Flooding of the Okavango Delta influences Connectivity for Dispersing African Wild Dogs

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Abstract

Climate change is expected to considerably impact vital rates of endangered species. In particular dispersal, the phase during which species leave their natal area and attempt to find a new territory to settle, may

We utilize seasonal changes in the flooding regime across the Okavango delta as a large scale natural experiment to investigate how environmental changes impact species' ability to disperse, and utlimately connectivity between remaining subpopulations. Specifically, we apply individual-based dispersal simualtions to simulate dispersal trajectories under two extreme scenarios, assuming minimal and maximum flood extents.

Our results show that during years of minimum flood extent, the Okavango delta releases vast areas that dispersers use as movement corridors, whereas during years of extreme flood the delta's floodwaters pose a considerable dispersal barrier that forces dispersing individuals closer towards human settlements. Besides a better understanding of the conservation needs for the African wild dog, our study also provides evidence that incorporating seasonality in studies of connectivity is imperative to more accurately predict the dispersal ability of endangered species.

Contents

1 Introduction

1.1 Climate Change

1.2 Vital Rates

1.3 Dispersal

1.4 Connectivity

Dispersal is an important, if not the important, driver of landscape connectivity and therefore of major interest to conservation authorities.

1.5 Okavango Delta and African Wild Dogs

The Okavango delta in Southern Africa poses a unique opportunity to study the impacts of environmetal change on species dispersal ability and connectivity in large scale natural experiment setup.

2 Methods

2.1 Study Area

The study area for this analysis was focused on the Okavango delta and its surroundings in Southern Africa, comprising parts of Angola, Namibia, Botswana, Zimbabwe, and Zambia Figure 1. To accomodate for the long distance dispersal events commonly observed in the African wild dog, we considered a large rectangular extent stretching from ... to ...., totalling to an area of xx km. The dominant geographical feature in this region is the Okavango delta, the world's largest inland delta and main driver of seasonal environmental change in the region. While local rainfalls marginally impact water levels across the delta, the main flood-pulsing rythm is driven by the water-influx from the Okavango river. The Okavango carries rain waters collected the Angolian highlands into the delta's distributaries. Although precipitation in Angola peaks around ..., the water arrives in the delta with a delay of ... It only slowly descends through the delta and reaches the distal ends (at the faults) around ... At minimum extent, the flood covers an area of around xx km, whereas during maximum flood it covers ... Vegetation in the study area can largely be categorized into dense mopane forest, mixed acacia woodland, and plain grassland. Human influence in the study area is generally low and mainly concentrated to small villages at the western periphery of the delta, as well as to the city of Maun at the southern tip of the delta. Large portions of land are dedicated national parks, game reserves or forest reserves and the area is part of the world's largest transboundary conservation initiative, the Kavango-Zambezi Transfrontier Conservation Area.

2.2 Spatial Habitat Layers

We represented the physical landscape through which dispersers could move by a set of spatially referenced habitat layers each resolve at 250m x 250m. The set of layers included water-cover, distance-to-water, tree-cover, shrub/grassland-cover, and a human influence layer depicting anthropogenic influences through villages, roads, and agriculture. A detailed description of the different layers is provided in **??**. Importantly, the water-cover and the derived distance-to water layers were generated using MODIS Terra satellite imagery, which enabled us to generate weekly updated layers that provided detailed information about the flood-extent at any given point in time. We had a total of 8xx remote sensed floodmaps at our disposal and used them to generate two extreme scenarios; a minimal and maximum flood scenario. To create the minimum flood scenario, we tallied the 50 floodmaps with smallest flood extent into an average image. Finally, we created a binary map... Similarly, we created an average image for high flood using the 50 most flooded maps. The resulting maps are depicted in Figure 2. For completeness we also generated an "average" floodmap by averaging across all 800 floodmaps available to us. The results based upond this layer are presented in the Appendix.

2.3 Dispersal Model

Our dispersal model was based on a previously parametrized and validated *integrated step-selection function (iSSF)* applied to the dispersal data of 16 dispersing African wild dogs inhabiting the surroundings of the Moremi National Park in the Okavango delta (**?**). The iSSF model consists of two complementary "kernels" plus their interactions. The first kernel is a movement kernel and describes general movement behavior of dispersing AWDs, irrespective of habitat conditions. The second kernel is a habitat kernel and describes preferences of AWDs with regards to environmental conditions. Finally, the model also includes interactions among the two kernels and therefore allows to render how movement behavior changes depending on habitat conditions.

2.4 Source Areas

We simulated dispersing AWDs originating from nine distinct source patches located in the vicinity of the Okavango delta. The source areas were generated as follows. First, we overlayed the OD with an oval that was bound by geographical landmarks; in the north, the oval was bound by the Inflow of the Okavango river into the "pan-handle" of the OD, north-east the oval was bound by the Selinda-Spillway and the Linyanty swamp, towards South-East it was bound by the Boteti river, and towards South-West by Lake Ngami. We then dissected the polygon into five distinct patches using the same natural landmarks (Figure 1). Patch one was given by the area south of the Boteti river and area two by the area north of it up until the panhandle. Area three stretched from the region easf of Maun towards north until the Selinda-spillway, whereas area four stretched north of the spillway until west towards the panhandle. Finally, a fifrth source area marked the peninsuale in the center of the OD. In addition to these five source patches, we also distributed small peripheral patches that we used to simulate individuals immigrating *into* system and to keep track of individuals leaving it.

2.5 Dispersal Simulation

For both environmental scenarios we simulated 1'000 individuals dispersing from each of the nine source area depicted in Figure 1. The simulation algorithm was based on the algorithm described in **??** and works as follows. A random location within the source area is chosen as starting point. Originating from the starting point, a set of 25 random steps are generated by sampling step lengths from a gamma distribution fitted to observed steps (what is a step?) (shape = , scale =) and turning angles from a uniform distibution on $(-\pi, +\pi)$. Along each random step the underlying spatial covariates are extracted and relevant movement metrics are computed (i.e. log(sl), cos(ta), ta).

We used a previously parametrized dispersal model to simulate dispersal trajectories of African wild dogs across the study area. To simulate dispersing wild dogs, we employed the simulation framework presented in **?**. In this framework, a movement model that renders habitat and movement preferences of dispersing individuals is parametrized using step-selection functions. Once parametrized, the model can be employed to simulate virtual dispersers moving across the landscape.

We released virtual dispersers at random locations within the four distinct source areas depicted in Figure 1. From each source area we simulated xx individuals moving across the landscape at minimum flood and another xx individuals at maximum flood. For comparison, we also ran the simulations for a medium flood extent, yet the results for this will be presented in the appendix.

2.6 Connectivity

To gain insights into landscape connectivity from the simulated dispersal events, we prepared three complementary connectivity maps (see again (**?**)); a heatmap, indicating the absolute frequency at which each pixel in the study area was traversed by a virtual disperser, a betweenness map, highlighting pixels of particular importance to facilitate movement from one area to another, and a map of interpatch connectivity, depicting the presence and intensity of functional links between source areas. To compute the heatmap, we counted how many times each pixel in the study area was traversed by a virtual disperser. To calculate betweenness, we overlayed the study area with a regular grid and used the simulated trajectories to determine movements from one grid-cell to another. Specifically, we counted how often transitions from one grid-cell to any other occured. The centerpoint of each grid-cell then served as network node, and the number of transitions from one cell to another as weights between the respective nodes. Based on the so generated network, we then computed betweenness scores for all network nodes (i.e. for all grid-cells across the study area). Lastly, to compute interpatch connectivity, we determined the frequency at which virtual dispersers originating from one source area reached any of the other source areas. We also calculated the average dispersal duration needed until individuals reached the respective area.

3 Results

4 Discussion

5 Authors' Contributions

D.D.H., D.M.B., A.O. and G.C. conceived the study and designed methodology; D.M.B., G.C., and J.W.M. collected the data; D.D.H. and D.M.B. analysed the data; G.C. and A.O. assisted with modeling; D.D.H., D.M.B., and G.C. wrote the first draft of the manuscript and all authors contributed to the drafts at several stages and gave final approval for publication.

6 Data Availability

GPS movement data of dispersing wild dogs is available on dryad (?). Access to R-scripts that exemplify the application of the proposed approach using simulated data are provided through Github (`https://github.com/DavidDHofmann/DispersalSimulation`). In addition, all codes required to reproduce the African wild dog case study will be made available through an online repository at the time of publication.

7 Acknowledgements

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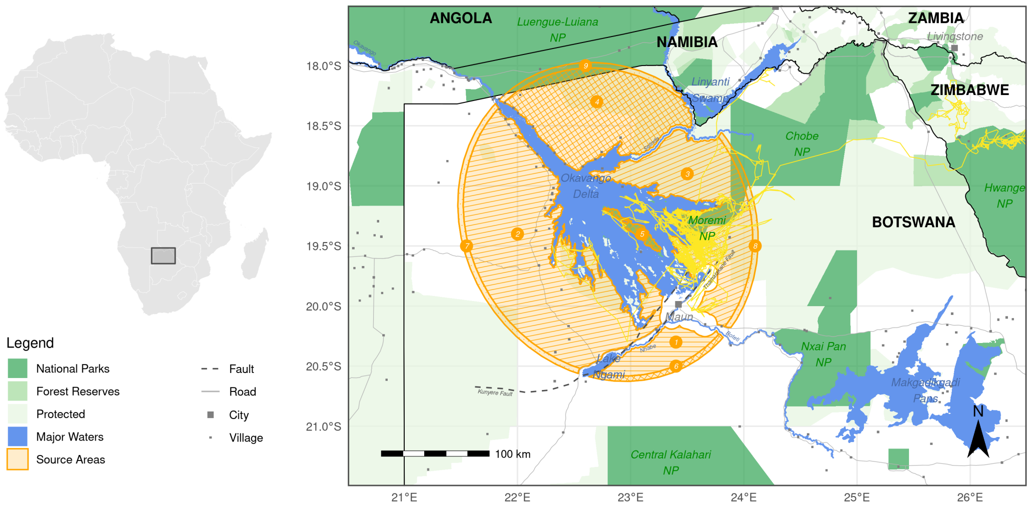
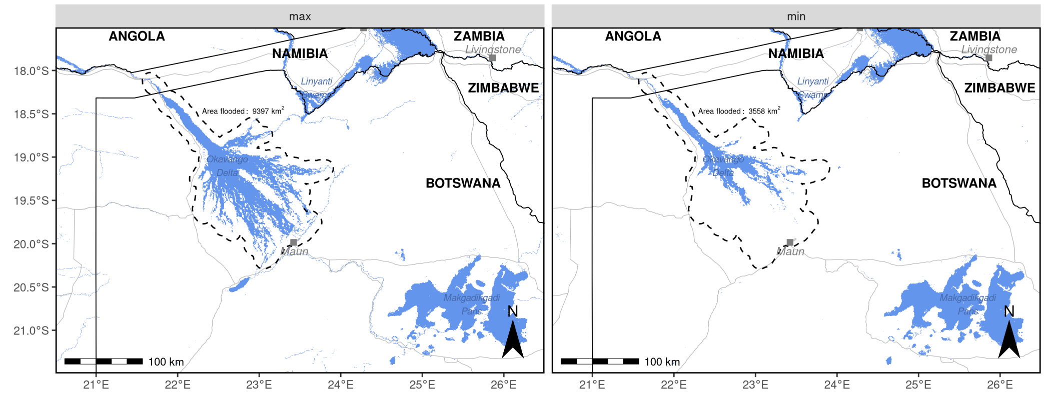


Figure 1: Study area across which we simulated dispersal events. Virtual dispersers were released at random locations within the orange source areas.



max
ANGOLA
NAMIBIA
ZAMBIA
Livingstone
ZIMBABWE
Linyanti
Swamp
Area flooded : 9397 km²
Okavango
Delta
BOTSWANA
Maun
Makgadikgadi
Pans
N
100 km
18.0°S
18.5°S
19.0°S
19.5°S
20.0°S
20.5°S
21.0°S
21°E
22°E
23°E
24°E
25°E
26°E
min
ANGOLA
NAMIBIA
ZAMBIA
Livingstone
ZIMBABWE
Linyanti
Swamp
Area flooded : 3558 km²
Okavango
Delta
BOTSWANA
Maun
Makgadikgadi
Pans
N
100 km
21°E
22°E
23°E
24°E
25°E
26°E

Figure 2

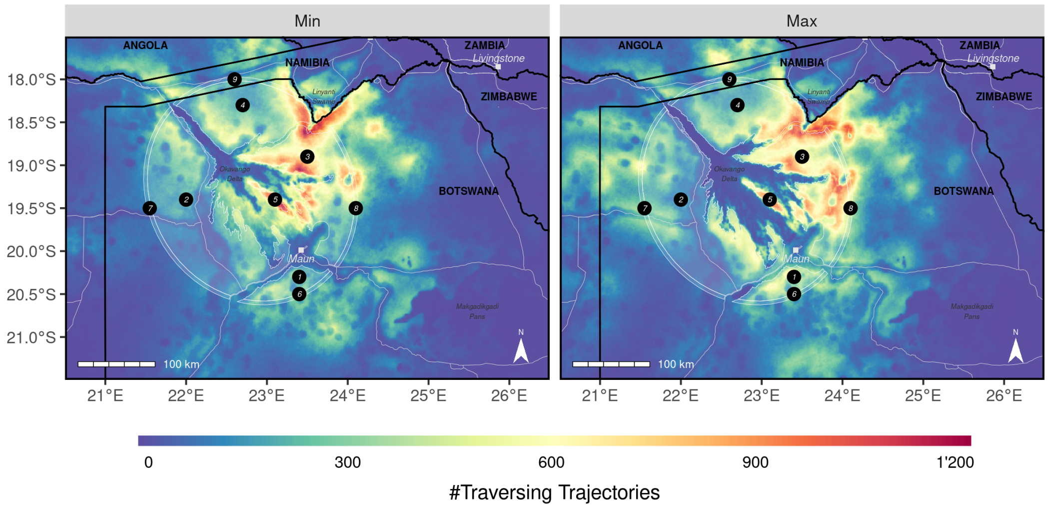
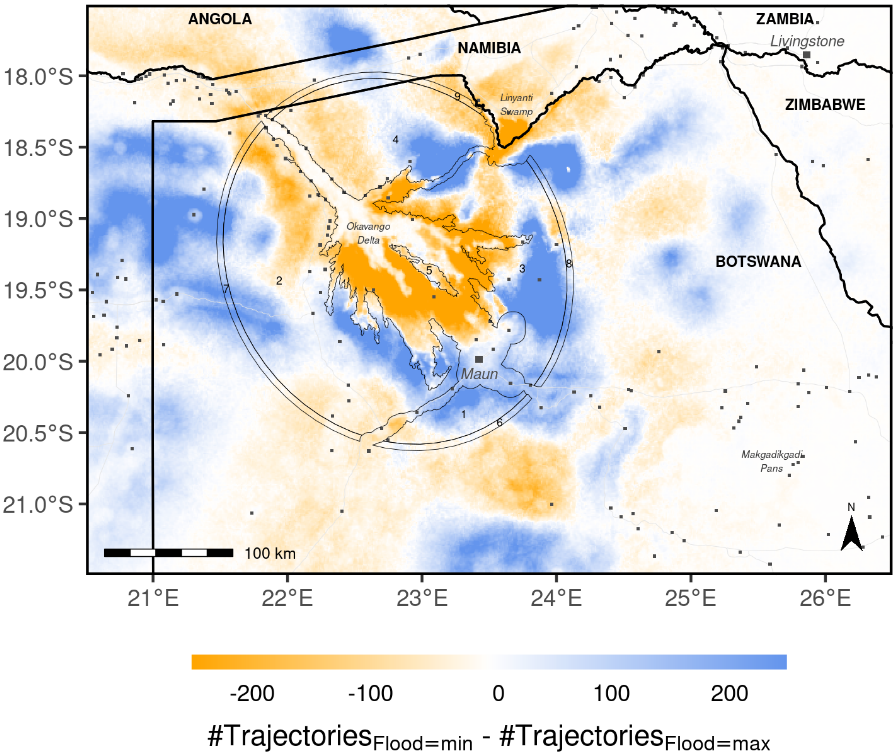

Min
Max
ANGOLA
NAMIBIA
ZAMBIA
Livingstone
ZIMBABWE
BOTSWANA
Maun
100 km
N
18.0°S
18.5°S
19.0°S
19.5°S
20.0°S
20.5°S
21.0°S
21°E
22°E
23°E
24°E
25°E
26°E
0
300
600
900
1'200
#Traversing Trajectories

Figure 3


ANGOLA
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19.5°S
20.0°S
20.5°S
21.0°S
21°E
22°E
23°E
24°E
25°E
26°E
-200
-100
0
100
200
#Trajectories$_{Flood=min}$ - #Trajectories$_{Flood=max}$

Figure 4