

Muskoka River Watershed IWM Natural Capital Inventory

Addendum 4: Habitat Connectivity Concept

DOUGAN & ASSOCIATES
ECOLOGICAL CONSULTING & DESIGN

3-7 EDINBURGH ROAD SOUTH GUELPH ON N1H 5N8
T 519.822.1609 F 519.822.5389 www.dougan.ca

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PREPARED FOR:

The District Municipality of Muskoka

70 Pine Street

Bracebridge, ON P1L 1N3

Attn. Glenn Cunnington

PREPARED BY:

Dougan and Associates Ecological Consulting and Design (D and A)

3-7 Edinburgh Rd S

Guelph ON N1H 5N8

www.dougan.ca

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1. INTRODUCTION AND OBJECTIVES

Landscape connectivity is an important characteristic of functioning ecosystems. In Ontario and the Muskoka River Watershed, land development, infrastructure, and road corridors continue to fragment natural areas, making it essential to identify and conserve corridors between habitat patches. Features with connectivity enhance genetic diversity making areas more resilient to stressors and climate change (Whitelaw and Eagles, 2007).

Building on the land cover and habitat suitability mapping developed for the Muskoka River Integrated Watershed Management (IWM) Study Natural Heritage Inventory, a watershed-scale wildlife habitat linkage analysis has been prepared using the Linkage Mapper tools which are powered by Circuitscape (McRae, 2006; McRae and Beier, 2007; McRae et al. 2008). Circuitscape has been used to model habitat connectivity of many natural systems, including the Great Lakes Basin in Ontario (Bowman and Cordes, 2015), the Credit River watershed, and as part of the Peel Climate Change Vulnerability study.

The method borrows algorithms from electronic circuit theory to predict connectivity in heterogeneous landscapes. It provides a simplified model of potential ways to connect features on the landscape, based on the degree to which land cover is ecologically permeable (i.e., how well animals can move across the landscape) as assigned by the user in the model; this is modeled using a parameter called resistance. As a simplified proxy for wildlife movement, this process can be used as one of several tools or considerations to evaluate the potential importance of corridors to support ecological linkage.

The habitat connectivity model prepared for this case study involved using White-tailed Deer (*Odocoileus virginianus*) winter habitat as an example of core area habitats. Resistance values for the watershed, which represent the energetic cost for deer to move through an area, are based on land cover types and topographic indices. The Linkage Pathways tool will be utilized to model linkage corridors between deer wintering habitats.

2. METHODS

The Linkage Pathways Tool is the primary tool used to map potential linkage areas based on core areas and landscape resistance. As noted, the core areas used for this exercise included White-tailed Deer winter habitat identified by the Province of Ontario. These areas represent important seasonal habitat for White-tailed Deer and are recognized in policy as Significant Wildlife Habitat, which is afforded protection through the Provincial Policy Statement and associated Municipal Official Plan policies.

White-tailed Deer winter habitat included Winter Yards (Stratum 1 habitat) and Wintering Areas (Stratum 2 habitat) shapefiles were downloaded from the Province of Ontario's Land Information Geohub. Polygons representing these habitats were clipped to the Muskoka River IWM study area (i.e., the Muskoka River Watershed boundary plus a 2km buffer). In the most easterly subwatersheds (i.e., Distress Pond – Big East River, Oxtongue River Outlet, and Tea Lake – Oxtongue River), it was noted that the Geohub data did not include may representative White-tailed Dear Winter Yard areas, despite the occurrence of potential habitat (e.g., coniferous forest stands). Therefore, the GeoHub data was supplemented with candidate White-tailed Deer Winter Yards that were determined in the Muskoka River IWM Study Natural Capital Inventory analysis. Features that were larger than 300 ha were included as core habitats.

Resistance scores were assigned to pixels for the same study area, outside of the winter habitat core areas, to represent the anticipated energetic cost of White-tailed Deer moving across the landscape. Energetic costs generally represent the assumed difficulty/avoidance of moving through particular landcover types, the potential risk associated with moving through particular landcover types, selection of areas for foraging, and areas that are assumed to be inaccessible. For this exercise, landscape resistance was scored using resistance values assigned to landcover types based on input from D&A wildlife ecologists, topography, and aspect largely adapted based on the details and associated reference provided in the *Forest Management Guidelines for the Provision of White-tailed Deer Habitat* (Voigt et al. 1997) (Table 1). Recognizing that White-tailed Deer undergo seasonal patterns in their movement, the resistance scores are intended to represent movement during ice-out conditions.

Landcover resistance scores were complemented with resistance scores that represent potential restrictions to movement/migration based on topography/slope and aspect (Tables 2 and 3, respectively).

Table 1: Land cover resistance scores for White-tailed Deer (scoring and rationale largely adapted from details provided in Voight et al., 1997).

Land Cover	Resistance Values	Details and Rationale
Highways	1000	Avoidance and high risk of mortality associated with highways. Includes buffer on 'Freeway' and 'Ramp' in Ontario Road network
Aquatic	900	Avoidance of traversing open water habitats, particularly open water/lakes.
Major Roads	900	Avoidance and high risk of mortality associated with major roads. Buffer on 'Express / Highway' and 'Arterial' in Ontario Road network
Bog / Fen	500	Assumes difficulty with traversing bog/fen habitats that often have open water fringes. Assumes low productivity of vegetation would not be preferred.
Anthropogenic	200	Recognizes general avoidance of anthropogenic lands with impervious surfaces and local roads.
Bridges/Major Watercourse Crossings	100	Assumes bridges and/or large culverts that are present along the road network facilitate White-tailed Deer movement. The same resistance value as Shallow Aquatic was applied, assuming a similar condition to shallow water and near shore areas of lakes, ponds, and/or other waterbodies.
Shallow Aquatic	100	Relatively accessible use of shallow water areas along the edge of watercourses and lakes. Slightly higher than Open Marsh as this could also include areas that are relatively deep (e.g., 2-5m).
Deciduous Swamp	50	Recognizes use of wooded areas and productivity of browse plants for foraging.
Open Marsh	40	Recognizes easy of mobility and productivity of vegetation for browsing.
Deciduous Forest	30	Recognizes use of wooded areas and productivity of browse plants for foraging.

Land Cover	Resistance Values	Details and Rationale
Thicket Swamp	30	Recognizes that Thicket Swamp is often alder thickets and assumed more difficult to move through than other shrub or sparse shrub habitat. Recognizes productivity of vegetation for browsing.
Mixed Forest	20	Recognizes that movement in mixed forests would be relatively high given mix of conifer and deciduous species. Recognizes use of wooded areas and productivity of browse plants for foraging.
Shrub	20	Recognizes that movement through open shrub or rock barren habitat is relatively un-impeded, and productivity of vegetation for browsing.
Sparse Shrub	15	Recognizes that movement through open shrub or rock barren habitat is relatively un-impeded, and productivity of vegetation for browsing.
Barren	10	Recognizes that movement through open shrub or rock barren habitat is relatively un-impeded, and productivity of vegetation for browsing.
Field	10	Recognizes importance of foraging in and/or along edges where open habitats exist (lawns, meadows, fields).
Lawn	10	Recognizes potential for foraging in and/or along edges where open habitats exist (lawns, meadows, fields).
Meadow	10	Recognizes foraging in and/or along edges where open habitats exist (lawns, meadows, fields).
Mixed Swamp	10	Features with coniferous species as dominant or mixed recognized as preferred habitat and lowest cost for movement.
Coniferous Forest	3	Features with coniferous species as dominant or mixed recognized as preferred habitat and lowest cost for movement.
Coniferous Swamp	1	Features with coniferous species as dominant or mixed recognized as preferred habitat and lowest cost for movement.

Table 2. Resistance scores used for topographical characteristics of the landscape related to slope, assuming increasing energetic costs and avoidance as slope progressively increases.

Slope (degrees)	Resistance
0-5	0
5.01-10	2
10.01-15	5
15.01-25	10
25.01-35	100
35.01-45	250
45.01-55	500
55.01-65	900
65.01-90	1000

Table 3. Resistance scores used for different topographical aspects (scoring and rationale largely adapted from details provided in Voight et al., 1997)

Aspect	Resistance
South	0
East	1
West	1
North	3
Flat	0

Resistances scores for landcover (Table 1), slope (Table 2), and aspect (Table 3) were summed to create the final resistance scores that were used as the raster input to the Linkage Pathway analysis.

Within the analysis platform, the linkage mapper tool called build network and map linkages was used. The tool identifies adjacent core areas and then constructs a network of core areas. The cost-weighted and Euclidean network adjacency method was used. The tool then calculates cost-weighted distances and least cost paths.

Given the size of the data, optional steps to reduce processing time were specified. This included pruning the network to a maximum of 4 connected nearest neighbors using the cost-weighted method. Corridors were further restricted based on specifying distances for the following parameters:

- Bounding circle buffer distance: Bounding circles created around core features are used to clip the resistance raster based on the specified distance, and then calculate cost-weighted distances based on the resulting reduced resistance raster space.
- Cost weighted distance threshold: The upper limit of cost-weighted distance that is used to truncate the distance of final corridors; values below the threshold are identified as no-data and not identified as mapped corridors.
- Maximum cost-weighted corridor distance: Restricts corridors to include only those that are less than or equal to the cost-weighted distance specified.

The values used to restrict the interpretation of corridors and corridor distances are presented in Table 5. In general, the scenarios represent a more restrictive model of potential linkage to a more relaxed model of potential linkage. All distance restrictions are well within the potential dispersal distances of White-tailed Deer. For example, a recent literature review of White-tailed Deer dispersal distances found that the average longest distance dispersal among 15 studies was 93.1 km (standard deviation: 68.1; range: 6.7–212.6 km) (Remington et al, 2001). The distances represent the total distance traversed, however the number of days were not included.

Table 4: Parameters specified to restrict the connection distance of core patches and corridors lengths (all values represent metres). These were specified to reduce the processing time given the size of the data.

Parameter	Scenario 1	Scenario 2	Scenario 3
Bounding circle buffer	10000	20000	25000
Maximum Euclidean corridor distance	40000	60000	60000
Cost-weighted Distance Threshold	6000	15000	15000

3. RESULTS AND DELIVERABLES

The resulting linkage analysis was used to identify corridors associated with 515 White-tailed Deer Winter Yards and Wintering Areas, representing over 617 km^2 of habitat (Table 5). The linkage analysis results are summarized in Table 6 and presented on Maps 1 to 3. Overall, the linkage analysis resulted in identifying progressively increasing number of corridors (899 to 1421) and area (774 to 2159 km^2) based on the more conservative linkage model (scenario 1) to the more relaxed linkage model (scenario 3). In general, this trend was consistent among subwatersheds with the highest corridor areas included Lake Rosseau, Hollow River, North Branch Muskoka River, Lake Muskoka-Muskoka River, and Lake Vernon; all which had corridor areas of over 81 km^2 in scenario 1, and over 180 km^2 in scenario 3. Blackstone Harbour, Moon River Bay, Tea Lake-Oxtongue River, and Distress Pond – Big East River had the lowest corridor areas mapped (ranging from 13.2 km^2 to 19.1 km^2 in scenario 1, to 63.2 km^2 to 163.4 km^2 in scenario 3).

Between Scenarios 1 and 2, there was an increase in the number of corridors and of total corridor area, for each subwatershed in the analysis. Most of the landscape-level corridor changes were in the central and eastern areas of the Muskoka watershed. Most new corridors in the central areas were identified within the subwatershed of Lake Rosseau and the neighbouring subwatersheds of Lake Vernon, Lake Muskoka – Muskoka River, North Branch Muskoka River, and South Branch Muskoka River Outlet (see Map 2). In the easterly areas, new corridors were identified in Little East River – Big East River, Distress Pond – Big East River, Tea Lake – Oxtongue River, Oxtongue River Outlet, and Hollow River. Many of these subwatersheds experienced an increase of over 100% in the total corridor area between Scenarios 1 and 2.

Between Scenarios 2 and 3, there was a less drastic increase in both the number of corridors and total corridor area, albeit with general increases identified for both measures for the majority of the subwatersheds. Six (6) subwatersheds, Baysville Narrows - South Branch Muskoka River, Lake Vernon, Little East River - Big East River, Musquash River, North Branch Muskoka River, and South Branch Muskoka River Outlet, experienced no increase in total corridor area between Scenarios 2 and 3. Five (5) out of these six (6) did experience small increases in the number of corridors identified, between Scenarios 2 and 3. New corridors were mostly concentrated in the easterly subwatersheds (Distress Pond – Big East River, Tea Lake – Oxtongue River, Oxtongue River Outlet, and Hollow River), in addition to some additions in the west, namely within Blackstone Harbour and Lake Rosseau (see Map 3).

Table 5: Summary of winter habitat areas and corridor areas within each Muskoka River subwatershed based on the linkage analysis.

Quaternary Watershed Name	Count of winter habitat polygons*	Area (km^2)
Baysville Narrows - South Branch Muskoka River	45	129.4
Blackstone Harbour	43	45.3
Distress Pond - Big East River	7	31.8
Hollow River	53	10.0
Lake Muskoka - Muskoka River	92	63.4
Lake Rosseau	114	65.3
Lake Vernon	21	49.8
Little East River - Big East River	10	31.8
Moon River Bay	62	19.9
Musquash River	11	62.1
North Branch Muskoka River	20	70.2
Oxtongue River Outlet	23	24.9
South Branch Muskoka River Outlet	9	6.2
Tea Lake - Oxtongue River	5	6.8

** Some winter habitat polygons extend across quaternary watersheds and are therefore counted more than once.*

Table 6: Summary of number of corridors and corridor area for each CircuitScape scenario for each subwatershed.

	Scenario 1		***Scenario 2***		***Scenario 3***	
Quaternary Watershed Name	**Corridor Number**	**Area (km2)**	**Corridor Number**	**Area (km2)**	**Corridor Number**	**Area (km2)**
Baysville Narrows - South Branch Muskoka River	101	33.96	113	86.96	117	86.96
Blackstone Harbour	33	13.25	40	37.77	48	63.23
Distress Pond - Big East River	9	19.07	20	107.85	24	163.44
Hollow River	155	81.45	181	181.37	189	188.46
Lake Muskoka - Muskoka River	144	115.94	222	266.41	272	271.01
Lake Rosseau	169	134.87	251	310.97	318	347.12
Lake Vernon	50	87.83	62	183.93	66	183.93
Little East River - Big East River	19	29.33	33	113.72	34	113.72
Moon River Bay	62	18.08	77	58.51	90	60.80
Musquash River	26	32.60	43	69.60	50	69.60
North Branch Muskoka River	38	95.26	64	224.33	64	224.33
Oxtongue River Outlet	65	48.60	81	116.96	87	134.78
South Branch Muskoka River Outlet	18	45.88	34	139.76	37	139.76
Tea Lake - Oxtongue River	10	18.48	15	85.80	25	111.99

The linkage analysis undertaken for this report represents one of many potential interpretations of the potential linkage of White-tailed Deer among its wintering habitat areas based on the assumptions and associated resistance values included in Tables 1 to 4. It is important to recognize that variations in the resulting linkage map would differ depending on the resistance inputs. As well, it is noted that the reduced number and area of corridors identified within the westerly subwatersheds (e.g., Distress Pond-Big East River and Tea Lake-Oxtongue River) is related to the lack of winter deer habitat identified by the province in that area (provincial data was complemented with candidate SWH data, but still may represent an under representation of true winter habitat). Should additional winter habitat exist within these areas, it is expected that the linkage analysis would have resulted in identifying additional corridor areas within these subwatersheds. The analysis domain was also restricted to the Muskoka River Watershed and adjacent 2km area. Therefore, corridors within the boundary areas may be influenced by habitat characteristics and landcover resistances that exist beyond the study domain.

Future analyses specific to landscape linkage would benefit from validating the identified corridors using various types of occurrence data. One example could be to determine which of the three linkage analysis scenarios best explains distribution patterns of White-tailed Deer across the watershed. Similarly, existing vehicular collision data involving White-tailed Deer could be analyzed to determine if collisions are associated with disproportionately high connectivity areas and/or areas where linkages are associated with road crossings. Where the linkage models predict these areas reasonably well, the results could be used to assist in additional traffic hazard signage and/or exclusion fencing.

The results presented in this analysis are also only representative of one species. Undertaking linkage analysis for other species, with different associations with land cover and landscape features, would help to produce a more fulsome understanding of multi-species landscape connectivity. Including linkage analysis for species that are representative of various life-histories and dispersal dynamics could help identify where various corridors overlap. In turn, this could help to identify and prioritize areas of the landscape that provide the most robust and best opportunities for ensuring the landscape remains connected.

Respectfully Submitted,



Janel Sauder, HBSc, GIS GCert.
GIS Manager



Steve Hill, PhD
Senior Ecologist, Director



Christina Myrdal, HBSc, Eco. Mgmt. Tech., ISA
Ecology Manager

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Map 1: Deer Wintering Habitat Connectivity

Muskoka River Watershed IWM -
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- Quaternary Watersheds
- White-tailed Deer Wintering Area (MNRF, 2023)

Least-cost Corridors

- Higher Cost
- Lowest Cost

0 3,750 7,500 15,000
Metres

1:400,000

North American 1983 CSRS UTM Zone 17N

Basemap Source: Esri, NASA, NGA, USGS, Province of Ontario, Esri Canada, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, NRCan, Parks Canada

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DOUGAN & ASSOCIATES
ECOLOGICAL CONSULTING & DESIGN

3-7 EDINBURGH ROAD SOUTH GUELPH ON N1H 5N8
T 519.822.1609 F 519.822.5389 www.dougan.ca

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DRAWN BY: J. Lacsamana / J. Sauder

Map 2: Deer Wintering Habitat Connectivity

Muskoka River Watershed IWM -
Natural Capital Inventory
Addendum 4: Habitat Connectivity Concept

Quaternary Watersheds

White-tailed Deer Wintering Area (MNRF, 2023)

Least-cost Corridors

Higher Cost

Lowest Cost

0 3,750 7,500 15,000
Metres

1:400,000

North American 1983 CSRS UTM Zone 17N

Basemap Source: Esri, NASA, NGA, USGS, Province of Ontario, Esri Canada, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, NRCan, Parks Canada

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Map 3: Deer Wintering Habitat Connectivity

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Quaternary Watersheds

White-tailed Deer Wintering Area (MNRF, 2023)

Least-cost Corridors

Higher Cost

Lowest Cost

0 3,750 7,500 15,000
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T 519.822.1609 F 519.822.5389 www.dougan.ca