Least Cost Path and Individual Based Models for Hominin Dispersal Routes Out of East Africa into the Levant

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Introduction

The successful dispersal of Pleistocene hominins out of Africa marked a crucial event in our lineage's rise as a dominant global species. Yet, questions remain regarding when and through which geographic routes hominins left Africa during their expansion to Eurasia. The Nile basin and the Strait of Bab-al-Mandab (southern end of the Red Sea) are often cited as the likely pathways of early human expansion out of Africa[1-2]. However, the role of other geographic regions in hominin dispersal remains unclear.

Objective

To identify areas that would have served as viable pathways for hominin dispersal from East Africa to the Levant.

Methods

The study employed analytical tools in the Geographic Information System (GIS) and computational statistics (in *R*) to construct models, namely Least Cost Path (LCP) and Individual Based Model (IBM) that would find the least-resistance pathways (in terms of energy cost and resource scarcity) from East Africa to the Levant. Elevation, topographic roughness, slope, stream flow and Net Primary Productivity for the present time were used as input variables in constructing the models.

Designing the LCP

Each input variable was classified into five classes, and each class assigned a cost-weight, ranging from 0 - 5; **0** = least cost or the most desirable, **5** = the least desirable (Table 1). In the subsequent steps, a cost raster map depicting the cost of travel through each represented pixel and the LCP (cost distance) between the origin and destination points were generated. Three hypothetical points-of-origin (**O-1** = 5.1^{0}N, 36.2^{0}E; **O-2** = 7.8^{0}N, 38.6^{0}E, and **O-3** = 10.2^{0}N, 40.7^{0}E) and one destination point (**D**) on northern Sinai (30.8^{0}N, 32.8^{0}E) were selected. These landmarks represent the modelled area reasonably.

Cost-weight ranges	Stream density	Topographic roughness	Elevation (m)
0	106.7 - 451		
1	25 - 106.7	0.7 - 3.8	0-3000
2	5.7 - 25	0 - 0.7	0-3000
3	1- 5.7	3.8 - 9.7	0-3000
4	0 -1	9.7 - 16	0-3000
5		16 - 31	>3000

Table 1. Classified input variables and corresponding cost-weight values.

Designing the IBM

There is a single individual in the simulation, a "disperser" who spawns in a random location along the Main Ethiopian Rift. Each loop of the simulation gives the disperser a "view" of the unvisited area surrounding it based on elevation, slope, fresh water density, salt water density, and net primary productivity. The program then weights each area (landscape cells) based on how well they compare to areas occupied by hunter gatherers from Binford's datasets[3]. Cell selection is repeated 15,000 times, until the individual crossed the landscape, thereby completing a dispersal event. We iterated 10,000 dispersal events. The result of the simulation is shown in Figure 6.

```r
coordslog <- matrix(NA,ncol=3,nrow=nsims)
coordslog[1,1:2] <- coords

a <- cellFromXY(DEM, coords)
g <- cbind(a, V=V[a], U=U[a], W=W[a], R=R[a], N=N[a], L1=L1[a], L2=L2[a], S=S[a])

occupied <- g[1]

for (i in 2:nsims) {

  b <- adjacent(DEM, cells=g[1], directions=16, sorted=TRUE, pairs=FALSE)
  d <- cbind(b, V=V[b], U=U[b], W=W[b], R=R[b], N=N[b], L1=L1[b], L2=L2[b], S=S[b])

  d <- d[!is.na(d[,2]),,drop=FALSE]
  d <- d[!(d[,1] %in% occupied),,drop=FALSE]

  # If stuck - expand
  while(nrow(d)<1) {
    a_candidates <- cellFromXY(DEM, xyFromCell(DEM, b))
    a <- sample(a_candidates)[1]
    b <- adjacent(DEM, cells=a, directions=16, sorted=TRUE, pairs=FALSE)
    d <- cbind(b, V=V[b], U=U[b], W=W[b], R=R[b], N=N[b], L1=L1[b], L2=L2[b], S=S[b])

    d <- d[!is.na(d[,2]),,drop=FALSE]
    d <- d[!(d[,1] %in% occupied),,drop=FALSE]
  }
```

A code sample for the extraction of the various variables used in the IBM generating process.

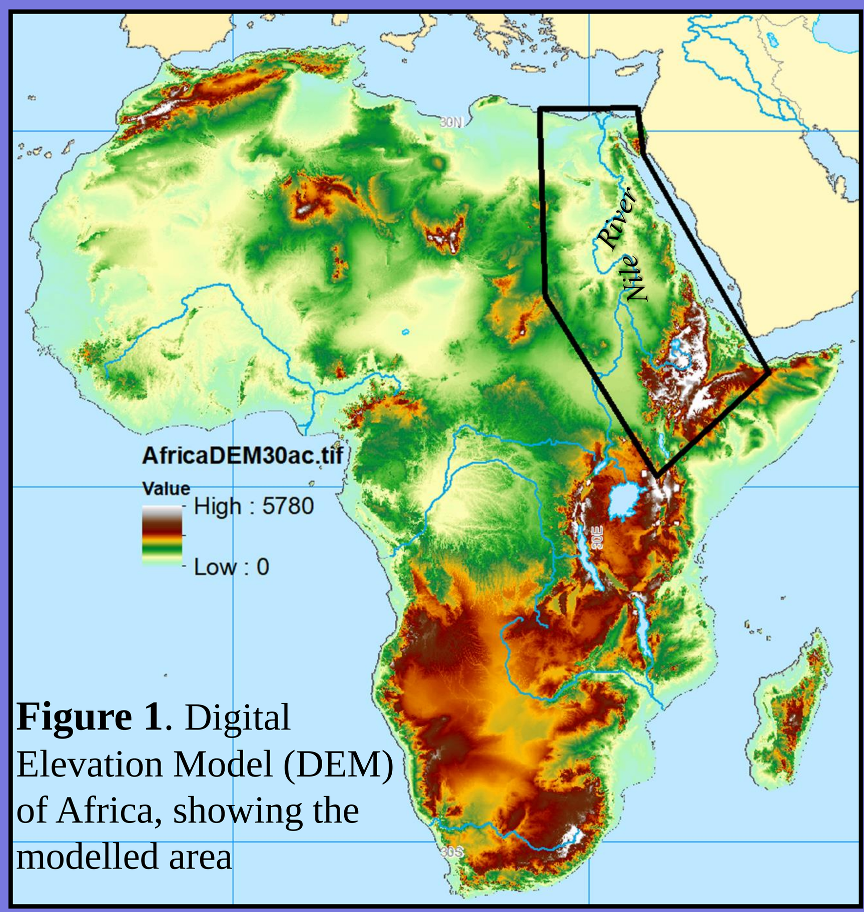

Figure 1. Digital Elevation Model (DEM) of Africa, showing the modelled area

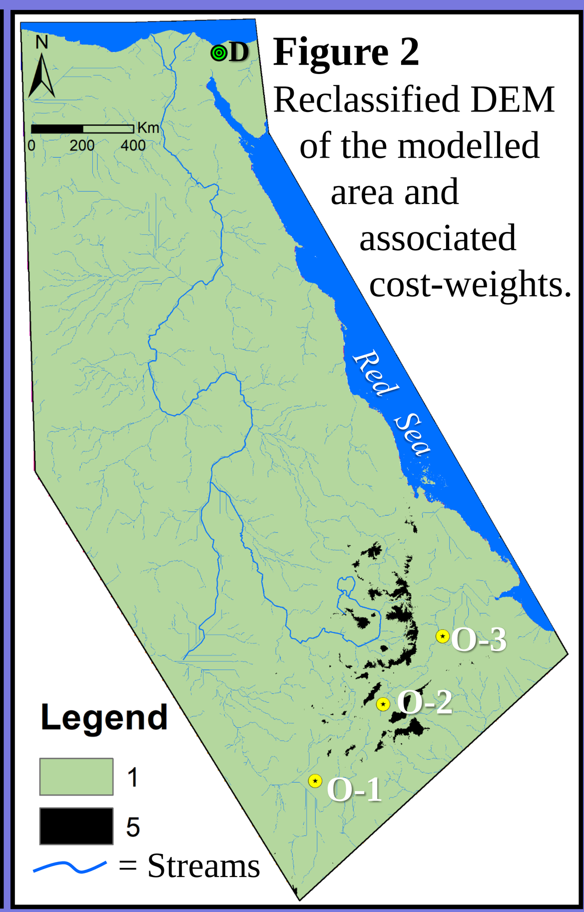

Figure 2 Reclassified DEM of the modelled area and associated cost-weights.

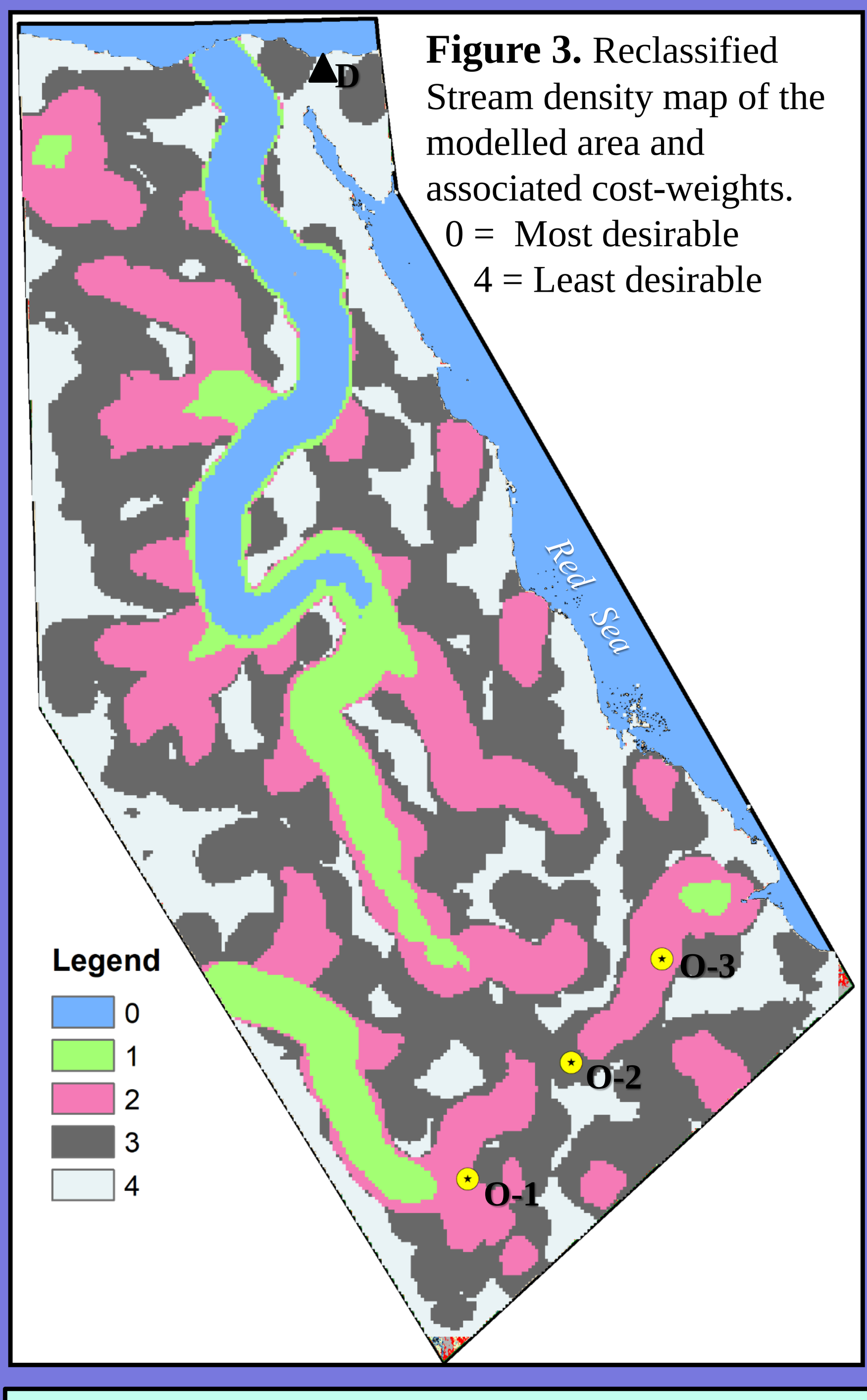

Figure 3. Reclassified Stream density map of the modelled area and associated cost-weights.
0 = Most desirable
4 = Least desirable

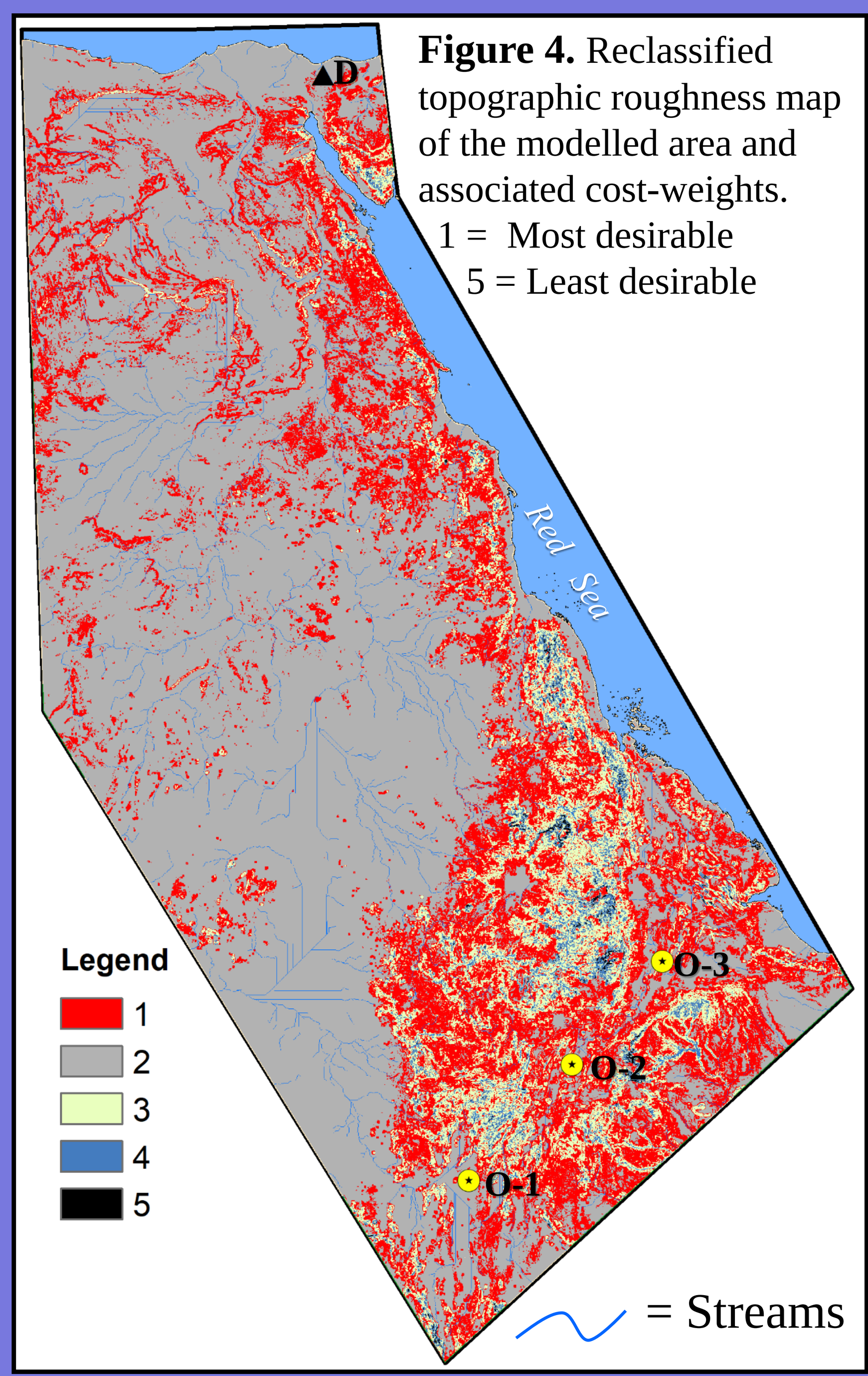

Figure 4. Reclassified topographic roughness map of the modelled area and associated cost-weights.
1 = Most desirable
5 = Least desirable

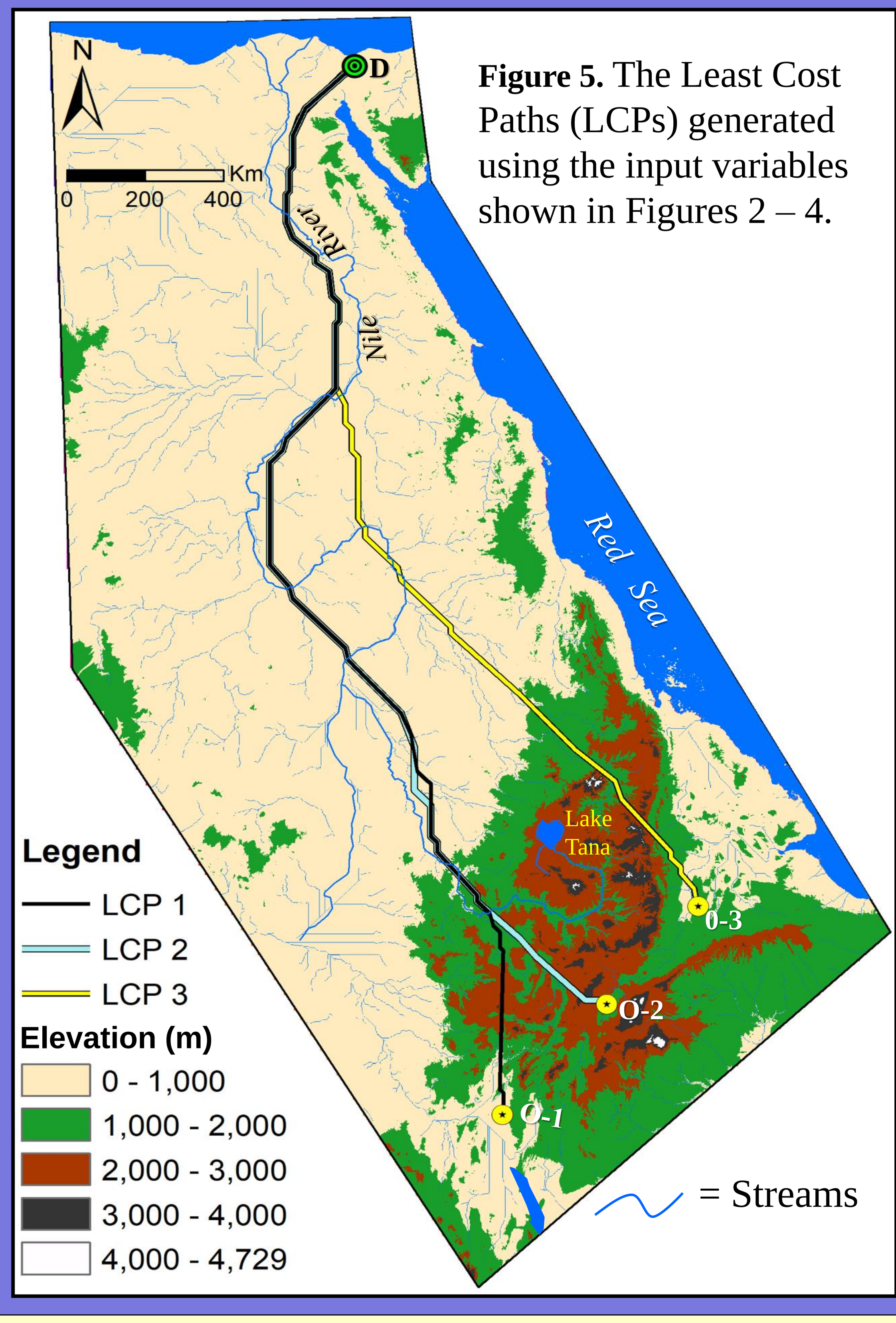

Figure 5. The Least Cost Paths (LCPs) generated using the input variables shown in Figures 2 – 4.

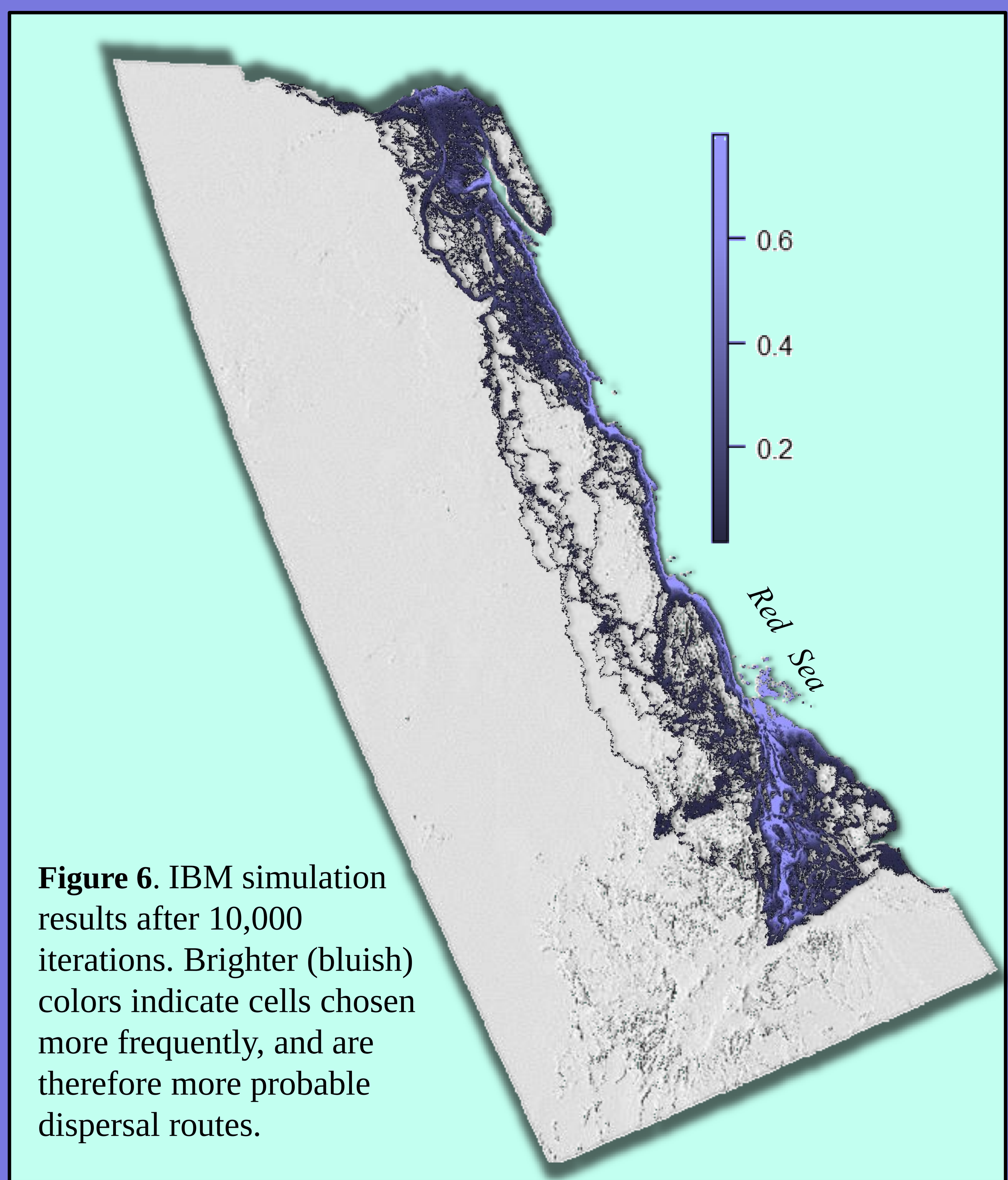

Figure 6. IBM simulation results after 10,000 iterations. Brighter (bluish) colors indicate cells chosen more frequently, and are therefore more probable dispersal routes.

Results

•Least Cost Path: The three LCPs have converged along the Nile (Fig. 5), suggesting that the Nile Route was an ideal (low risk) path for a putative population trying to migrate out of eastern Africa during conditions that are similar to the present time. It is particularly interesting to observe that all three paths have crossed the Ethiopian highlands before converging at the Nile even though the three points-of-origin were placed along the Main Ethiopian Rift. In reference to Table 1, we note that landscapes hosting dense streams, and those below 3000 m in altitude and featuring a modest topographic roughness (derived from slope variability[4]) were assigned the least cost-weight. Suh area are presumed to be more desirable than flat plains with no viable water source. While it is likely that the LCPs we obtained were predicated on the cost-weights we established (Table 1), there are plausible reasons as to why the Ethiopian highlands stood out as the most desirable- a) they feature complex topographies, which could have provided hominins diverse habitat-choices for foraging, resting and dispersal[5], b) the rich ecosystem, a network of tributary streams and major rivers (eg. the Blue Nile), and humid conditions that characterize the region could support human life when other regions become inhospitable.

Individual Based Model: After executing 10,000 dispersal events, it became evident that the Red Sea coast was preferred over the Nile Route (Fig. 6), but the Nile was also utilized several times over the course of the simulation, indicating its use as an alternative route.

Conclusions

- The study succeeded in identifying areas that would have provided low-risk (least cost) paths for a putative hominin population trying to disperse out of eastern Africa toward the Levant during conditions that are similar to the present time.
- According to the **Least Cost Path** model, the western Ethiopian highlands stand out as the most desirable dispersal landscapes between the Main Ethiopian Rift and the Nile proper. This region had seen little Paleolithic-focused research in the past (with a few exceptions[6]), thus our model provides a critically needed baseline for future systematic fieldwork in the region.
- According to the **Individual Based Model**, the Red Sea route is preferred, although parts of the Nile basin were found to be desirable as well. This model also reveals the feasibility of an inland route through the Red Sea Mountains onto the Red Sea coastal plains. This result is congruent with recent findings along the Sudanese Red Sea coast[7].
- Taken all together, our models show that hominin dispersal out of Africa involved multiple routes.

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