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Article

Using a Cost-Distance Time-Geographic Approach to Identify Red Deer Habitat Use in Banff National Park, Alberta, Canada

Katherine Ho * and Rebecca Loraamm

Department of Geography and Environmental Sustainability, University of Oklahoma, Norman, OK 73019, USA; rloraamm@ou.edu
* Correspondence: khgeography23@gmail.com

Abstract: Animal movements are realizations of complex spatiotemporal processes. Central to these processes are the varied environmental contexts in which animals move, which fundamentally im-pact the movement trajectories of individuals at fine spatial and temporal scales. An emerging per-spective in time geography is the direct examination of the influence that varying contexts may have on observed movements. An approach that considers environmental context can yield actionable information for wildlife management, planning, and conservation; for instance, identifying areas of probable occupancy by an animal may improve the efficiency of fieldwork. This research develops the first known practical application of a new cost-distance-based, probabilistic voxel space–time prism (CDBPSTP) in efforts to more realistically characterize the unobserved habitat occupancies of animals occurring between known positions provided by location-aware technologies. The CDBPSTP method is applied to trajectory data collected for a group of red deer (*Cervus elaphus*) tracked near Banff National Park, Alberta, Canada. As a demonstration of the added value from examining how context influences movement, CDBPSTP habitat occupancy results are compared to the earlier PSTP method in context with empirical and theoretical understandings of red deer habi-tat preference and space-use behaviors. This comparison reveals that with CDBPSTP, variation pre-sent in the mover's environment is explicitly considered as an influence on the mover's probable path and occupancies between observations of its location. With the increasing availability of high-resolution geolocational and associated environmental data, this study highlights the potential for CDBPSTP to be leveraged as a broadly applicable tool in animal movement analysis.

Keywords: animal movement; habitat utilization; cost distance

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Supplementary Materials

All anchor pairs listed in Table 2 were evaluated through both PSTP and CDBPSTP and were found to be consistent with the results reported for the two anchor pairs detailed in the article. The Supplementary Materials contain occupancy probability surfaces for all the other anchor pairs that were not included in the main article, showing both CDBPSTP and PSTP results. Each anchor pair's occupancy probability surfaces are shown side by side, with PSTP results on the left and CDBPSTP results on the right. The direction of movement can be noted through the point labels, where movement is from the lower number to the higher number. Additional details on the deer from which the points were taken can be found in Table 2 by locating the deer ID (top left corner of each panel) and the point labels. The Supplementary Materials also include tables denoting the sum of occupancy probabilities for occupancy probability surfaces for each anchor pair not shown in the main text, summed according to the underlying cost surface value.

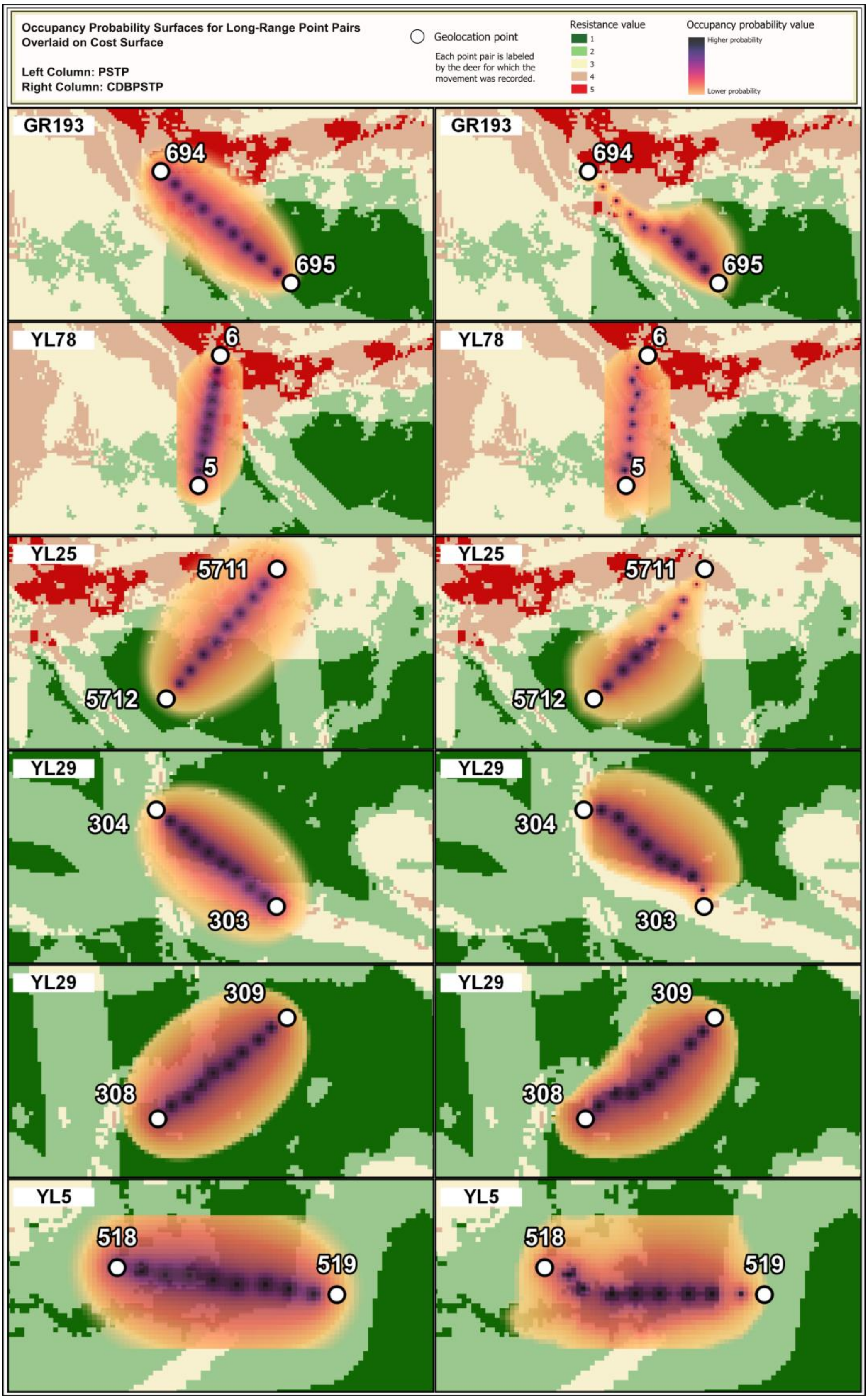

Figure S1: Occupancy probability surfaces for anchor pairs considered to have a long-distance range between points, overlaid with transparency on the cost surface. Panels on the left were generated by the PSTP model, and panels on the right were generated by the CDBPSTP model. Each panel is labeled by Deer ID and each point is labeled by Point Location ID. Darker colors signify higher probabilities that the deer was located at that site as it traveled between points.

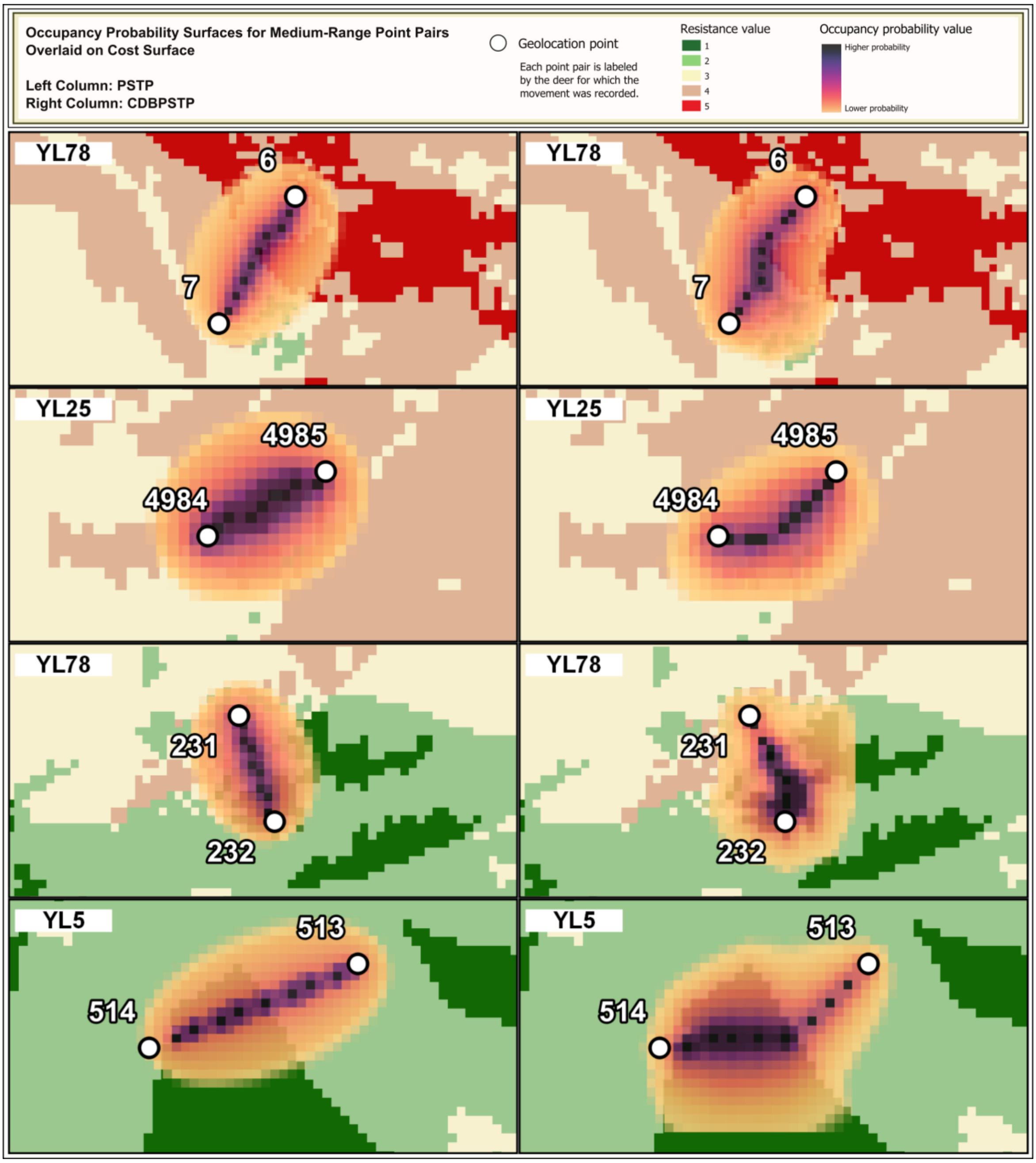

Figure S2: Occupancy probability surfaces for anchor pairs considered to have a medium-distance range between points, overlaid with transparency on the cost surface. Panels on the left were generated by the PSTP model, and panels on the right were generated by the CDBPSTP model. Each panel is labeled by Deer ID and each point is labeled by Point Location ID. Darker colors signify higher probabilities that the deer was located at that site as it traveled between points.

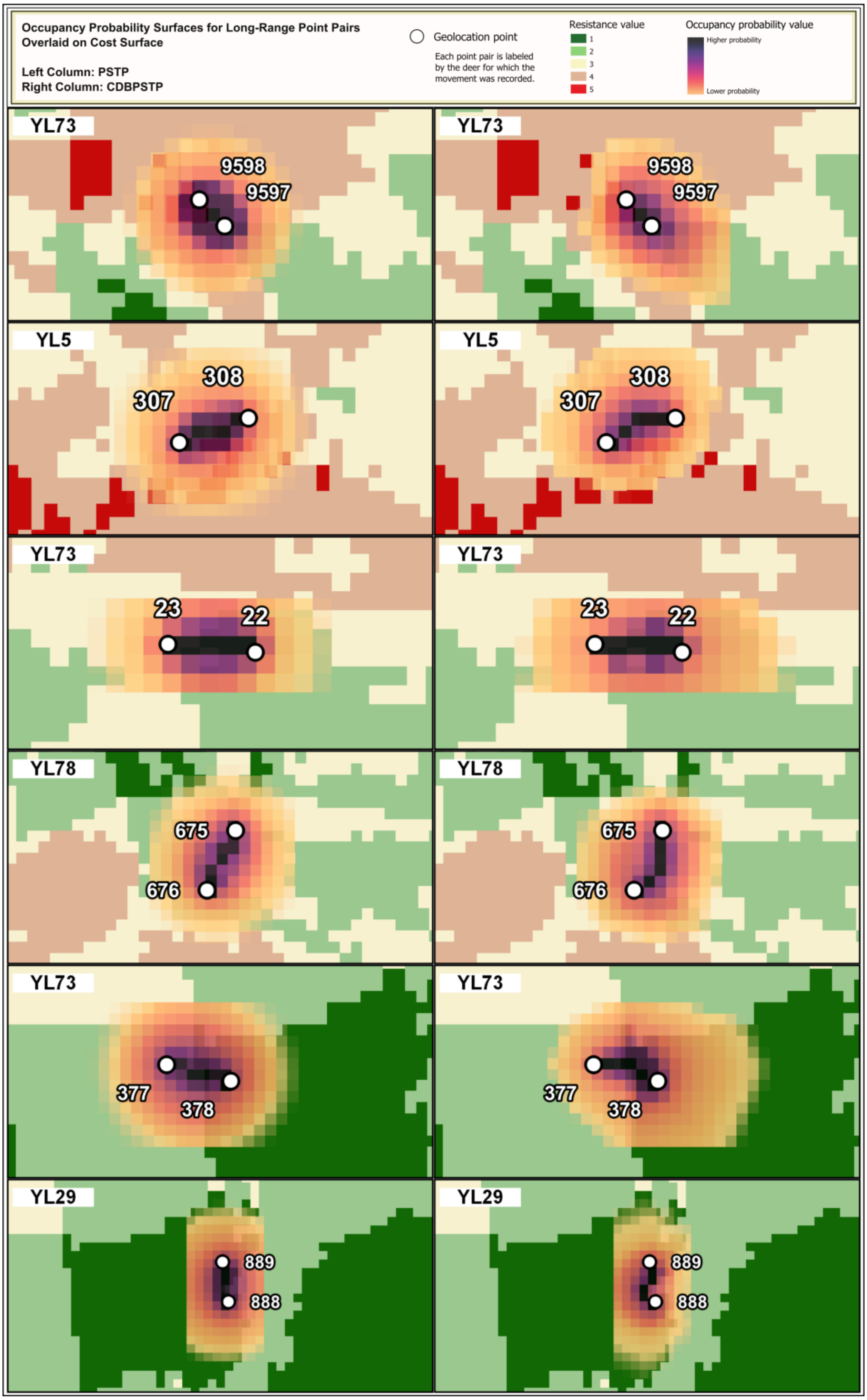

Figure S3: Occupancy probability surfaces for anchor pairs considered to have a short-distance range between points, overlaid with transparency on the cost surface. Panels on the left were generated by the PSTP model, and panels on the right were generated by the CDBPSTP model. Each panel is labeled by Deer ID and each point is labeled by Point Location ID. Darker colors signify higher probabilities that the deer was located at that site as it traveled between points.

Table S1: The sum of occupancy probabilities for the occupancy probability surfaces for anchor pairs considered to have a long-distance range between points, summed according to the underlying cost surface value.

Code	Deer ID	Point Location ID	Cost Surface Value	Sum of occupancy probabilities, CDBPSTP	Sum of occupancy probabilities, PSTP
LH_GR193	GR193	694, 695	1	3.764	3.530
			2	2.162	1.525
			3	2.056	2.774
			4	1.936	1.933
			5	0.080	0.235
LH_YL78	YL78	5, 6	1	0.032	0.061
			2	3.885	1.175
			3	3.960	5.557
			4	2.072	2.201
			5	0.048	1.001
LM_YL25	YL25	5711, 5712	1	4.642	3.737
			2	3.020	2.815
			3	0.376	1.460
			4	1.929	1.916
			5	0.030	0.070
LM_YL29	YL29	303, 304	1	6.525	4.688
			2	1.551	2.640
			3	1.914	2.656
			4	0.006	0.011
			5	0.000	0.000
LL_YL29	YL29	308, 309	1	9.410	9.200
			2	0.439	0.589
			3	0.135	0.190
			4	0.010	0.015
			5	0.000	0.000
LL_YL5	YL5	518, 519	1	6.483	3.839
			2	3.393	5.967
			3	0.103	0.162
			4	0.016	0.027
			5	0.000	0.000

Table S2: The sum of occupancy probabilities for the occupancy probability surfaces for anchor pairs considered to have a medium-distance range between points, summed according to the underlying cost surface value.

Code	Deer ID	Point Location ID	Cost Surface Value	Sum of occupancy probabilities, CDBPSTP	Sum of occupancy probabilities, PSTP
MH_YL78	YL78	6, 7	1	0.000	0.000
			2	0.972	0.040
			3	2.965	2.866
			4	5.985	6.790
			5	0.073	0.289
MH_YL5	YL5	1, 2		*See main text.*	
MM_YL25	YL25	4984, 4985	1	0.000	0.000
			2	0.001	0.003
			3	6.900	2.028
			4	3.090	7.944
			5	0.000	0.000
MM_YL78	YL78	231, 232	1	4.809	2.012
			2	2.113	1.278
			3	2.056	4.773
			4	1.009	1.917
			5	0.000	0.000
ML_YL29	YL29	812, 813	1	9.564	2.480
			2	0.394	7.445
			3	0.029	0.051
			4	0.002	0.004
			5	0.000	0.000
ML_YL5	YL5	513, 514	1	4.813	4.694
			2	5.174	5.287
			3	0.004	0.008
			4	0.000	0.000
			5	0.000	0.000

Table S3: The sum of occupancy probabilities for the occupancy probability surfaces for anchor pairs considered to have a short-distance range between points, summed according to the underlying cost surface value.

Code	Deer ID	Point Location ID	Cost Surface Value	Sum of occupancy probabilities, CDBPSTP	Sum of occupancy probabilities, PSTP
SH_YL73	YL73	9597, 9598	1	0.001	0.002
			2	0.025	0.061
			3	2.040	2.123
			4	0.046	0.166
			5	1.007	1.032
SH_YL5	YL5	307, 308	1	0.000	0.000
			2	0.001	0.004
			3	2.094	2.211
			4	4.045	3.237
			5	0.016	0.066
SM_YL73	YL73	22, 23	1	0.000	0.000
			2	3.069	3.148
			3	2.060	2.154
			4	0.006	0.015
			5	0.000	0.000
SM_YL78	YL78	675, 676	1	0.010	0.025
			2	2.081	2.202
			3	5.021	5.924
			4	0.020	0.055
			5	0.000	0.000
SL_YL73	YL73	377, 378	1	3.252	3.135
			2	3.100	4.249
			3	0.018	0.037
			4	0.000	0.000
			5	0.000	0.000
SL_YL29	YL29	888, 889	1	6.204	4.223
			2	0.146	2.124
			3	0.035	0.058
			4	0.000	0.000
			5	0.000	0.000