evolution*, *7*(5), 619–630. https://doi.org/10.1111/2041-210X.12528

Behr, D. M., Ozgul, A., & Cozzi, G. (2017). Combining Human Acceptance and Habitat Suitability in a Unified Socio-Ecological Suitability Model: A Case Study of the Wolf in Switzerland. *Journal of Applied Ecology*, *54*(6), 1919–1929. https://doi.org/10.1111/1365-2664.12880

Fieberg, J., Signer, J., Smith, B., & Avgar, T. (2021). A 'How to' Guide for Interpreting Parameters in Habitat-Selection Analyses. *Journal of Animal Ecology*, *90*(5), 1027–1043. https://doi.org/10.1111/1365-2656.13441

Fortin, D., Beyer, H. L., Boyce, M. S., Smith, D. W., Duchesne, T., & Mao, J. S. (2005). Wolves Influence Elk Movements: Behavior Shapes a Trophic Cascade in Yellowstone National Park. *Ecology*, *86*(5), 1320–1330. https://doi.org/10.1890/04-0953

Ghoddousi, A., Buchholtz, E. K., Dietsch, A. M., Williamson, M. A., Sharma, S., Balkenhol, N., Kuemmerle, T., & Dutta, T. (2021). Anthropogenic Resistance: Accounting for Human Behavior in Wildlife Connectivity Planning. *One Earth*, *4*(1), 39–48. https://doi.org/10.1016/j.oneear.2020.12.003

Hofmann, D. D., Cozzi, G., McNutt, J. W., Ozgul, A., & Behr, D. M. (2023). A Three-Step Approach for Assessing Landscape Connectivity Via Simulated Dispersal: African Wild Dog Case Study. *Landscape Ecology*, *38*(4), 981–998. https://doi.org/10.1007/s10980-023-01602-4

McNutt, J. W., Stein, A. B., McNutt, L. B., & Jordan, N. R. (2017). Living on the Edge: Characteristics of Human-Wildlife Conflict in a Traditional Livestock Community in Botswana. *Wildlife Research*, *44*(7), 546. https://doi.org/10.1071/WR16160

Muff, S., Signer, J., & Fieberg, J. (2020). Accounting for Individual-Specific Variation in Habitat-Selection Studies: Efficient Estimation of Mixed-Effects Models Using Bayesian or Frequentist Computation. *Journal of Animal Ecology*, *89*(1), 80–92. https://doi.org/10.1111/1365-2656.13087

Signer, J., Fieberg, J., & Avgar, T. (2017). Estimating Utilization Distributions from Fitted Step-Selection Functions. *Ecosphere*, *8*(4), e01771. https://doi.org/10.1002/ecs2.1771

Thurfjell, H., Ciuti, S., & Boyce, M. S. (2014). Applications of Step-Selection Functions in Ecology and Conservation. *Movement Ecology*, *2*(1), 4. https://doi.org/10.1186/2051-3933-2-4

Turchin, P. (1998). *Quantitative Analysis of Movement: Measuring and Modeling Population Redistribution in Animals and Plants*. Sinauer Associates.