Analyzing a Prospective Red Wolf (*Canis rufus*) Reintroduction Site for Suitable Habitat

by Jon Shaffer

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Abstract

Since its declared extinction in the wild in 1980, the red wolf has been reintroduced into two areas of the South. The reintroduction in Northeastern North Carolina has been quite successful, while the reintroduction into the Great Smoky Mountains National Park was unsuccessful. The USFWS Red Wolf Recovery Plan calls for the additional establishment of two more wild populations of wolves. I analyzed the potential of one prospective release site to contain enough suitable habitat to support a reintroduction of red wolves. The Central Coastal North Carolina area was chosen for analysis as it met general criteria for the likely success of reintroduction, including a similar geography to the successful Northeastern North Carolina site, and a large amount of land in conservation. ArcGIS 9.2 was used to identify core patches of potential habitat within the study area and calculate the amount of their areas occurring on protected lands. The patches were examined for connectivity using least-cost path analysis, and optimal corridors containing the top 5^{th} percentile best paths between patches were calculated. Three patches, that combined would provide suitable habitat for wolf reintroduction, were identified. Together these patches contained an area larger than the 68,800 hectares of habitat required for red wolf reintroductions. And over 75 % of this area occurred on conservation lands. It is therefore possible that the Central Coastal North Carolina area contains enough suitable habitat for the reintroduction of red wolves. The approach used in this analysis could by applied to other prospective red wolf release sites.

Introduction:

The red wolf (*Canis rufus*) was declared extinct in the wild in 1980. As a result of the Endangered Species Act of 1973, the U.S. Fish and Wildlife Service (USFWS) initiated the Red Wolf Recovery Program. It established a captive breeding program, and a reintroduction plan with a goal of establishing at least three wild populations of wolves totaling 220 animals; each population should occupy at least 178,000 acres (68,800 hectares) of contiguous habitat (USFWS 1990). Red wolves have been successfully reintroduced into Northeastern North Carolina; there is currently a population of approximately 100 centered among the Alligator River and Pocosin Lakes National Wildlife Refuges. However, a similar reintroduction effort was unsuccessful in the Great Smoky Mountains National Park (Kelly et al. 2004).

The USFWS is considering other prospective release sites for establishing additional red wolf populations. Thirty one prospective release sites have been identified throughout the former range of the red wolf (Van Manen et al. 2000). I will examine one of these potential sites, the Central Coastal North Carolina area. The goal of my analysis is to determine if this site contains enough physically suitable habitat to support a reintroduction of red wolves. The site will be analyzed for the amount of core habitat it contains, the connectivity of these areas, and the protection status of the core areas' land. An approach similar to that taken by Paquet et al. (1999) in their determination of habitat suitability for gray wolf reintroduction in the Adirondacks will be used, with some modifications to the methodology.

Methods:

Choice of site:

The Central Coastal North Carolina area consists of the land area, excluding barrier islands, of four counties: Carteret, Craven, Jones, and Onslow (Figure 1). This site was chosen for several reasons. First, it is geographically very similar to the northeastern North Carolina site where red wolves have been successfully reintroduced. Next, it contains several large protected areas of conservation lands including the Croatan National Forest and the Hofmann State Forest. Third, the site has a low coyote density compared to other areas of the state, and as much of the area is bounded by water, it may be possible to exclude coyotes from the site. Coyotes present one of the greatest challenges to the success of red wolf reintroductions as they readily hybridize with the wolves, and can quickly dilute the gene pool (Kelly et al. 2004, Phillips et al. 2003). Finally, the close proximity of the study site to the successful reintroduction site in Northeastern North Carolina will allow for easier exchange of resources, expertise, and personnel between reintroduction areas.

Data:

The National Elevation Dataset (1 arc second) and National Land Cover Dataset 2001 from the USGS were used to determine elevation and land cover at the site. Highway, county boundary, state boundary, and waterbody vector data were obtained from the USGS National Atlas of the United States. Vector data on municipal town boundaries and roads were obtained from the North Carolina Flood Mapping Program. Vector data on protected conservation lands were obtained from the North Carolina Corporate Geographic Database's "Lands Managed for Conservation and Open Space" data layer (NCCGDB 2003). Deer density data were obtained from the North Carolina Wildlife Resources Commission. The ranges of red wolf populations reintroduced into the Great Smoky Mountains and Northeastern North Carolina were obtained in the form of vector data from NatureServe (Patterson et al. 2003). All data were projected to NAD 1983 UTM Zone 18N and most layers were clipped to the four county research site. All raster data throughout the analysis were set to a 30 by 30 meter resolution.

Analysis:

Analysis was conducted in ArcMap 9.2 (See Appendix for models and Python Scripts).

Patches of core habitat for red wolves were identified in the study area based on the following criteria:

1. Road density of less than 0.25 km/km^2.
2. 1 km from highways.
3. 2 km from incorporated towns.
4. Land cover of one of the following classes: deciduous, evergreen, or mixed forest, shrub/scrub, grassland/herbaceous, woody wetlands, or emergent herbaceous wetlands.
5. Deer density of at least 5 deer/km^2.
6. Slopes no greater than 20^o.
7. Patch area of at least 45.6 km^2.

Low human density and distance from roads are among the most important predictors of potential red wolf habitat in North Carolina (Kelly et al. 2004). Following the model of Patterson et al. (2003), road density was used as an approximation of human density. Road density was calculated by converting the roads data into a raster and calculating focal statistics on a moving 1km by 1km window. The highway and town data were buffered and combined into a raster of unsuitable habitat. The land cover data were reclassified to reflect the habitat preferences of red wolves depicted above. Deer are the most important prey item for red wolves, accounting for 43% of the biomass digested by wolves in Northeastern North Carolina (Phillips et al. 2003). As such, a raster was created from the deer data identifying areas with a deer density of at least 5 deer/km^2. As slopes greater than 20^o may be avoided by wolves (Callaghan 1999), a slope raster was created from the elevation data.

The above raster layers were combined to create a raster of potential habitat patches. Then habitat patches with an area of at least 45.6 km^2 were extracted from this raster to create the core habitat patches raster. The area of 45.6 km^2 represents the minimum home range size for a pack of red wolves (Phillips et al. 2003). The area of core habitat patches existing on protected conservation land was then extracted and tabulated.

Least-cost path analysis was used to examine functional connectivity between core habitat areas. A raster cost surface reflecting the variable resistance to wolf movement was created. Each value of the raster represented how much relative cost a wolf would face when traveling through each 30 by 30 meter pixel. The cost surface was generated from a composite of three different cost rasters: land cover cost, road density cost, and highways cost. Table 1 displays the features associated with these rasters and their respective costs. Estimates of the relative costs of different features were adapted from Paquet et al. (1999) when possible and estimated from knowledge gleaned from the literature on wolves. The minimal cost distance from core habitat patches was then calculated through the cost surface. Allocation boundaries were drawn at the locations where the maximum least-cost distance occurred between any two core patches. The cells along each allocation boundary with the minimum 5% of cost distance values were then used (as described by Theobald 2006) to create multiple pathways and a corresponding corridor containing the top 5th percentile best paths between patches.

Results:

Nine core patches of habitat were identified in the study area (Fig. 2). These ranged in size from 48 to 432 km^2 (Table 2). Three of the core patches (4, 5, and 7) were better connected to each other than the other patches; these other patches tended to lay along the periphery of the study area. The lower cost distances between these three patches can be seen in Figure 3. Much of the land in patches 4, 5, and 7 had the added benefit of existing under conservation protection (Croatan National Forest and Hofmann State Forest), while almost none of the land in the other core patches was protected (Table 2). Most of the likely corridors between core patches did not lie on protected land. The exception to this was the corridor between patches 5 and 7, which occurred almost completely on conservation lands (Fig. 4).

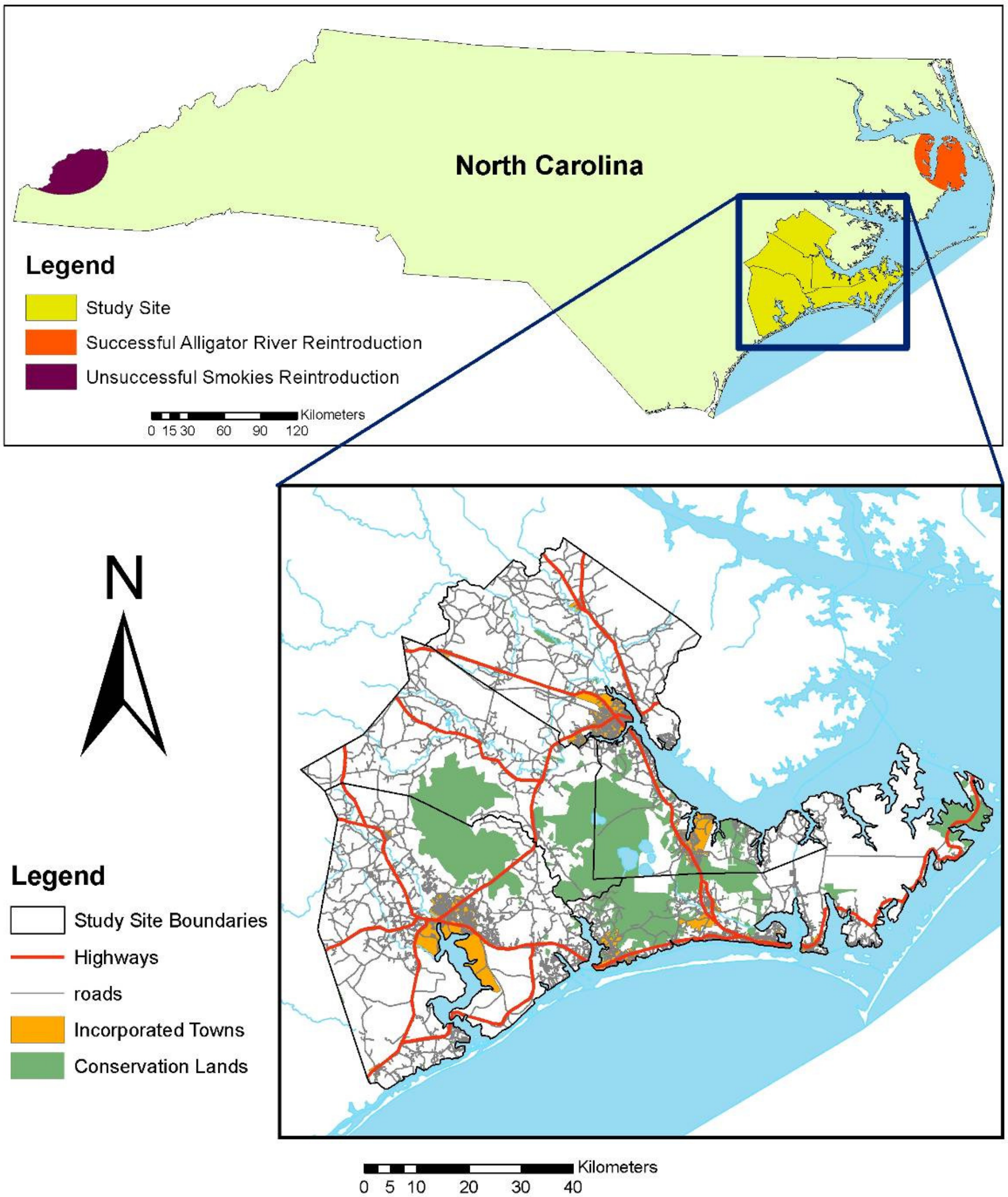
Discussion:

In light of the large cost distances between many of the potential core habitat patches, their relatively small size, and their peripheral location where they may be less protected from coyote immigration, it is recommended that only the three central, connected patches be considered as suitable habitat (patches 4, 5, and 7). This selection includes the two largest habitat patches and has the added benefit of being mostly contained within conservation lands. Taken together these patches have an area of 84.0 km^2 (Table 3). This meets the reintroduction requirement of 170,000 acres (68.8 km^2) of wolf habitat. Especially encouraging is that over 75% of this suitable habitat occurs on protected conservation lands, and the most likely corridors between two of the patches are protected.

There were several limitations to this analysis. First, it did not take coyote density into account. Hybridization with coyotes is the one of the greatest challenges to successful red wolf reintroduction, and it was one of the main factors preventing the success of the Great Smoky Mountain reintroduction effort (Kelly et al. 2004, Phillips et al. 2003). Anecdotally, coyote density is low in the study area, but actual numbers need to be accurately surveyed. Another limitation to the study was the use of land cover data that is several years old. Although this is the most recent data available, the study site is located in a fast growing area of North Carolina and faces continuing development pressure. A third limitation is the subjectivity involved in the estimation of cost for the cost surfaces. Actual costs of movement for wolves over certain surfaces may be much different than those estimated. Also, it is tough to determine the magnitude of cost distance at which travel between two core patches of habitat becomes unlikely or impossible. But, as more information is gleaned from telemetry and behavioral studies we can update the relative costs of movement in the model.

Though there are limitations, this geospatial approach provides a useful framework for determining if the prospective reintroduction site will provide suitable wolf habitat. It is flexible in that costs can be adjusted and more variables added as more data are obtained regarding the habitat needs of the red wolf. On the basis of this study, it appears quite possible that the Central Coastal North Carolina area contains enough suitable habitat for the reintroduction of red wolves. I recommend that this site be analyzed further for consideration for red wolf reintroduction. The models used in this approach may be useful when analyzing other prospective reintroduction sites for the red wolf.

Figure 1. Study Site Location and Overview



Projection: NAD 1983 UTM Zone 18N.

Map Produced by Jon Shaffer, April 2007.

Figure 2. Identified Core Red Wolf Habitat Patches

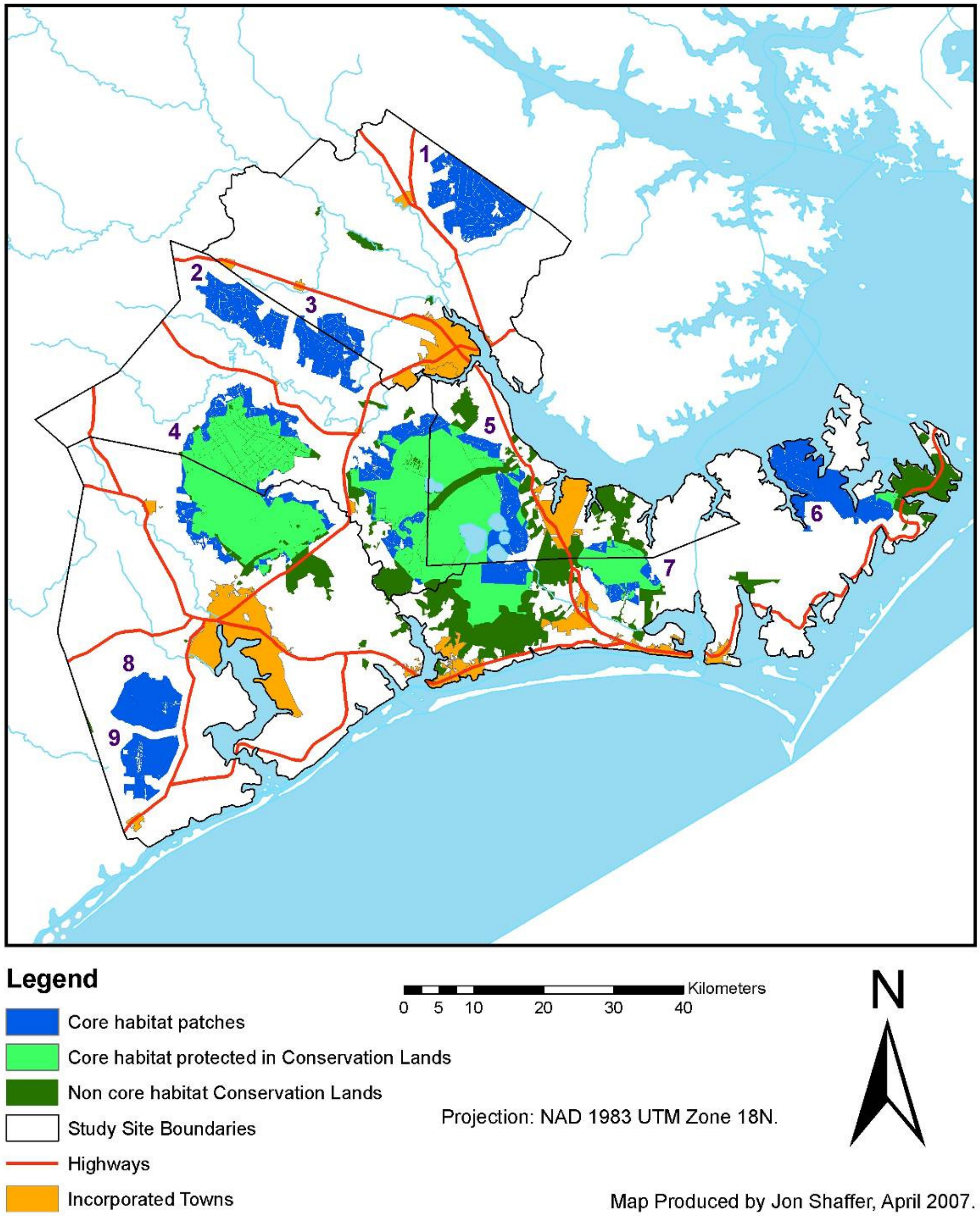


Figure 3. Travel Cost from Core Habitat Patches

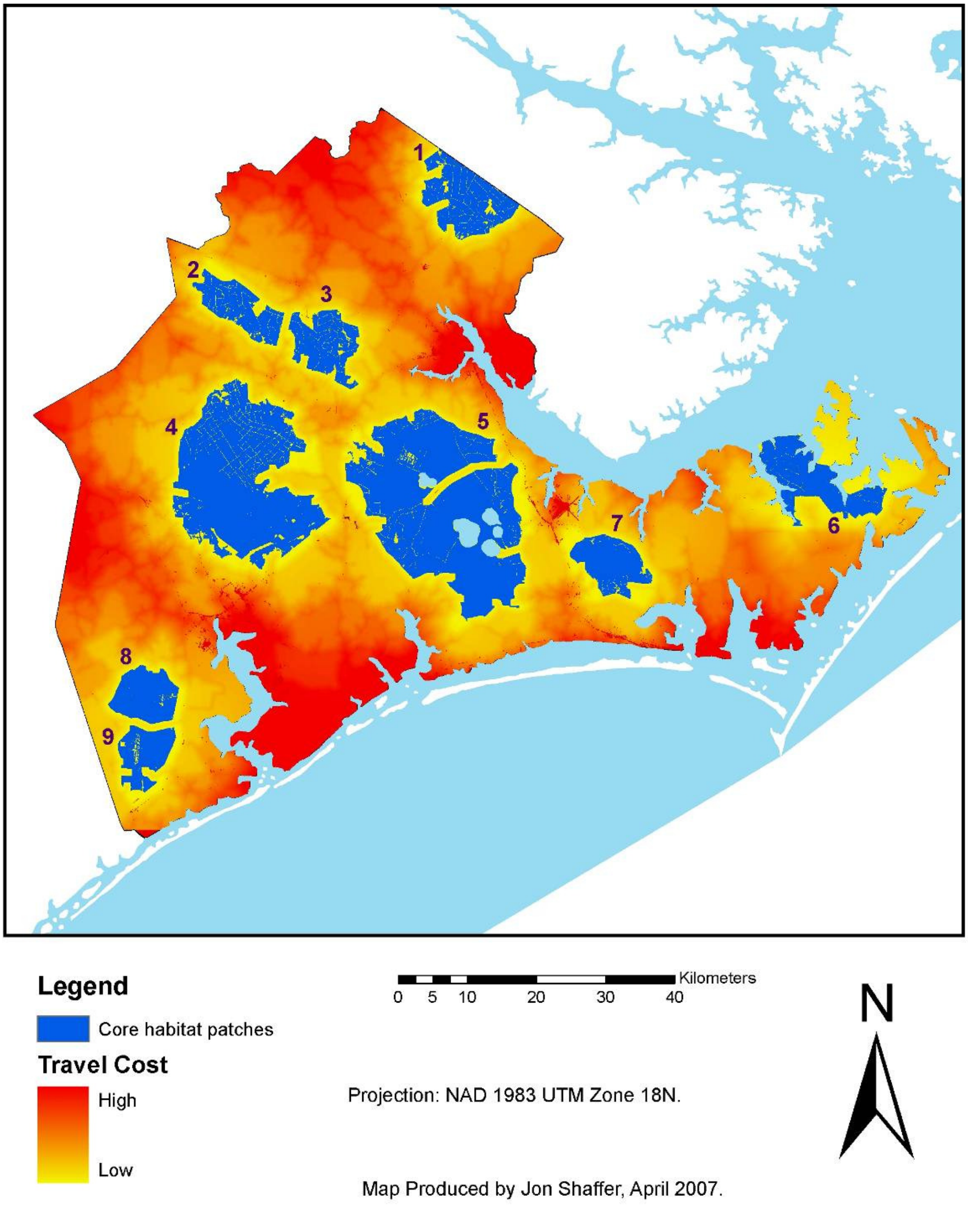
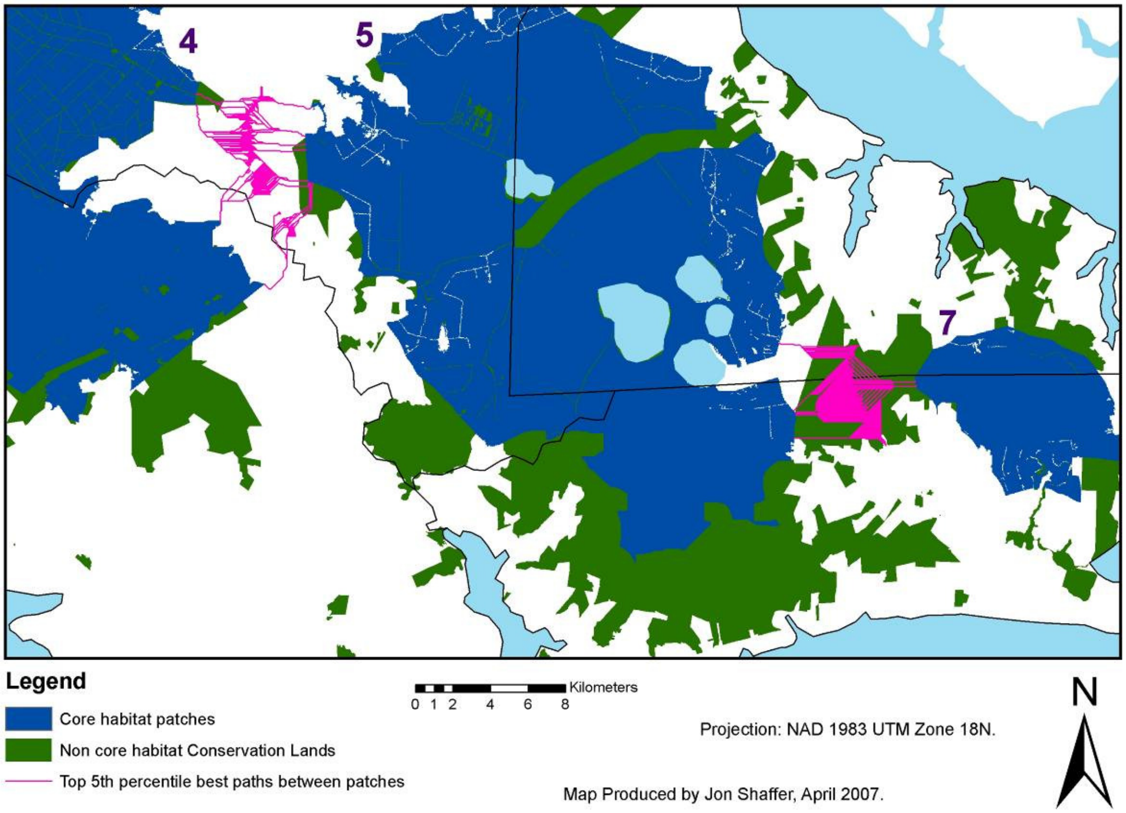


Figure 4. Optimal Corridors between Habitat Patches 4, 5, and 7.



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Data Sources:

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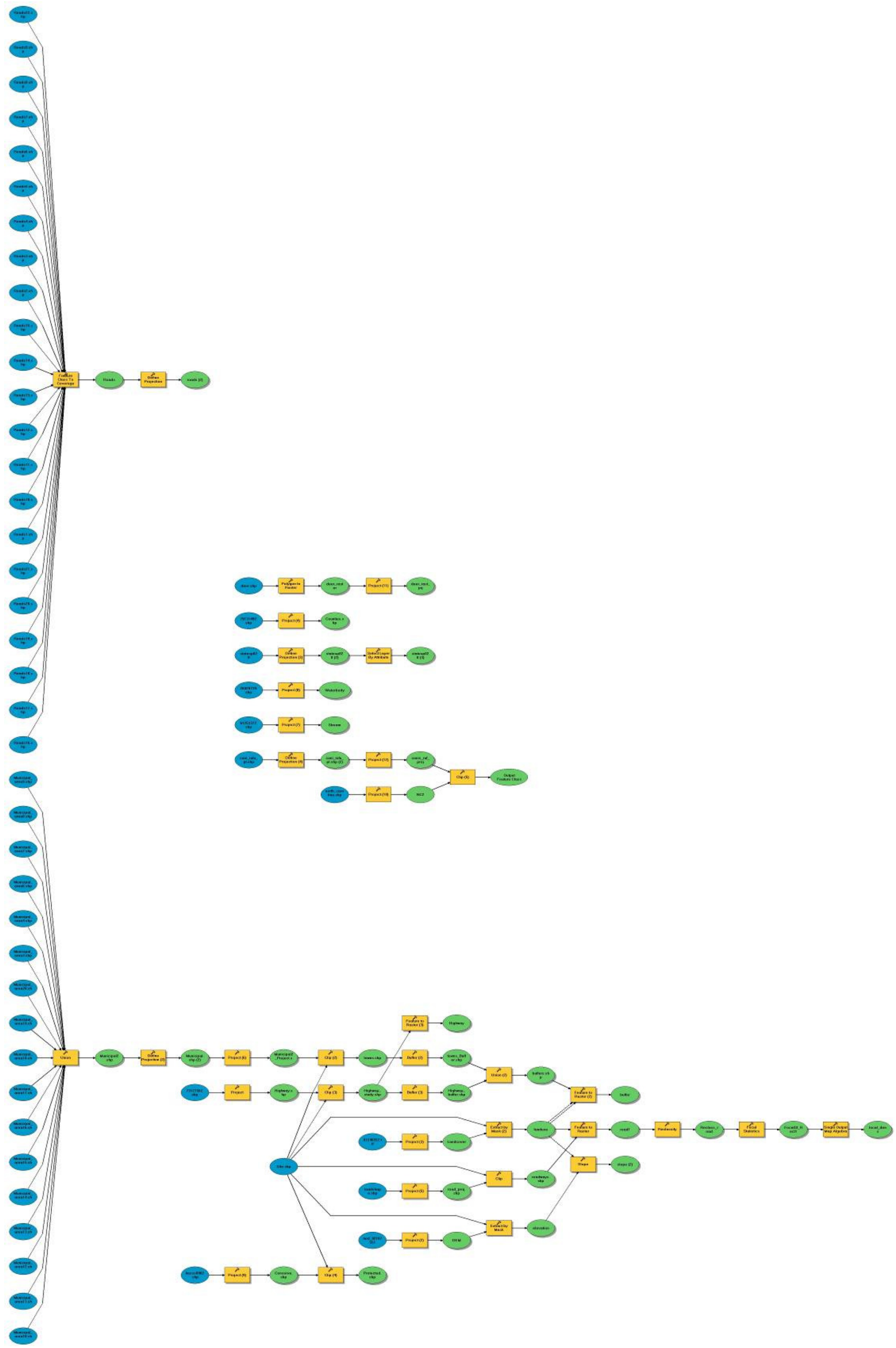
Table 1. Cost Surface Assignment for Study Site	
Landcover Surface	***Cost***
Open Water	10
Developed, Open Space	8
Developed, Low Intensity	10
Developed, Medium Intensity	No Data
Developed, High Intensity	No Data
Barren Land	8
Deciduous Forest	1
Evergreen Forest	1
Mixed Forest	1
Shrub/Scrub	1
Grassland/Herbaceous	3
Pasture/Hay	6
Cultivated Crops	7
Woody Wetlands	1
Herbaceous Wetlands	1
Road Density Surface (km/km^2)	***Cost***
0 - 0.25	0
0.25 - 0.5	5
> 0.5	10
Highway Surface	***Cost***
Highway Presence	5
Highway Absence	0

Table 2. Summary Statistics of Core Habitat Patches			
Core Patch #	*Area (ha)*	*Area (ha) in Conservation*	*% Protected*
1	9,063.18	-	0.0%
2	5,996.70	-	0.0%
3	6,593.04	-	0.0%
4	34,496.28	27,775.26	80.5%
5	43,184.25	31,142.79	72.1%
6	9,181.17	368.64	4.0%
7	6,334.92	4,547.43	71.8%
8	5,918.67	-	0.0%
9	4,796.73	-	0.0%
Total	125,564.94	63,834.12	50.8%

Table 3. Summary Statistics of Suitable Habitat Patches			
Core Patch #	*Area (ha)*	*Area (ha) in Conservation*	*% Protected*
4	34,496.28	27,775.26	80.5%
5	43,184.25	31,142.79	72.1%
7	6,334.92	4,547.43	71.8%
Total	84,015.45	63,465.48	75.5%

Appendix A: Data Preparation Model and Scripts



```
# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create()

# Set the necessary product code
gp.SetProduct("ArcInfo")

# Check out any necessary licenses
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial
Analyst Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Conversion
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Roads, "", "DOUBLE")

# Process: Define Projection...
gp.DefineProjection_management(Roads,
"PROJCS['NAD_1983_StatePlane_North_Carolina_FIPS_3200_Feet',GEOGCS['GCS
_North_American_1983',DATUM['D_North_American_1983',SPHEROID['GRS_1980'
,6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174
532925199433]],PROJECTION['Lambert_Conformal_Conic'],PARAMETER['False_E
asting',2000000.002616666],PARAMETER['False_Northing',0.0],PARAMETER['C
entral_Meridian',-
79.0],PARAMETER['Standard_Parallel_1',34.33333333333334],PARAMETER['Sta
ndard_Parallel_2',36.16666666666666],PARAMETER['Latitude_Of_Origin',33.
75],UNIT['Foot_US',0.3048006096012192]]")

# Process: Project (4)...
gp.Project_management(v79131492_shp, Counties_shp,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")

# Process: Project (7)...
gp.Project_management(v61253372_shp, Stream,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")

# Process: Project (8)...
gp.Project_management(v26828739_shp, Waterbody,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")
```

```
# Process: Project (5)...
gp.Project_management(roadshape_shp, road_proj_shp,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"PROJCS['NAD_1983_StatePlane_North_Carolina_FIPS_3200_Feet',GEOGCS['GCS
_North_American_1983',DATUM['D_North_American_1983',SPHEROID['GRS_1980'
,6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174
532925199433]],PROJECTION['Lambert_Conformal_Conic'],PARAMETER['False_E
asting',2000000.002616666],PARAMETER['False_Northing',0.0],PARAMETER['C
entral_Meridian',-
79.0],PARAMETER['Standard_Parallel_1',34.33333333333334],PARAMETER['Sta
ndard_Parallel_2',36.16666666666666],PARAMETER['Latitude_Of_Origin',33.
75],UNIT['Foot_US',0.3048006096012192]]")

# Process: Clip...
gp.Clip_analysis(road_proj_shp, Site_shp, roadways_shp, "")

# Process: Project (3)...
gp.ProjectRaster_management(v61246557_tif, Landcover,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]];-5120900 -9998100
450445547.391054;#;#;0.001;#;#;IsHighPrecision", "NEAREST", "30", "",
"",
"PROJCS['USA_Contiguous_Albers_Equal_Area_Conic_USGS_version',GEOGCS['G
CS_North_American_1983',DATUM['D_North_American_1983',SPHEROID['GRS_198
0',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.01
74532925199433]],PROJECTION['Albers'],PARAMETER['False_Easting',0.0],PA
RAMETER['False_Northing',0.0],PARAMETER['Central_Meridian',-
96.0],PARAMETER['Standard_Parallel_1',29.5],PARAMETER['Standard_Paralle
l_2',45.5],PARAMETER['Latitude_Of_Origin',23.0],UNIT['Meter',1.0]];-
16901100 -6972200 266467840.990852;#;#;0.001;#;#;IsHighPrecision")

# Process: Extract by Mask (2)...
gp.ExtractByMask_sa(Landcover, Site_shp, landuse)

# Process: Feature to Raster...
gp.FeatureToRaster_conversion(roadways_shp, "LPOLY_", road1, landuse)

# Process: Reclassify...
gp.Reclassify_sa(road1, "VALUE", "0 1;NODATA 0", Reclass_road, "DATA")

# Process: Focal Statistics...
gp.FocalStatistics_sa(Reclass_road, FocalSt_Recl1, "Rectangle 1000 1000
MAP", "SUM", "DATA")

# Process: Single Output Map Algebra...
```

```
gp.SingleOutputMapAlgebra_sa("z:\\classes\\ENV261\\Project\\scratch\\fo
calst_recl1*0.03", local_dens,
"z:\\classes\\ENV261\\Project\\scratch\\focalst_recl1")

# Process: Project (2)...
gp.ProjectRaster_management(ned_92187551, DEM,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]];-5120900 -9998100
450445547.391054;#;#;0.001;#;#;IsHighPrecision", "NEAREST", "<Null>",
"", "",
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]],VERTCS['Unknown VCS from ArcInfo
Workstation',VDATUM['Unknown'],PARAMETER['Vertical_Shift',0.0],PARAMETE
R['Direction',1.0],UNIT['Meter',1.0]];-400 -400
11258999068426.2;#;#;8.98315284119521E-09;#;#;IsHighPrecision")

# Process: Extract by Mask...
gp.ExtractByMask_sa(DEM, Site_shp, elevation)

# Process: Slope...
tempEnvironment0 = gp.cellSize
gp.cellSize = "z:\\classes\\ENV261\\Project\\Data\\landuse"
gp.Slope_sa(elevation, slope__2_, "DEGREE", "1")
gp.cellSize = tempEnvironment0

# Process: Union...
gp.Union_analysis("z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_ar
ea10.shp #;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area11.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area12.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area13.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area14.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area15.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area16.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area17.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area18.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area19.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area20.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area3.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area4.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area6.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area7.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area8.shp
#;z:\\classes\\ENV261\\Project\\NC_flood\\Municipal_area9.shp #",
Municipal2_shp, "ALL", "", "GAPS")

# Process: Define Projection (2)...
gp.DefineProjection_management(Municipal2_shp,
"PROJCS['NAD_1983_StatePlane_North_Carolina_FIPS_3200_Feet',GEOGCS['GCS
_North_American_1983',DATUM['D_North_American_1983',SPHEROID['GRS_1980'
,6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174
532925199433]],PROJECTION['Lambert_Conformal_Conic'],PARAMETER['False_E
```

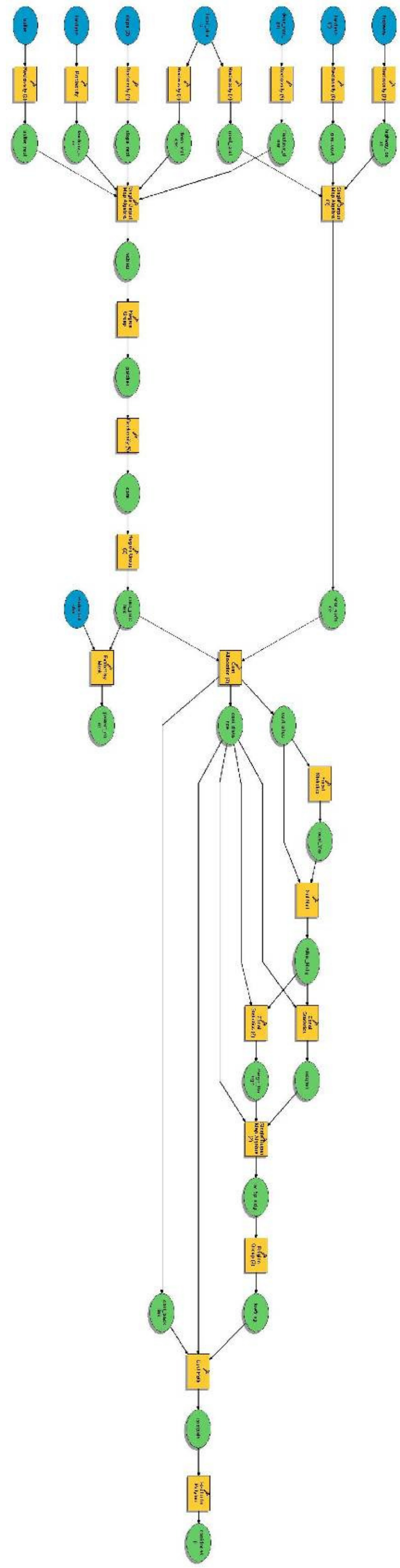
```
asting',2000000.002616666],PARAMETER['False_Northing',0.0],PARAMETER['C
entral_Meridian',-
79.0],PARAMETER['Standard_Parallel_1',34.33333333333334],PARAMETER['Sta
ndard_Parallel_2',36.16666666666666],PARAMETER['Latitude_Of_Origin',33.
75],UNIT['Foot_US',0.3048006096012192]]")

# Process: Project (6)...
gp.Project_management(Municipal_shp__2_, Municipal2_Project_shp,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"PROJCS['NAD_1983_StatePlane_North_Carolina_FIPS_3200_Feet',GEOGCS['GCS
_North_American_1983',DATUM['D_North_American_1983',SPHEROID['GRS_1980'
,6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174
532925199433]],PROJECTION['Lambert_Conformal_Conic'],PARAMETER['False_E
asting',2000000.002616666],PARAMETER['False_Northing',0.0],PARAMETER['C
entral_Meridian',-
79.0],PARAMETER['Standard_Parallel_1',34.33333333333334],PARAMETER['Sta
ndard_Parallel_2',36.16666666666666],PARAMETER['Latitude_Of_Origin',33.
75],UNIT['Foot_US',0.3048006096012192]]")

# Process: Clip (2)...
gp.Clip_analysis(Municipal2_Project_shp, Site_shp, towns_shp, "")

# Process: Buffer (2)...
tempEnvironment0 = gp.newPrecision
gp.newPrecision = "SINGLE"
tempEnvironment1 = gp.XYResolution
gp.XYResolution = ""
tempEnvironment2 = gp.scratchWorkspace
gp.scratchWorkspace = "z:\\classes\\ENV261\\Project\\scratch"
tempEnvironment3 = gp.MTolerance
gp.MTolerance = ""
tempEnvironment4 = gp.randomGenerator
gp.randomGenerator = "0 ACM599"
tempEnvironment5 = gp.outputCoordinateSystem
gp.outputCoordinateSystem = ""
tempEnvironment6 = gp.projectCompare
gp.projectCompare = "NONE"
tempEnvironment7 = gp.outputZFlag
gp.outputZFlag = "Same As Input"
tempEnvironment8 = gp.qualifiedFieldNames
gp.qualifiedFieldNames = "true"
tempEnvironment9 = gp.extent
gp.extent = "DEFAULT"
tempEnvironment10 = gp.XYTolerance
gp.XYTolerance = ""
tempEnvironment11 = gp.outputZValue
gp.outputZValue = ""
tempEnvironment12 = gp.outputMFlag
gp.outputMFlag = "Same As Input"
tempEnvironment13 = gp.geographicTransformations
gp.geographicTransformations = ""
```

```
tempEnvironment14 = gp.ZResolution
gp.ZResolution = ""
tempEnvironment15 = gp.workspace
gp.workspace = "z:\\classes\\ENV261\\Project\\Data"
tempEnvironment16 = gp.MResolution
gp.MResolution = ""
tempEnvironment17 = gp.derivedPrecision
gp.derivedPrecision = "HIGHEST"
tempEnvironment18 = gp.ZTolerance
gp.ZTolerance = ""
gp.Buffer_analysis(towns_shp, towns_Buffer_shp, "2 Kilometers", "FULL",
"ROUND", "ALL", "")
gp.newPrecision = tempEnvironment0
gp.XYResolution = tempEnvironment1
gp.scratchWorkspace = tempEnvironment2
gp.MTolerance = tempEnvironment3
gp.randomGenerator = tempEnvironment4
gp.outputCoordinateSystem = tempEnvironment5
gp.projectCompare = tempEnvironment6
gp.outputZFlag = tempEnvironment7
gp.qualifiedFieldNames = tempEnvironment8
gp.extent = tempEnvironment9
gp.XYTolerance = tempEnvironment10
gp.outputZValue = tempEnvironment11
gp.outputMFlag = tempEnvironment12
gp.geographicTransformations = tempEnvironment13
gp.ZResolution = tempEnvironment14
gp.workspace = tempEnvironment15
gp.MResolution = tempEnvironment16
gp.derivedPrecision = tempEnvironment17
gp.ZTolerance = tempEnvironment18

# Process: Project...
gp.Project_management(v73121562_shp, Highway_shp,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")

# Process: Clip (3)...
gp.Clip_analysis(Highway_shp, Site_shp, Highway_study_shp, "")

# Process: Buffer (3)...
gp.Buffer_analysis(Highway_study_shp, Highway_buffer_shp, "1
Kilometers", "FULL", "ROUND", "NONE", "")

# Process: Union (2)...
gp.Union_analysis("z:\\classes\\ENV261\\Project\\scratch\\towns_Buffer.
shp #;z:\\classes\\ENV261\\Project\\scratch\\Highway_buffer.shp #",
buffers_shp, "ALL", "", "GAPS")
```

```
# Process: Feature to Raster (2)...
tempEnvironment0 = gp.cellSize
gp.cellSize = "z:\\classes\\ENV261\\Project\\Data\\landuse"
tempEnvironment1 = gp.mask
gp.mask = "z:\\classes\\ENV261\\Project\\Data\\landuse"
gp.FeatureToRaster_conversion(buffers_shp, "Id", buffer, "30")
gp.cellSize = tempEnvironment0
gp.mask = tempEnvironment1

# Process: Project (9)...
gp.Project_management(lmcos0902_shp, Conserve_shp,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"PROJCS['NAD_1983_StatePlane_North_Carolina_FIPS_3200',GEOGCS['GCS_Nort
h_American_1983',DATUM['D_North_American_1983',SPHEROID['GRS_1980',6378
137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.017453292
5199433]],PROJECTION['Lambert_Conformal_Conic'],PARAMETER['False_Eastin
g',609601.22],PARAMETER['False_Northing',0.0],PARAMETER['Central_Meridi
an',-
79.0],PARAMETER['Standard_Parallel_1',34.33333333333334],PARAMETER['Sta
ndard_Parallel_2',36.16666666666666],PARAMETER['Latitude_Of_Origin',33.
75],UNIT['Meter',1.0]]")

# Process: Clip (4)...
gp.Clip_analysis(Conserve_shp, Site_shp, Protected_shp, "")

# Process: Feature to Raster (3)...
gp.FeatureToRaster_conversion(Highway_study_shp, "NAME", Highway, "30")

# Process: Define Projection (3)...
gp.DefineProjection_management(statesp020,
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")

# Process: Select Layer By Attribute...
gp.SelectLayerByAttribute_management(statesp020__2_, "NEW_SELECTION",
"\"STATE\" = 'North Carolina'")

# Process: Polygon to Raster...
gp.PolygonToRaster_conversion(deer_shp, "Dens_km", deer_raster,
"CELL_CENTER", "NONE", "30")

# Process: Project (11)...
gp.ProjectRaster_management(deer_raster, deer_rast_prj,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]];-5120900 -9998100
```

```
450445547.391054;#;#;0.001;#;#;IsHighPrecision", "NEAREST", "30", "",
"",
"PROJCS['NAD_1983_UTM_Zone_17N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
81.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]];-5120900 -9998100
450445547.391054;#;#;0.001;#;#;IsHighPrecision")

# Process: Define Projection (4)...
gp.DefineProjection_management(cani_rufu_pl_shp,
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")

# Process: Project (12)...
gp.Project_management(cani_rufu_pl_shp__2_, canis_ruf_proj,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")

# Process: Project (10)...
gp.Project_management(north_carolina_shp__2_, NC2,
"PROJCS['NAD_1983_UTM_Zone_18N',GEOGCS['GCS_North_American_1983',DATUM[
'D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['T
ransverse_Mercator'],PARAMETER['False_Easting',500000.0],PARAMETER['Fal
se_Northing',0.0],PARAMETER['Central_Meridian',-
75.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0
.0],UNIT['Meter',1.0]]", "",
"GEOGCS['GCS_North_American_1983',DATUM['D_North_American_1983',SPHEROI
D['GRS_1980',6378137.0,298.257222101]],PRIMEM['Greenwich',0.0],UNIT['De
gree',0.0174532925199433]]")

# Process: Clip (5)...
gp.Clip_analysis(canis_ruf_proj, NC2, Output_Feature_Class, "")
```

<u>**Appendix B: Analysis Model and Scripts**</u>



```
# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create()

# Check out any necessary licenses
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial
Analyst Tools.tbx")
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Conversion
Tools.tbx")

# Set the Geoprocessing environment...
gp.XYResolution = ""
gp.scratchWorkspace = "z:\\classes\\ENV261\\Project\\scratch"
gp.MTolerance = ""
gp.randomGenerator = "0 ACM599"
gp.outputCoordinateSystem = ""
gp.outputZFlag = "Same As Input"
gp.qualifiedFieldNames = "true"
gp.extent = "798393.534402281 3818666.10197191 931413.534402281
3926216.10197191"
gp.XYTolerance = ""
gp.cellSize = "30"
gp.outputZValue = ""
gp.outputMFlag = "Same As Input"
gp.geographicTransformations = ""
gp.ZResolution = ""
gp.mask = "landuse"
gp.workspace = "z:\\classes\\ENV261\\Project\\Data"
gp.MResolution = ""
gp.ZTolerance = ""


# Local variables...
buffer = "z:\\classes\\ENV261\\Project\\scratch\\buffer"
landuse = "z:\\classes\\ENV261\\Project\\Data\\landuse"
local_dens = "z:\\classes\\ENV261\\Project\\scratch\\local_dens"
landcov_cor = "z:\\classes\\ENV261\\Project\\scratch\\landcov_cor"
buffer_recl = "z:\\classes\\ENV261\\Project\\scratch\\buffer_recl"
dens_reclass = "z:\\classes\\ENV261\\Project\\scratch\\dens_reclass"
slope_recl = "z:\\classes\\ENV261\\Project\\scratch\\slope_recl"
habitat = "z:\\classes\\ENV261\\Project\\Data\\habitat"
patches = "z:\\classes\\ENV261\\Project\\scratch\\patches"
core = "z:\\classes\\ENV261\\Project\\Data\\core"
core_patches = "z:\\classes\\ENV261\\Project\\Data\\core_patches"
landuse__2_ = "z:\\classes\\ENV261\\Project\\Data\\landuse"
land_cost = "z:\\classes\\ENV261\\Project\\scratch\\land_cost"
cost_alloc = "z:\\classes\\ENV261\\Project\\scratch\\cost_alloc"
cost_distance = "z:\\classes\\ENV261\\Project\\Data\\cost_distance"
cost_backlink = "z:\\classes\\ENV261\\Project\\Data\\cost_backlink"
Focal_Var = "z:\\classes\\ENV261\\Project\\scratch\\Focal_Var"
Alloc_Ridg = "z:\\classes\\ENV261\\Project\\Data\\Alloc_Ridg"
ridgmin = "z:\\classes\\ENV261\\Project\\scratch\\ridgmin"
```

```
Ridge_Range = "z:\\classes\\ENV261\\Project\\scratch\\Ridge_Range"
lw_5p_ridg = "z:\\classes\\ENV261\\Project\\scratch\\lw_5p_ridg"
low5_rg = "z:\\classes\\ENV261\\Project\\scratch\\low5_rg"
costpath = "z:\\classes\\ENV261\\Project\\Data\\costpath"
road_cost = "z:\\classes\\ENV261\\Project\\scratch\\road_cost"
highway = "z:\\classes\\ENV261\\Project\\scratch\\highway"
highway_cost = "z:\\classes\\ENV261\\Project\\scratch\\highway_cost"
cost_surface = "z:\\classes\\ENV261\\Project\\scratch\\cost_surface"
slope__2_ = "z:\\classes\\ENV261\\Project\\Data\\slope"
protect_core = "z:\\classes\\ENV261\\Project\\scratch\\protect_core"
Protected_shp = "z:\\classes\\ENV261\\Project\\Data\\Protected.shp"
deer_rast_prj = "Z:\\classes\\ENV261\\Project\\scratch\\deer_rast_prj"
Reclass_deer = "z:\\classes\\ENV261\\Project\\scratch\\Reclass_deer"
corridor_shp = "z:\\classes\\ENV261\\Project\\Data\\corridor.shp"

# Process: Reclassify (2)...
gp.Reclassify_sa(buffer, "VALUE", "0 NODATA;NODATA 0", buffer_recl,
"DATA")

# Process: Reclassify (4)...
gp.Reclassify_sa(slope__2_, "Value", "0 20 0;20 30 NODATA", slope_recl,
"DATA")

# Process: Reclassify...
gp.Reclassify_sa(landuse, "VALUE", "11 NODATA;21 NODATA;21 24 NODATA;24
31 NODATA;41 43 0;43 52 0;52 71 0;81 82 NODATA;90 95 0", landcov_cor,
"DATA")

# Process: Reclassify (3)...
gp.Reclassify_sa(local_dens, "Value", "0 0.25 0;0.25 17.600000000000001
NODATA", dens_reclass, "DATA")

# Process: Reclassify (9)...
gp.Reclassify_sa(deer_rast_prj, "Value", "0 NODATA;0 5 NODATA;5
17.374500274658203 0", Reclass_deer, "DATA")

# Process: Single Output Map Algebra...
gp.SingleOutputMapAlgebra_sa("z:\\classes\\ENV261\\Project\\scratch\\bu
ffer_recl+z:\\classes\\ENV261\\Project\\scratch\\dens_reclass+z:\\class
es\\ENV261\\Project\\scratch\\slope_recl+z:\\classes\\ENV261\\Project\\
scratch\\landcov_cor +
z:\\classes\\ENV261\\Project\\scratch\\reclass_deer", habitat,
"z:\\classes\\ENV261\\Project\\scratch\\buffer_recl;z:\\classes\\ENV261
\\Project\\scratch\\slope_recl;z:\\classes\\ENV261\\Project\\scratch\\l
andcov_cor;z:\\classes\\ENV261\\Project\\scratch\\dens_reclass;z:\\clas
ses\\ENV261\\Project\\scratch\\Reclass_deer")

# Process: Region Group...
gp.RegionGroup_sa(habitat, patches, "FOUR", "WITHIN", "ADD_LINK", "")

# Process: Reclassify (5)...
gp.Reclassify_sa(patches, "COUNT", "1 50666 NODATA;50667 500000 0",
core, "DATA")

# Process: Region Group (2)...
gp.RegionGroup_sa(core, core_patches, "FOUR", "WITHIN", "ADD_LINK", "")
```

```
# Process: Extract by Mask...
gp.ExtractByMask_sa(core_patches, Protected_shp, protect_core)

# Process: Reclassify (7)...
gp.Reclassify_sa(local_dens, "Value", "0 0.25 0;0.25 0.5 5;0.5
17.600000000000001 10", road_cost, "DATA")

# Process: Reclassify (8)...
gp.Reclassify_sa(highway, "VALUE", "1 14 5;NODATA 0", highway_cost,
"DATA")

# Process: Reclassify (6)...
gp.Reclassify_sa(landuse__2_, "VALUE", "11 10;21 8;22 10;23 NODATA;24
NODATA;31 8;41 52 1;71 3;81 6;82 7;90 95 1", land_cost, "DATA")

# Process: Single Output Map Algebra (3)...
gp.SingleOutputMapAlgebra_sa("z:\\classes\\ENV261\\Project\\scratch\\hi
ghway_cost + z:\\classes\\ENV261\\Project\\scratch\\land_cost +
z:\\classes\\ENV261\\Project\\scratch\\road_cost", cost_surface,
"z:\\classes\\ENV261\\Project\\scratch\\road_cost;z:\\classes\\ENV261\\
Project\\scratch\\highway_cost;z:\\classes\\ENV261\\Project\\scratch\\l
and_cost")

# Process: Cost Allocation (2)...
gp.CostAllocation_sa(core_patches, cost_surface, cost_alloc, "", "",
"VALUE", cost_distance, cost_backlink)

# Process: Focal Statistics...
gp.FocalStatistics_sa(cost_alloc, Focal_Var, "Rectangle 3 3 CELL",
"VARIETY", "DATA")

# Process: Set Null...
gp.SetNull_sa(Focal_Var, cost_alloc, Alloc_Ridg, "\"VALUE\" = 1")

# Process: Zonal Statistics...
gp.ZonalStatistics_sa(Alloc_Ridg, "VALUE", cost_distance, ridgmin,
"MINIMUM", "DATA")

# Process: Zonal Statistics (2)...
gp.ZonalStatistics_sa(Alloc_Ridg, "VALUE", cost_distance, Ridge_Range,
"RANGE", "DATA")

# Process: Single Output Map Algebra (2)...
gp.SingleOutputMapAlgebra_sa("Con(cost_distance <= (ridgmin +
(Ridge_Range / 20)) , 1)
", lw_5p_ridg,
"z:\\classes\\ENV261\\Project\\scratch\\ridgmin;z:\\classes\\ENV261\\Pr
oject\\scratch\\Ridge_Range;z:\\classes\\ENV261\\Project\\Data\\cost_di
stance")

# Process: Region Group (3)...
gp.RegionGroup_sa(lw_5p_ridg, low5_rg, "EIGHT", "WITHIN", "ADD_LINK",
"")

# Process: Cost Path...
gp.CostPath_sa(low5_rg, cost_distance, cost_backlink, costpath,
"EACH_CELL", "VALUE")
```

```
# Process: Raster to Polyline...
gp.RasterToPolyline_conversion(costpath, corridor_shp, "ZERO", "0",

"SIMPLIFY", "VALUE").
```