Measuring Shortest Distance between Fisheries Tag-Recapture Locations within Estuaries

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Abstract
In fisheries research, tag and recapture data is very common. Fisheries scientists are often interested in the measurement of shortest distance between tag and recapture locations. In open marine systems, this is easily calculated within a Geographic Information System. However, in estuarine systems where fish movement is constrained by land, the calculation of shortest distance becomes more complicated. This presentation will compare using cost distance within Spatial Analyst and distance along a network to measure shortest distance in the Indian River Lagoon estuarine environment.

Introduction

Shortest distance is a measurement often used in mark-recapture research. There are four common ways to use a Geographic Information System (GIS) to measure shortest distance between two points for mark-recapture studies. When there are a small number of mark-recapture points, it is easy to measure shortest distance by digitizing the paths between points. For larger mark-recapture data sets, researchers often use straight line distance, or “as the crow flies distance,” as an efficient method for measuring distance. This works well when travel between the two points is not constrained by boundaries. An example of a constraining boundary would be land features constraining fish movement. Measuring shortest distance along a network is a viable alternative to straight line distance though it is limited to linear features. Finally, raster-based GIS can be used to measure the shortest distance between points. In the ESRI ArcGIS environment, Spatial Analyst’s “Cost Distance” tool allows constraints on measuring distance between point locations. Intuitively, measuring distance using raster-based GIS may result in exaggerated distance values.

At the Florida Fish and Wildlife Conservation Commission’s Fish and Wildlife Research Institute (FWC-FWRI), three important estuaries commonly studied are Charlotte Harbor, Tampa Bay, and Indian River Lagoon (Figures 1 & 2). In Indian River Lagoon, one FWRI-FWC research project used a network to measure shortest distance between mark/release and recapture locations for the common snook (*Centropomus undecimalis*). In Tampa Bay, another FWRI-FWC research project is using the ArcGIS Spatial Analyst “Cost Distance” method to measure distances between mark/release and recapture locations for red drum (*Sciaenops ocellatus*) and the common snook (*Centropomus undecimalis*). For studies analyzing multiple estuaries, we need to know the advantages and disadvantages of the four types of measurement of shortest distance.

This study specifically compares distances measured using the straight line distance, network-derived distance, and cost distance methodologies for a small data set of mark-recapture data in the Indian River Lagoon. Additionally, we perform a multiscale analysis of error generated for the ArcGIS Spatial Analyst “Cost Distance” tool based on two extents and five different spatial resolutions.

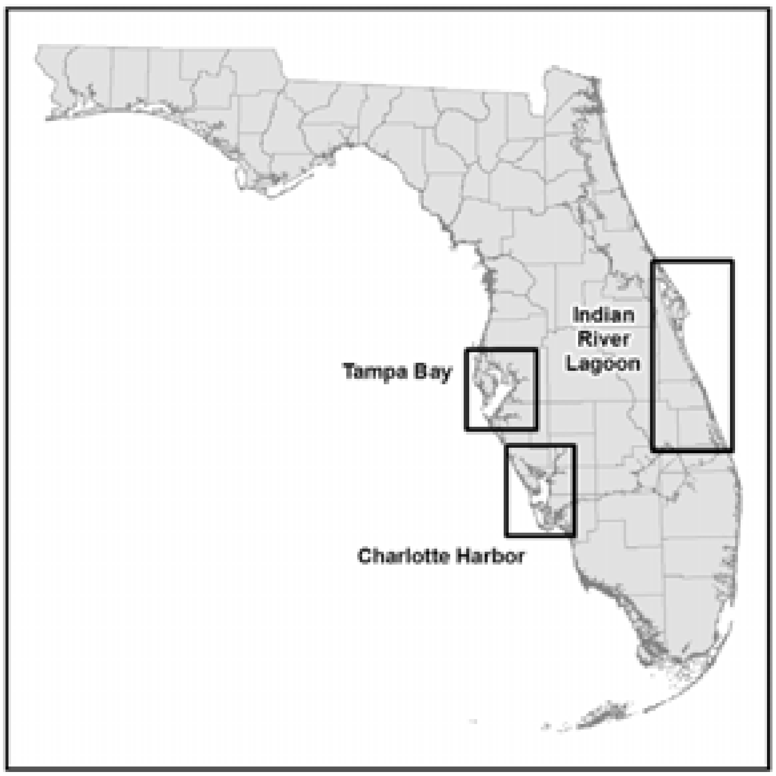


Figure 1. Map of Florida identifying the locations of Charlotte Harbor, Indian River Lagoon, and Tampa Bay.

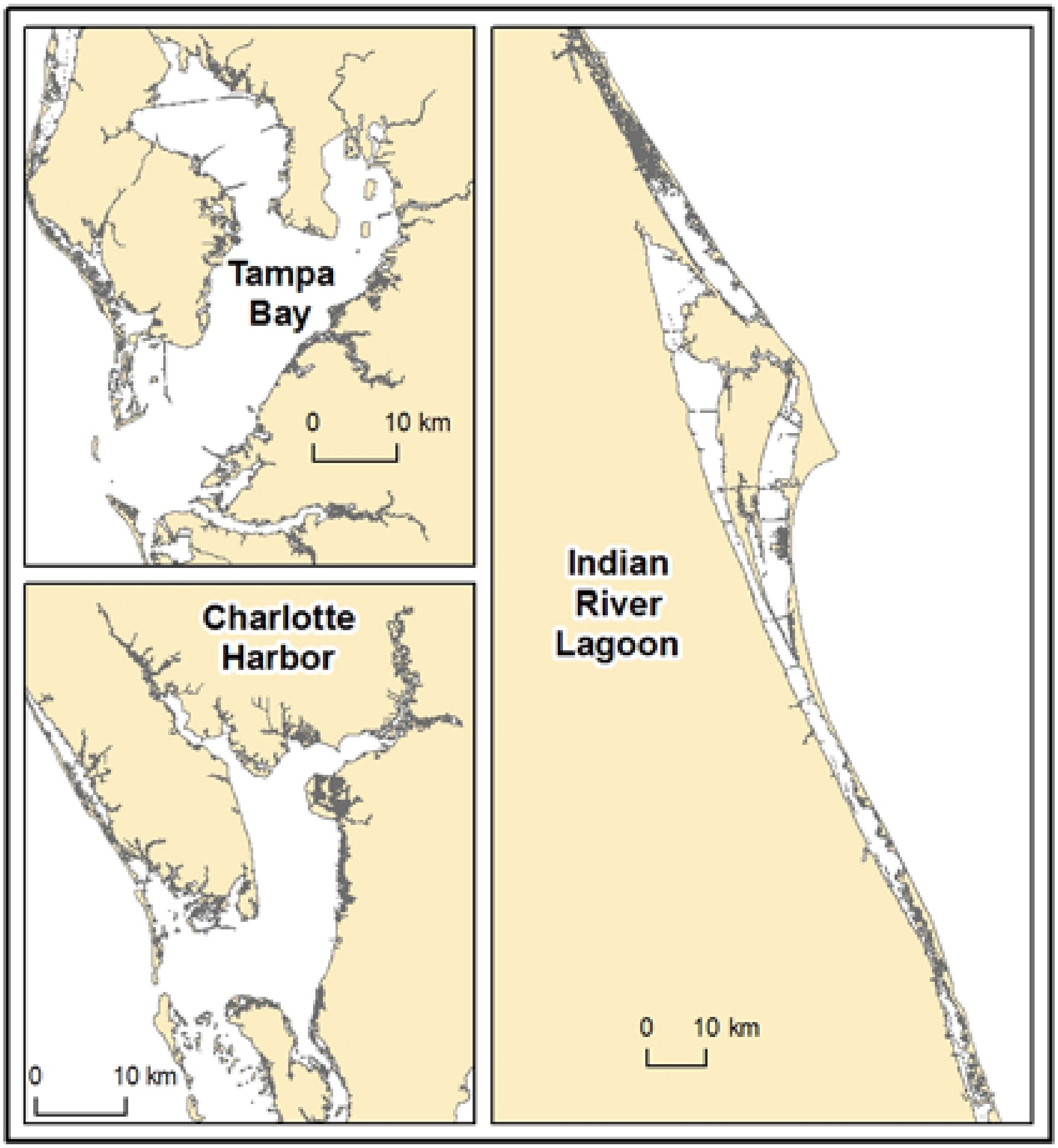


Figure 2. Maps identifying the morphologic structure of Charlotte Harbor, Indian River Lagoon, and Tampa Bay.

Methods

Comparing Shortest Path Distance Methods in Indian River Lagoon

In order to compare shortest path distance methods, we selected a small data set consisting of twenty-five mark-recapture samples in the Indian River Lagoon. The twenty-five recapture locations corresponded to two mark/release locations. Distances were measured using three methods. Digitizing paths to measure distance was considered too time intensive and therefore, was not performed. Straight line distance was measured directly from point locations using the GIS. Network distance was calculated using a network that was built for the Indian River Lagoon estuary (Figure 3-A). Two cost distance rasters were generated using a raster describing water as well as one of the two mark/release locations. The resolution of the water raster dataset was 20-foot grid cells. This scale was chosen so that streams and rivers maintained their continuity. Figure 3-B shows a map of one of these cost distance rasters.

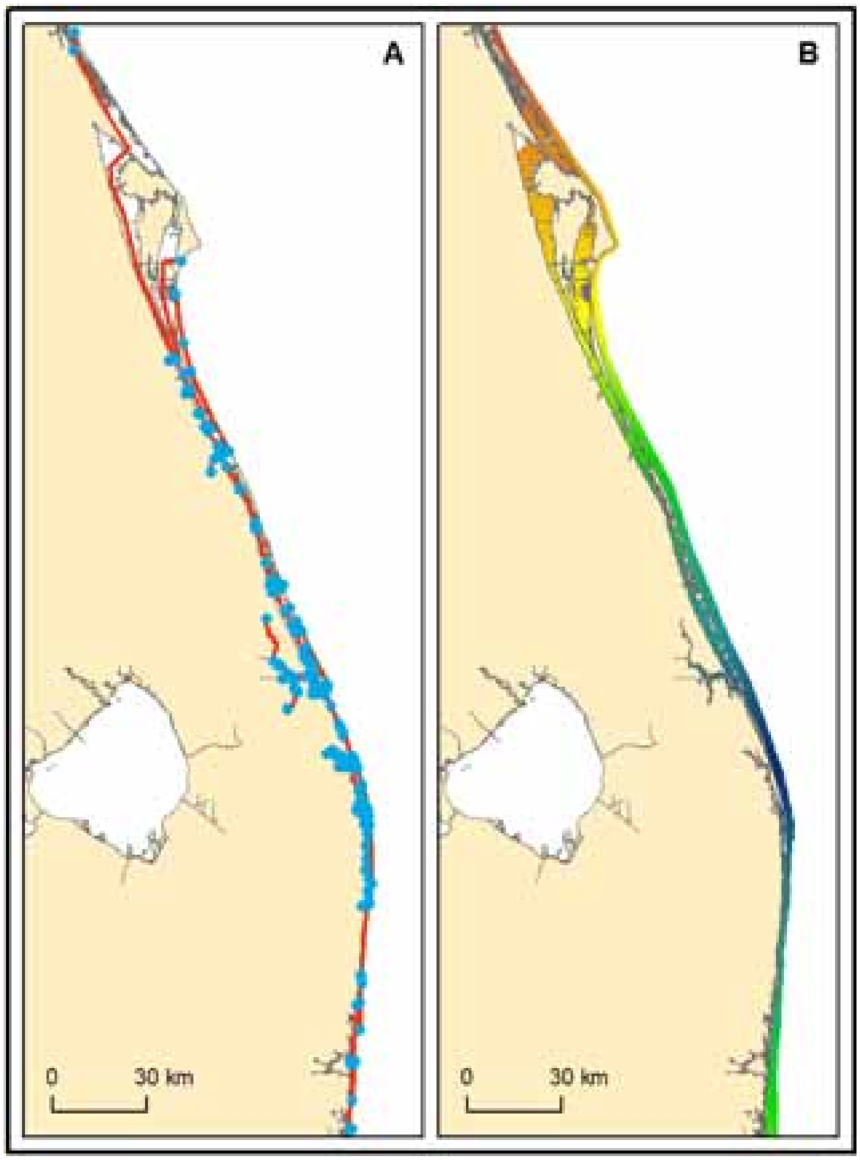


Figure 3. Indian River Lagoon maps comparing a network approach to shortest distance with a raster distance generated using the cost distance function.

<u>Measuring Percent Error for Cost Distance Method</u>
For estuaries such as Charlotte Harbor and Tampa Bay, the network distance approach is not applicable. This makes using the cost distance method a necessity. To further understand the amount of error generated from using the cost distance method to measure shortest distance, we built hypothetical rasters at various resolutions (1, 2, 5, 10, 20 meters) and at two extents (1,000 and 10,000 meters). We then measured cost distance and straight line distance for points generated along a buffer between 0 and 90 degrees. The percent difference in measured distance was calculated at each resolution and extent.

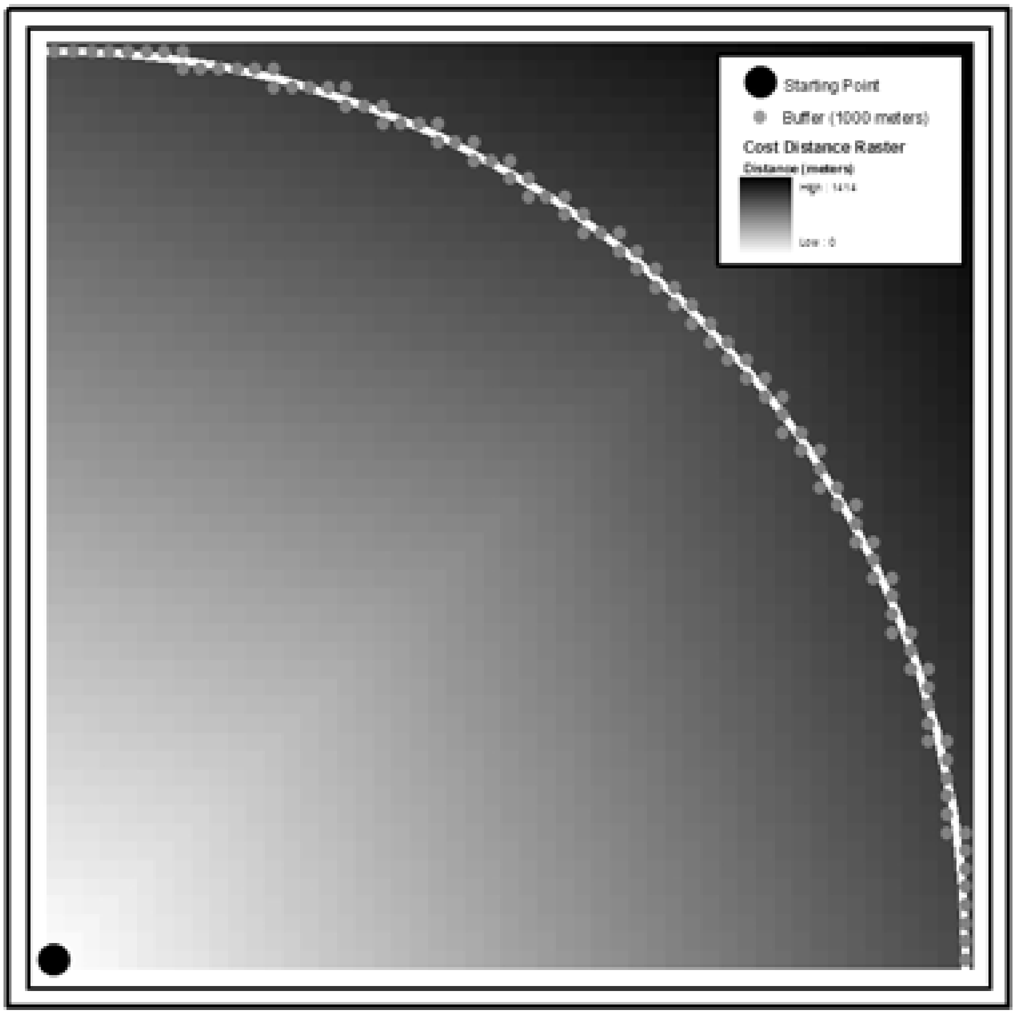


Figure 4. Map identifying the resulting cost distance raster with the initial start point and the 1000 meter buffer.

Results & Discussion

Comparing Shortest Path Distance Methods in Indian River Lagoon
A comparison between the straight line distance, cost distance, and network distance methods is reported (Table 1).

Percent Difference	Cost Distance to Straight Line Distance	Network Distance to Straight Line Distance	Cost Distance to Network Distance
Min	3.1	0.3	-7.4
Max	45.5 (13.7*)	44.3 (15.2)	6.1
Average	9.7 (8.2**)	7.2 (5.7**)	3.8***
Number Negative	---	---	5

Table 1. Percent differences in distance measurements between straight line distance, network distance, and cost distance (* Second largest difference is also reported when largest difference is an outlier. ** Average values with largest difference removed when largest difference is an outlier. *** When negative percent differences occur, average percent difference was calculated for the absolute values of those percent differences.)

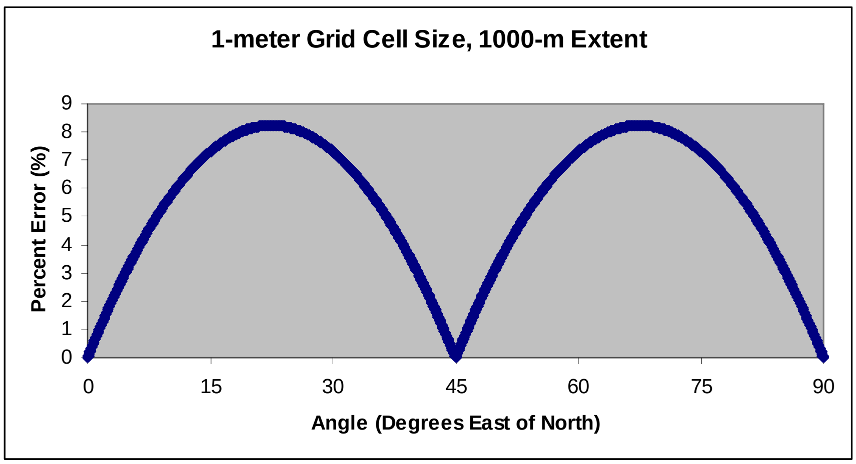
As expected, both the cost distance and network distance methods resulted in greater distance measurements than the straight line distance method. Note that the straight line distance measurements severely underestimated distance in cases where recapture locations were in rivers.

The cost distance method tended to produce higher distance measurements than the network distance method. It is believed part of the reason for this is that the Indian River Lagoon has an overall direction that would lead to exaggerated shortest distance values when using the cost distance method. However, several cases were identified where the network distances were greater. The reasons for these cases were either it was shorter to travel along the shoreline (Atlantic Ocean) than along the network (followed intracoastal waterway) or the network meandered along the intracoastal waterway (did not follow centerline).

Measuring Percent Error for Cost Distance Method
With our derived hypothetical landscapes, we identified percent differences between the cost distance method and the straight line distance method (Table2 and Figure 5). Percent Error ranged from 0 at 0, 45, and 90 degrees East of North to 8.24 at approximately 22.5 and 67.5 degrees East of North. The amount of error and the associated charts were the same for all resolutions (1, 2, 5, 10, and 20 meters) and all extents (1,000 meters and 10,000 meters). This was a surprise as we expected error to increase as pixel resolution became more coarse.

Grid Resolution (meters)	Angles (Degrees) with 0 Percent Difference	Angles (Degrees) with Maximum Percent Difference	Maximum Percent Difference
1,000 Meter Extent			
1	0, 45, 90	22.5, 67.5	8.24
2	0, 45, 90	22.5, 67.5	8.24
5	0, 45, 90	22.6, 67.4	8.24
10	0, 45, 90	22.4, 67.6	8.24
20	0, 45, 90	22.4, 67.6	8.24
10,000 Meter Extent			
1	0, 45, 90	22.5, 67.5	8.23
2	0, 45, 90	22.5, 67.5	8.24
5	0, 45, 90	22.5, 67.5	8.24
10	0, 45, 90	22.5, 67.5	8.24
20	0, 45, 90	22.5, 67.5	8.24

Table 2. Measurement of error in distance measurements between straight line distance and cost distance methods for a hypothetical landscape.



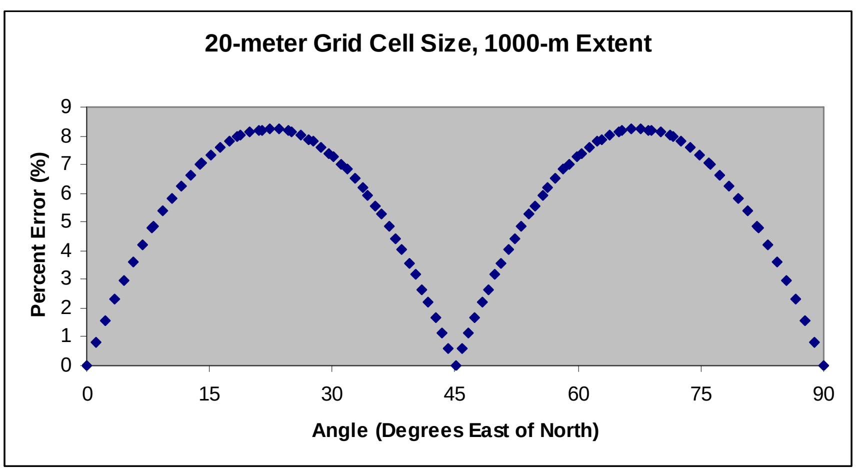


Figure 5. Charts describing percent error between the cost distance and straight line distance methods for a hypothetical landscape.

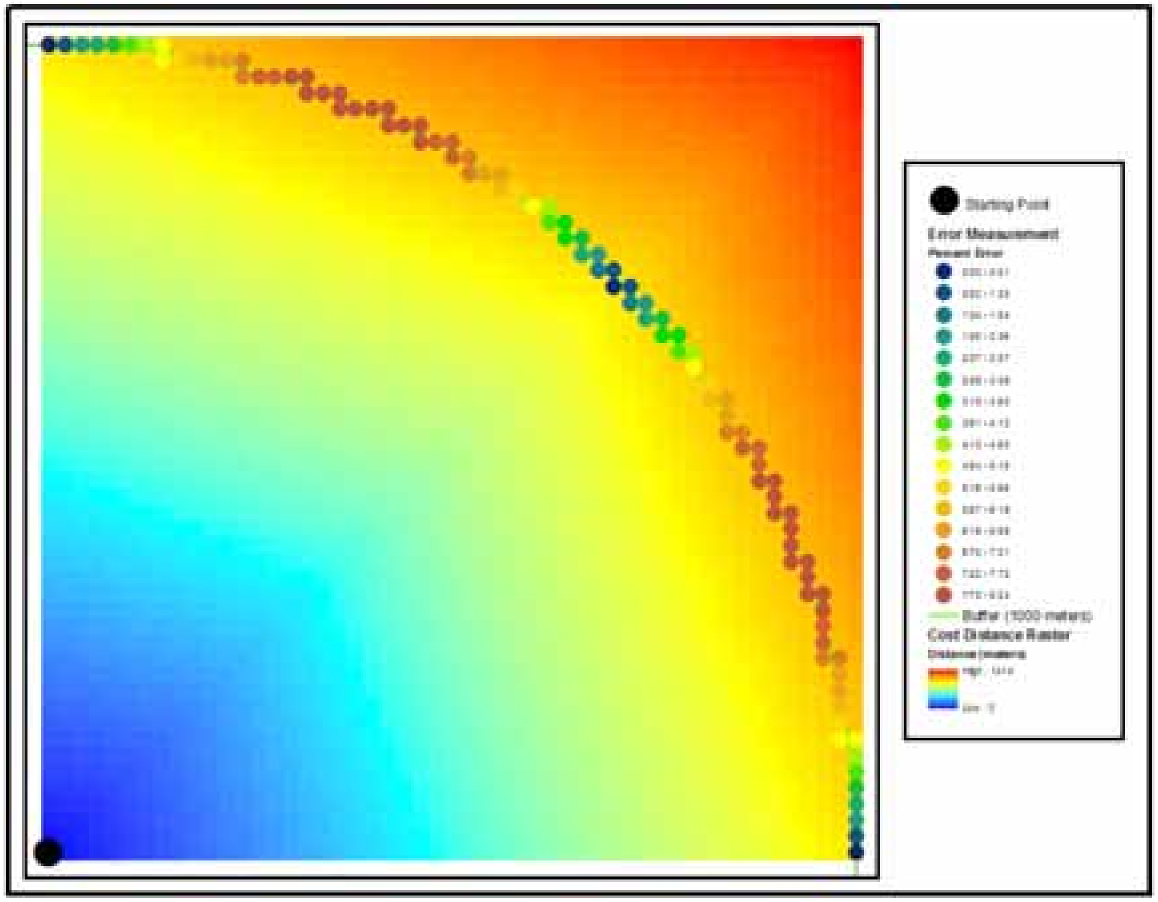


Figure 6. Map graphically showing the variations in percent error between the cost distance and straight line distance methods for a hypothetical landscape.

<u>Advantages and Disadvantages of Methods to Derive Shortest Path Distance</u>
The identified advantages and disadvantages of different methods to derive shortest path distance are described in the following table (Table 3):

Method	Advantages	Disadvantages
Digitized Distance	• Most accurate method	• Time to perform method prohibitive for more than a small number of samples • Distances vary based in digitization effort/detail • Not replicable
Straight Line Distance	• Very fast to compute distances • Replicable	• Often produces severe underestimations of distance when movements are constrained by land
Network Distance	• Works well for study areas that are morphologically linear in nature (i.e. Indian River Lagoon, riverine systems) • Fast to compute distances once network is developed • Replicable	• Difficult to develop network in complex systems • Does not work well in systems that are not linear (i.e. Charlotte Harbor, Tampa Bay) • Distances can be exaggerated if network is incomplete (i.e. distance along intracoastal is greater than distance along shoreline)
Cost Distance	• Consistent, replicable way to measure shortest path distance • Works in systems where you have land constraining movement and that are not linear (i.e. Charlotte Harbor, Tampa Bay)	• Very computer intensive • Distances can be exaggerated based on angle of path (< 10% error) • Percent errors vary greatly (0 to <10% error) based on angle of path

Table 3. Advantages and disadvantages of different shortest path distance methodologies.

Future Research
Examples of future areas of research are:

- Test whether cost distance errors increase using smaller extents and larger grid cell resolutions.
- Research whether one can derive an average error in the cost distance methodology.
- Research whether you can correct for cost distance errors based on an average path angle.
- Study how a range of cost distance errors may effect conclusions derived from specific mark-recapture studies.

Conclusion
The cost distance method to measure shortest path distance is our preferred methodology for the three commonly studied estuaries in Florida (Charlotte Harbor, Indian River Lagoon, and Tampa Bay). However, to appropriately use the distances generated by the cost distance method, it is necessary to understand the relationship between angle of path traveled and how distance measurements may be exaggerated.

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