Cost Distance and Least Cost Path of Southern Killer Whales in the Coastal Waters of British Columbia

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1 Introduction

Orcas, or killer whales are the largest member of the dolphin family and have many distinguishing features, the most notable being their distinctive black and white markings. Killer whales are considered to be the top predator in the Pacific waters off the coast of BC (WILDS, n.d). Despite their legendary reputation as powerful hunters, the northeast pacific southern resident population has been classified as endangered by Canada's Species at Risk Act (SARA) and by the Committee of Endangered Wildlife in Canada (Fisheries and Oceans Canada, 2018).

There are two types of killer whales in the waters off of Vancouver Island; transient and resident killer whales. Transient killer whales primarily hunt marine mammals such as sea lions or seals (WILDS, n.d). Transient whales do not have a restricted range and tend to travel along the western Vancouver Island coast, but they have been recorded all along the coast (Fisheries and Oceans Canada, 2018). Resident killer whales are social animals and form distinct family groups or *matrilines* (Fisheries and Oceans Canada, 2018). The primary source of food for resident killer whales is Chinook salmon (WFC-RCF, 2018). There are two groups found off the coast of Vancouver Island, the southern residents focused in the waters of the San Juan Islands and the Gulf Islands, and the northern residents are found in the waters off the coast of Tofino to southern Alaska (WILDS, n.d).

There are many factors affecting the health of the killer whale populations off of the coast of BC. Pollution, competition for habitat and food, and noise and traffic from marine vessels are considered to be some of the main factors threatening killer whales. Acoustic measurements taken in the waters off of the coast of northeast BC have shown that ocean noise has increased due to an increase in shipping traffic (Merchant et al, 2014). Killer whales use a variety of acoustic sounds to communicate and navigate. To navigate and localize objects underwater, killer whales use echolocation (Filatova at al, 2015). The increased traffic of large vessels in the known habitat of the southern killer whale population produces sound waves that interfere with the killer whales ability to navigate, hunt and therefore survive. This study aimed at using Multi Criteria Decision Analysis (MCDA) to analyze the cost-effect of large vessel traffic in the coastal waters of BC. The cost distance was then used to determine the theoretical path of a transient southern killer whale from the southern waters off the coast of Victoria to the northern waters off the eastern coast of Haida Gwaii.

2 Methods

2.1 Study Area and Data

2.1.1 Study Area

The study area ranges from the waters off of the coast of Victoria and Southern BC to the coastal waters just north of Haida Gwaii. Figure 1 shows the extent of the study area, as well as approximate killer whale territory as classified by the Vancouver Aquarium. This Figure also shows the origin and destination points of the theoretical least cost path. This path was chosen because the shortest path through an unweighted representation of the region travels through known killer whale territory.

2.1.2 Data

The data used in this study was a 5000 meter, 2010 Vessel Traffic Polygon Feature Layer of the coastal BC waters provided by The British Columbia Marine Conservation Analysis (BCMCA). The data contained information on different vessel traffic, however only fishing, merchant, passenger and cruise, and tanker were considered in the study as they were deemed to pose the highest threat to killer whales.

2.2 Analysis Methods

2.2.1 Data Preprocessing

The 2010 Vessel Traffic Polygon Feature Layer was loaded into ArcGIS 10.5 software. Four attribute queries were performed to create four new layers representing fishing vessel traffic, merchant vessel traffic, passenger and cruise vessel traffic, and tanker traffic. These four polygon feature layers were then converted to raster format with a 5000 meter grid cell resolution matching the resolution of the input 2010 vessel traffic layer.

2.2.2 Reclassification

The four raster traffic layers derived in 2.2.1 were then reclassified using a 10 class natural breaks classification. Cells with the largest amount of vessel traffic were given a value of 10 and similarly cells with the least amount of traffic were given a value of 1. The natural breaks classification was chosen due to the distribution of the data. Due to the vastness of the coastal waters of BC, the vessel traffic is located primarily in the highly populated southern regions. Due to this clustering, the data is not normally distributed and an equal interval classification would result in many values in the same class and many classes with no values at all.

2.2.3 Layer Integration

The four reclassified raster suitability surfaces created in 2.2.2 were then intersected to create a integrated cost surface using the following equation:

$$(f * 0.4) + (t * 0.4) + (pc * 0.1) + (m * 0.1) \tag{1}$$

where f,t,pc and m represent fishing, tanker, passenger and cruise, and merchant vessel traffic. These weights were chosen to reflect the potential impact on killer whale habitat. The impact of fishing vessels may result in less prey for the killer whales and force them to seek new areas to hunt, thus they were given a large weight. Similarly with tankers, the size and noise production as well as the devastating results of a potential oil spill gave tanker traffic a larger weight.

2.2.4 Cost Distance and Least Cost Path

The integrated cost raster created in 2.2.3 was then input to a cost distance tool along with the origin point of the theoretical transient killer whale path, producing a cost distance raster and a back-link raster. These outputs were input to a least cost path tool along with the destination point of the path, producing a final least cost path from origin to destination on a weighted representation of the region.

3 Results

Figure 2 shows the input raster layers derived in 2.2.1 and Figure 3 shows the reclassified vessel traffic surfaces created in 2.2.2 as well as the integrated surface created in 2.2.3. All four reclassified surfaces show high vessel traffic in the southern regions of Vancouver Island and the Salish Sea. Additionally, the merchant vessel traffic surface in particular shows high vessel in traffic in the northern regions off the coast of Haida Gwaii. The integrated surface reflects the weighting scheme and the input layers, showing high weighted vessel traffic in the Salish Sea and southern regions. The values of this surface reflect weighted large vessel traffic and thus represent degrees of noise and risk to killer whales. The open ocean areas have low vessel traffic on all four reclassified surfaces and similarly had a low weighted vessel traffic value in the integrated surface. The attribute tables for the reclassified raster surfaces are summarized in Table 1.

The cost-distance surface and the back-link surface created in 2.2.4 are shown in Figure 4. The distances are fairly euclidean however there are some transformations due to the weighting in the southern Salish Sea region. A final map of the least cost path is shown in Figure 5. The least cost path reflects the inputs and the cost-distance surface as it is fairly absolute and does not have any drastic transformation due to the criterion. The path remains close to the coastlines of Vancouver Island and Haida Gwaii.

4 Discussion

The resulting least cost path shown in Figure 5 is a logical path when compared to the integrated surface as it tends to stick to lower vessel traffic areas when given the option. The areas traversed through are known to be inhabited by both Northern and Southern Resident killer whales (Ford, 2006). Although these regions are inhabited, a journey such as this one is unlikely for a killer whale, especially a resident killer whale. Killer whales typically inhabitant distinct regions, but some transient killer whales have been recorded travelling distances of over 2000 kilometers (Ford, 2006).

The weighting of rasters used throughout this analysis had a slight effect on the least cost path however when observing the integrated cost raster in Figure 3, it is evident that the shortest path was weighted relatively low. This results in a minimal impact on transforming the shortest path into a least cost path. An Analytical Hierarchy Process would have also benefited the weighting scheme by providing more consistency.

A future analysis of this topic would benefit from more criteria layers to aid in the construction of the least cost path. These layers could include bathymetry data, fishery data and pollution data to provide further insight on threats to killer whales. The focus of this study was on large vessel traffic and its impacts on killer whales however there are many more factors to consider. Additionally, the 5000 meter resolution of the initial input raster adds a lot of inherent uncertainty due to magnitude of each grid cell.

5 Conclusion

In conclusion, Multi Criteria Decision Analysis is an effective framework for studying complicated problems such as the least cost traversal of endangered killer whales. With enough data and a more detailed model, it may be possible to predict the movement of killer whales through the coastal waters of BC, so measures can be put in place to protect the remaining resident and transient killer whales.

6 References

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7 Figures and Tables

Table 1: Table of Reclassified Vessel Traffic Raster Values

VALUE	1	2	3	4	5	6	7	8	9	10
SURFACE										
Fishing (Reclassified)	17548	410	230	34	16	24	8	3	4	4
Merchant (Reclassified)	16637	899	356	195	99	43	27	15	6	4
Tanker (Reclassified)	17099	701	213	123	49	33	19	15	18	11
Pass./Cruise (Reclassified)	17145	584	166	136	126	49	40	14	15	6

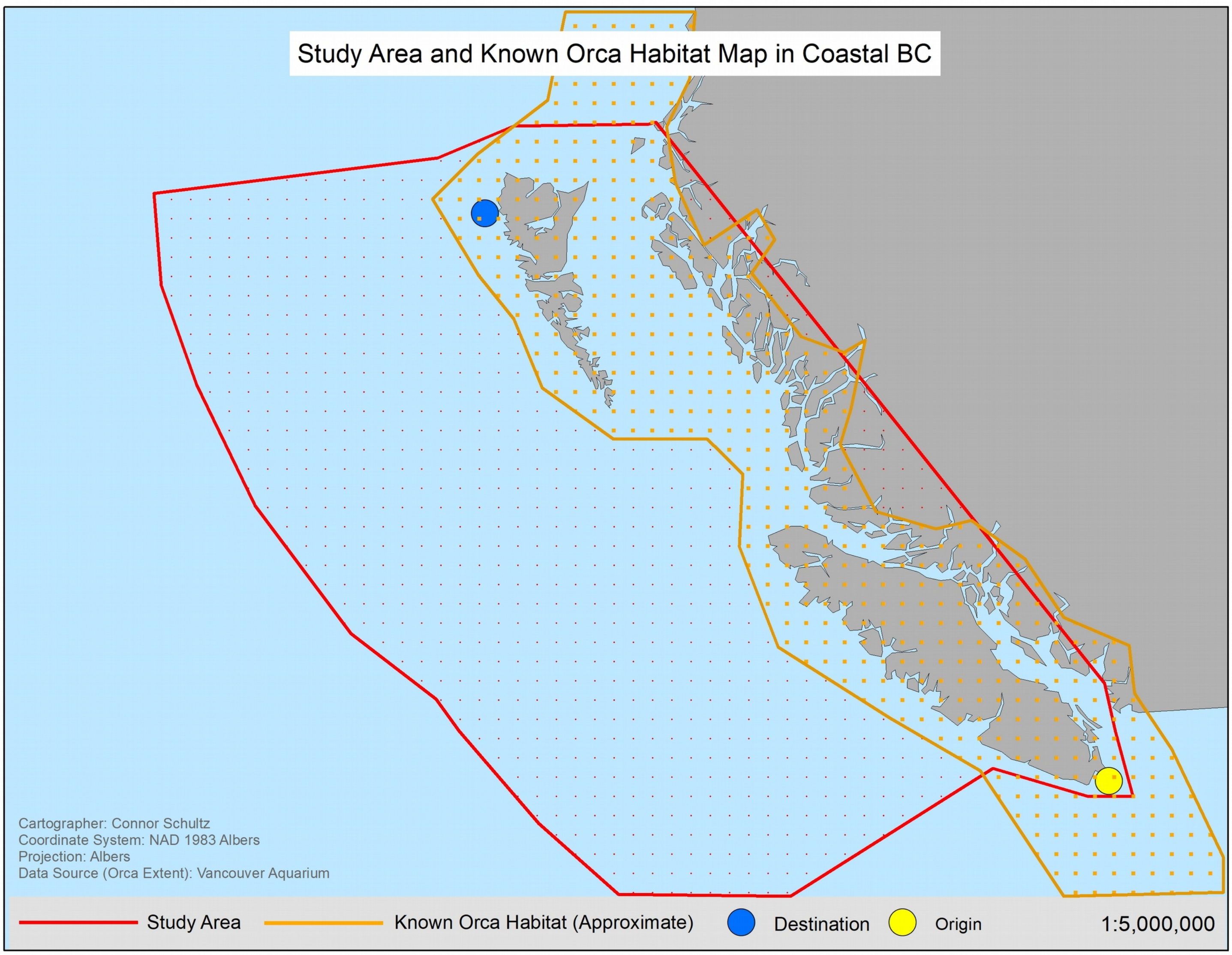

Figure 1: Study Area Map and Known Orca Habitat in Coastal BC

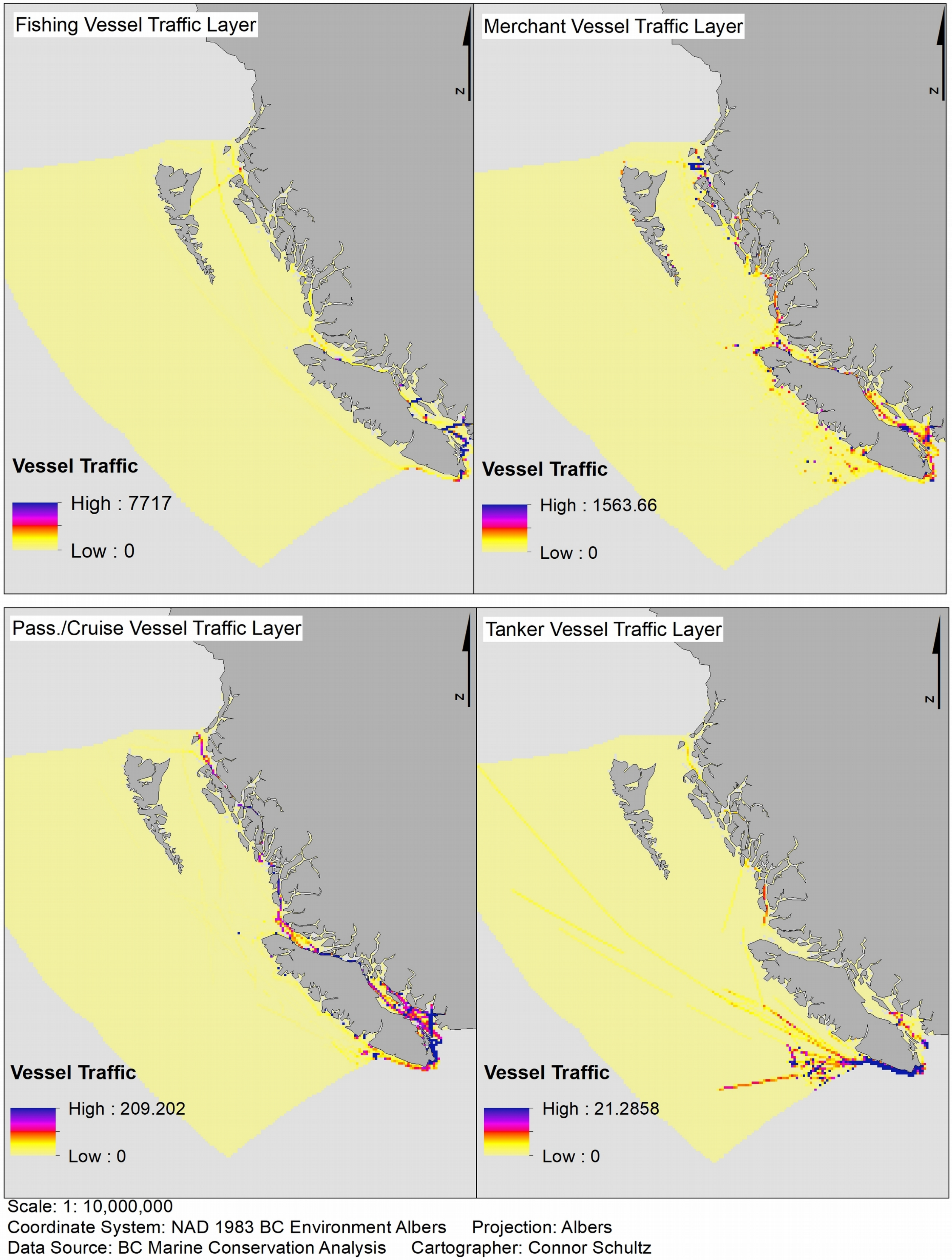

Figure 2: Input Vessel Traffic Rasters

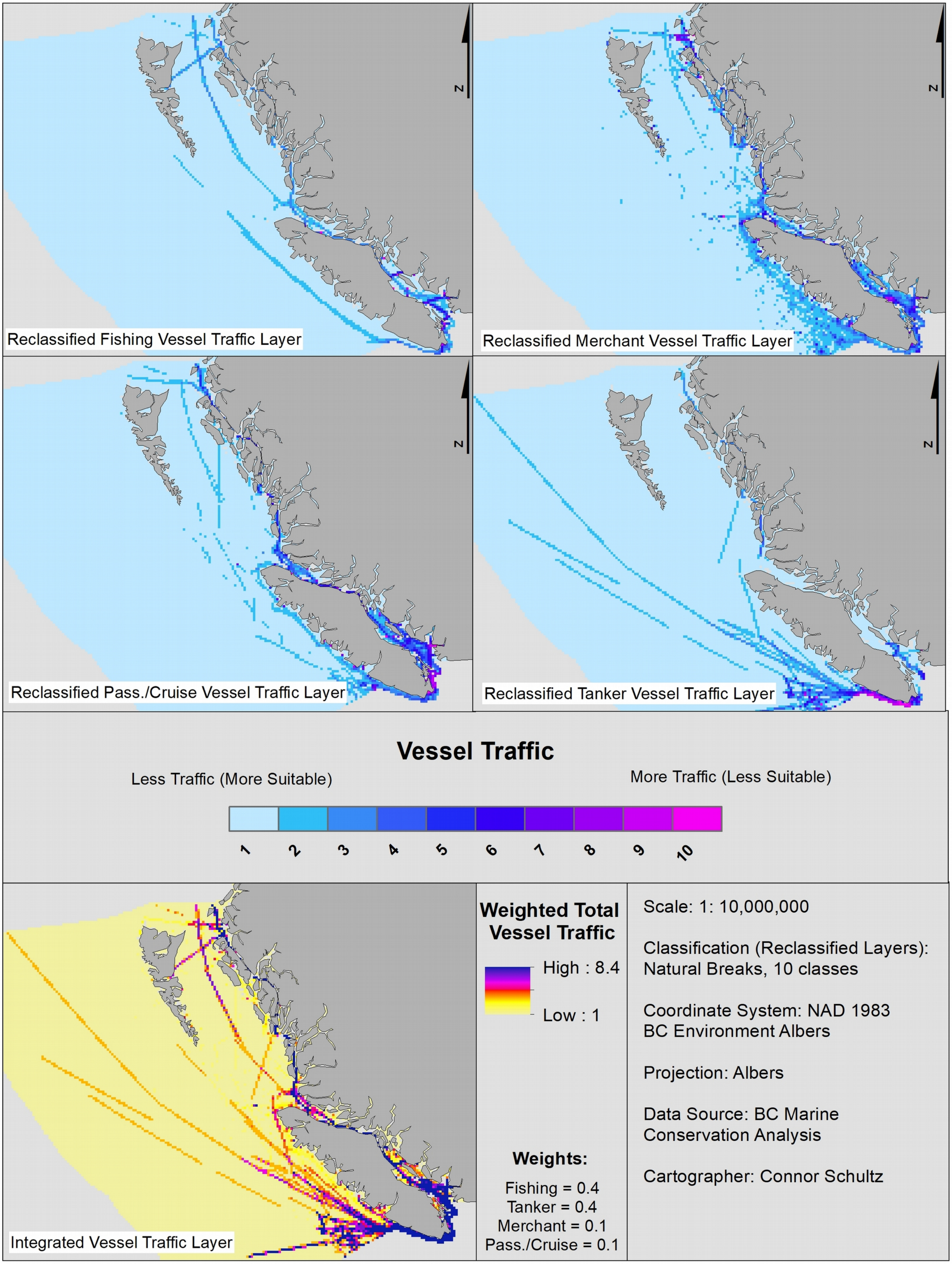

Figure 3: Reclassified Vessel Traffic Surfaces and Integrated Weighted Vessel Traffic Suitability Surface

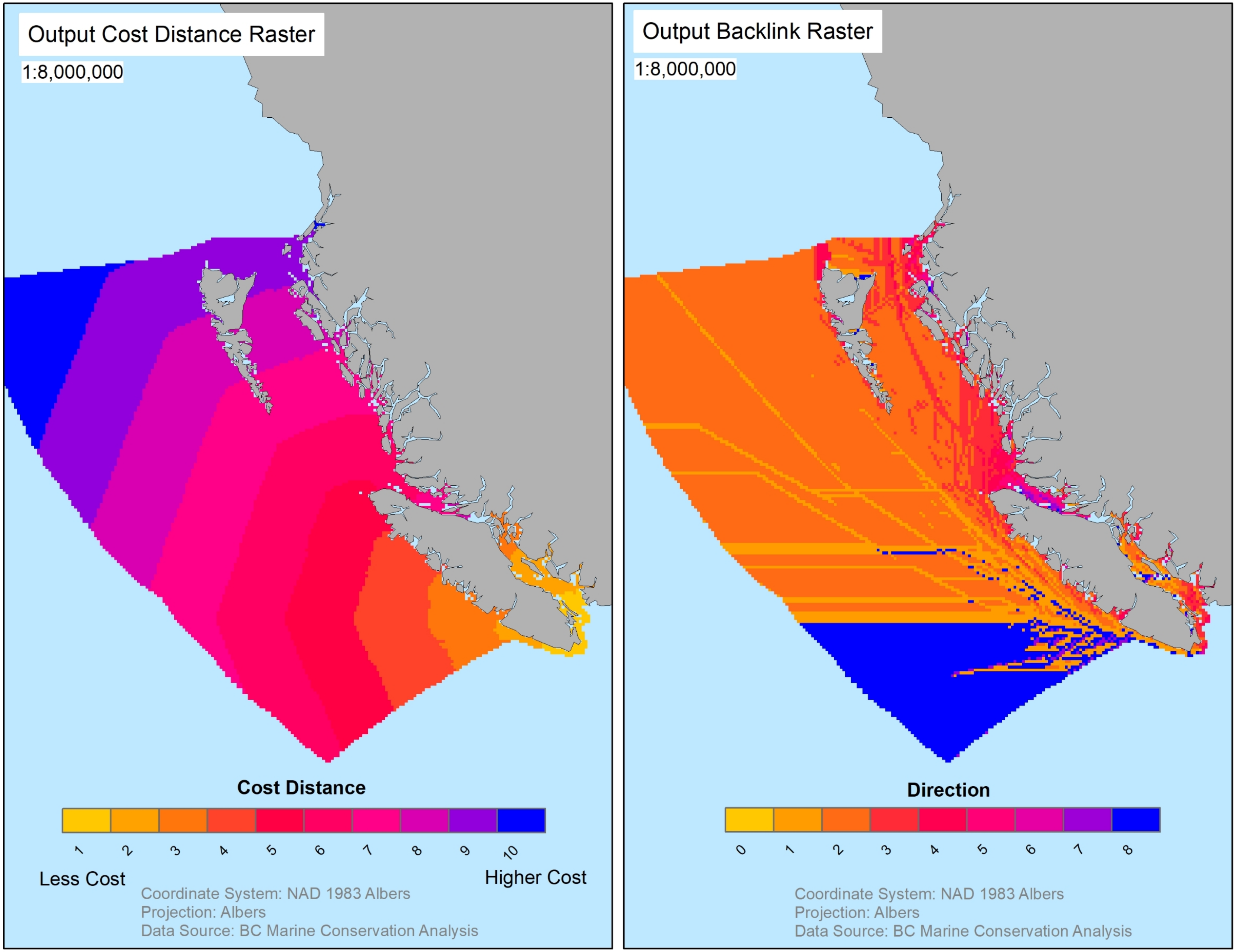

Figure 4: Cost Distance and Back-Link Rasters

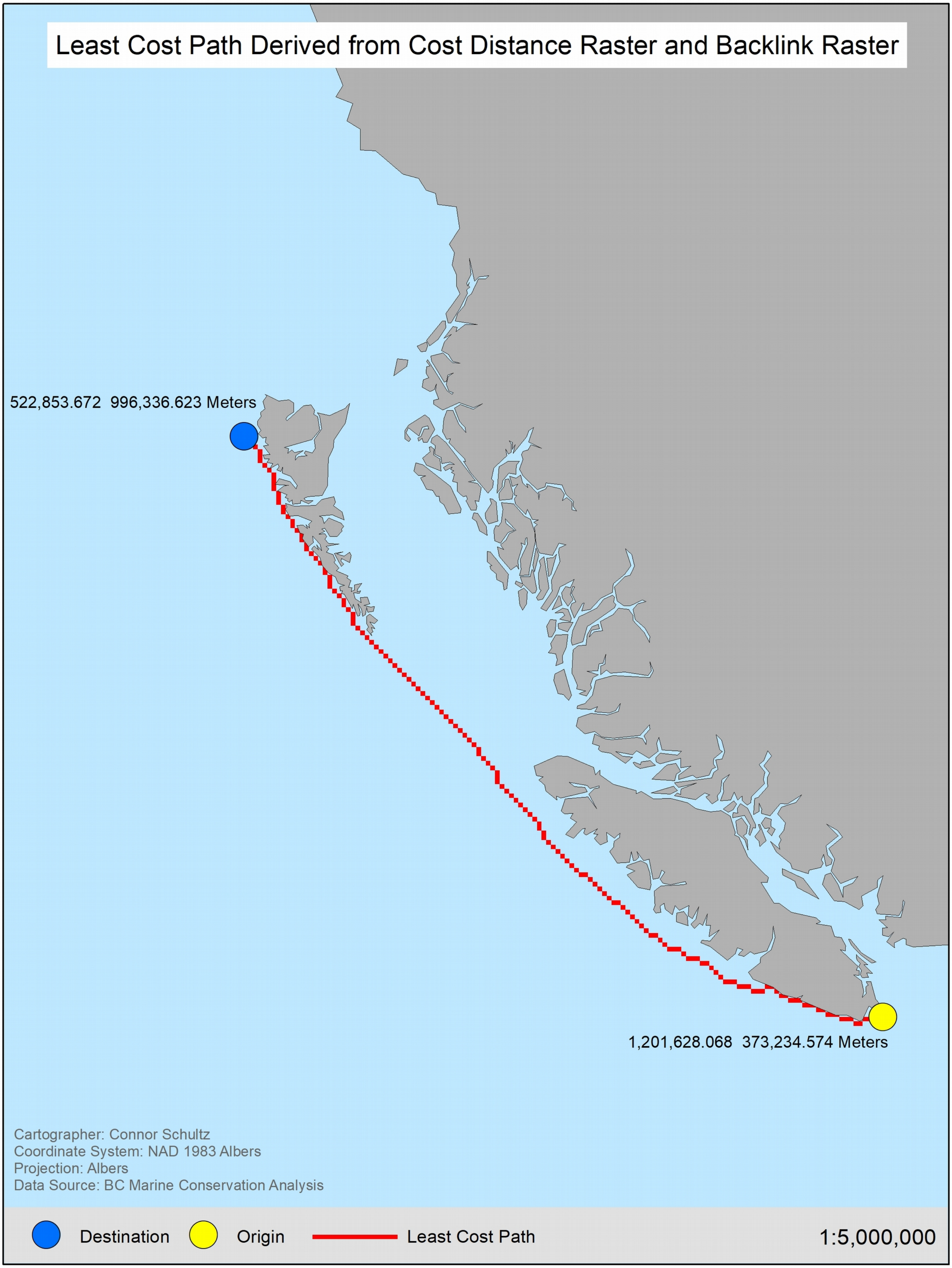

Figure 5: Least Cost Path from Distance to Origin

re_passcruise

Rowid	VALUE	COUNT
0	1	17145
1	2	584
2	3	166
3	4	136
4	5	126
5	6	49
6	7	40
7	8	14
8	9	15
9	10	6

re_merchant

Rowid	VALUE	COUNT
0	1	16637
1	2	899
2	3	356
3	4	195
4	5	99
5	6	43
6	7	27
7	8	15
8	9	6
9	10	4

re_tankers

Rowid	VALUE	COUNT
0	1	17099
1	2	701
2	3	213
3	4	123
4	5	49
5	6	33
6	7	19
7	8	15
8	9	18
9	10	11

re_fishing

Rowid	VALUE	COUNT
0	1	17548
1	2	410
2	3	230
3	4	34
4	5	16
5	6	24
6	7	8
7	8	3
8	9	4
9	10	4

Figure 6: Attribute Tables from Reclassified Rasters in Figure 3

path

Rowid	VALUE	COUNT	PATHCOST	STARTROW	STARTCOL
0	1	1	0	0	0
1	3	157	1395603	37	73

Figure 7: Attribute Table from Least Cost Path in Figure 5