Maritime Least Cost Path Analysis of Paleoamerican Migration on the Northwest Coast of North America

by

Robert Holger Gustas

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Department of Anthropology
University of Alberta

Abstract

In this thesis, I use the Geographic Information System (GIS) technique of least cost path analysis to recreate the maritime movement events of Paleoamerican peoples traveling through five different North American Northwest Coast landscapes during the late Pleistocene and early Holocene. I make use of multiple modeling simulations, movement cost-weighting scenarios, and spatial data resolutions to predict the paths that early mariners may have used to travel through the physical world that existed between 10,000 and 16,000 cal. yr BP. This spatial analysis helps to identify areas that may have been inhabited by the first peoples to arrive in the New World by ranking locations within landscapes by ease of access as determined from physiological, environmental, and cultural variables. Using these values, the paths of least resistance between movement event origin and destination points are plotted and the patterns of predicted movement event routes are analyzed within the context of biogeographically oriented transient explorers undertaking long range leap-frog boat based journeys. By looking at least cost path clustering patterns, directional mean, coastline proximity, and amount of overland travel significant new insights are made into the application of least cost path analysis to prehistoric maritime migrations and the Paleoamerican history of the Northwest Coast. Lastly, I use this knowledge to suggest locations that have a high probability of containing Paleoamerican sites based on the results of my maritime least cost path modeling.

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Chapter 1: Least Coast Analysis of Northwest Coast Paleoamerican Migrations

1.0 Introduction

Some of the oldest and most important questions in North American archaeology are those that ask how and when the first humans arrived in the New World (Dixon 1999, Erlandson *et al.* 2007, Fladmark 1979). Many different answers to these questions, falling on a broad spectrum of possibilities, have been suggested over the last 100 years. Some scholars have insisted that the first humans arrived in the Americas at least 35,000 years ago, while those taking the opposite position argue that the human presence on this continent cannot possibly predate 13,000 years before present (Dixon 1999:3; Meltzer 2009:82). During the last 50 years, many archaeologists have adopted positions falling between these two extremes and a vigorous debate has emerged, centering on the method and location of migration events that allowed for humans to move through the Pleistocene New World landscape (Erlandson *et al.* 2007; Graf *et al.* 2014; Meltzer 2010). Researchers taking the traditional view advocate that the first people arrived via land based travel down the Ice Free Corridor through the continental interior, while others believe that first migrations took place via maritime routes down the northwest coast of Cascadia, and yet still others have suggested migrations from Europe over the Atlantic Ice Sheet (Adovasio and Pedler 2013:512; Arnold 2002:437; Beck and Jones 2013:273; Bradly and Stanford 2004; Mandryk *et al.* 2001; Erlandson *et al.* 2007; Fladmark 1979). These discussions are at the center of modern archaeological conversations about initial Paleoamerican peopling events and the answers to questions that they pose will have far reaching impacts for the history of the Americas.

1.1 Research Rationale

My thesis contributes to the discussion about the initial peopling of the New World by modeling the migration routes that Paleoamerican peoples might have used in coastal environments. The identification of these movement corridors has the potential to help researchers develop a greater understanding of the pre-contact history of North America through the discovery of very old archaeological sites on the Pacific Northwest Coast. The method and chronology of the Peopling of the New World is not clearly understood, largely due to the inability of existing site prospection modeling techniques to locate Paleoamerican sites (Mackie *et al.* 2011:94; Fedje *et al.* 2011:461). The landscape of the Northwest Coast has been greatly modified by geologic and environmental processes over the last 20,000 years, meaning that traditional predictive techniques often are unsuitable or yield poor results (Mackie *et al.* 2013:145). This thesis uses a new method of analysis based on least cost analysis techniques to look at Pleistocene human maritime movement patterns to identify contemporary terrestrial and submerged areas which have a high potential for having been passed through by human groups in the deep past. The accurate prediction of these areas should allow for the discovery of sites and the recovery of material culture with the potential to fill in the gaps in our knowledge of Paleoamerican peoples (Erlandson 2013:131; Mackie 2013:144; McLaren 2008:174; Monteleone 2013:18). The excavation and analysis of such sites could shed light on many topics, including the role of coastal migration in peopling events.

1.2 Research Questions

My research addresses several important questions about possible Paleoamerican maritime migrations in the New World by using a new analysis method to figure out where these early travelers may have physically traveled and stopped. The overarching question being addressed here is can least cost path analysis be used to determine the migration routes that might have been used to travel through Northwest Coast during the Late Pleistocene and Early Holocene? This is a complicated question that looks at the application of a particular methodology within specific temporal and geographical boundaries. I ask both if least cost analysis can be applied to human *maritime* movement and if it can be applied to a specific spatiotemporal context. In this thesis, I present a new approach to the analysis of human travel, the outcome of which pertains to the study of many past movement events over water. I also present a new glimpse into the Paleoamerican history of British Columbia and Southeast Alaska by contributing to the identification of high potential locations for the discovery of information relating to the activities of the first colonizers of North and South America.

In order to apply least cost analysis to Paleoamerican migrations, I use a theoretical framework that looks at these events from the perspective of migration and landscape archaeology. I argue that early mariners used biogeographically based limitational knowledge to conduct long distance multistage movement events. These migrations would have been undertaken by small transient explorer groups through ideational and conceptual landscapes in which both the terrestrial and marine areas are of equal importance. Early coastal journeys conform to the classic leapfrog pattern with groups passing from refugia to refugia over long physical and chronological distances. The result of these migrations was the initial peopling of the New World and it is essential in this process to consider both social and environmental knowledge placed in an appropriate balance. By determining how Paleoamerican peoples would have understood and interacted with their world, we can look at a spectrum of different times, places, and spaces in which they would have traveled and model these different scenarios.

In order to address my primary research question I developed a series of smaller targeted questions to guide my efforts. The first is how do different movement cost-weighting scenarios designed to emphasize different environmental, cultural, and physiological aspects of movement logic affect the least cost routes that are predicted through a landscape? An essential element of trying to recreate any human event from the deep past is to capture how ancient peoples would have perceived and thought about the world in which they lived (Tilley 1994:77). Different modes of thinking and worldviews are going to cause different groups of people to take varying routes through a given landscape. Variation in path routes can also be caused by aspects of the environment that would be extremely difficult or impossible to travel over. These features act as absolute barriers and include things like human endurance, extremely high slopes, dangerous ocean hydrological features, and the absence of freshwater. These constraints are contrasted against aspects of a culture that might cause groups to travel through difficult terrains such as the desire to pass sacred sites or to avoid certain taboo locations. Looking at different possible logics for movement and migration allows for a balanced and more nuanced approach as many past geospatial analyses in archaeology have been driven solely by environmental variables. The environmentally deterministic approach creates problems because it does not account for the social agency in human cultures (Hu 2011:5).

The Northwest Coast is a dynamic and restless landscape that is controlled by complex environmental and geological processes (Shugar *et al.* 2014:1). Sea levels changes have dramatically and quickly inundated dry landscapes and exposed drowned areas. It is not sufficient to simply look at one chronological slice of the deep past. Geospatial analysis on the Northwest Coast should be run at a variety of time intervals in order to understand how changes in the physical environment would influence the movement of people. How do the movement corridors predicted by least cost analysis change through time? Each individual analysis in this project represents a single static point on a spectrum of possible conditions that existed in the deep past and the entire spectrum must be considered to form a complete picture.

The accuracy of the data being used in a geospatial analysis is an important element that cannot be ignored. With this consideration in mind I explore the issue of what data resolution provides the appropriate combination of model accuracy and computational accessibility. Each time the cell size of a raster data set is halved; this creates four times as much data covering the same area (Wheatley and Gillings 2012:47). Smaller cell sizes allow for more accurate analysis, but they also mean that calculations will take significantly longer to run. For example, there is a difference of a factor of 24 between running an analysis at the 30 m and 5 m levels. This difference in computational requirements can have a large impact on the usefulness of a methodology, especially if it is implemented by researchers lacking access to cutting edge computing resources. In working with study areas that cover tens of thousands of square kilometers and datasets with hundreds of millions of points, I found it can take a very long time for desktop computers to generate results. In order to maximize efficiency I explore how running least cost analysis on different resolution input datasets affects the predicted paths. How do different input data resolutions affect analysis results and what is the appropriate balance of computational power and spatial accuracy?

The last question that must be considered is what exactly constitutes maritime travel? Is it solely movement over water or is it the act of crossing a hybrid of marine and terrestrial environments? How do we account for and to what extent include in this analysis the fact that portions of Paleoamerican migrations may have been overland portaging boats and supplies (Moss 2008:38)? How do least cost paths change when the possibility of overland travel is removed from a simulation and how do these results compare to scenarios that allow terrestrial movement?

My thesis has several distinct facets dealing with chronology, scale, and accuracy. These various topics are bound together by the overarching question of whether least cost analysis can be applied to maritime human movement. Specifically, can this new methodology be used to recreate the location of movement events that took place down the Northwest Coast of North America during the Late Pleistocene and Early Holocene?

1.3 Thesis Organization

My thesis is divided into seven chapters, each covering a different aspect of this project. Chapter 2 is a brief examination of the project's study areas. Here the physical boundaries of the study are delineated in detail and how each area was selected is explained. In this chapter I define the temporal units and historical timeline of the study area, setting the chronological intervals at which each analysis was run. I also present a brief overview of the cultural groups that live within the study areas and consider different forms of knowledge for learning about them. Chapter 2 also discusses the current state of knowledge of Paleoamerican culture focusing on the information that can be used in a geospatial analysis. Lastly the paleoclimate, geology, and sea level history of the Northwest coast are reviewed in detail. This chapter serves to establish the background of the physical and cultural landscapes through time in which this study takes place.

Chapter 3 is a literature review of the current state of scholarship in Northwest Coast geospatial archaeology. This chapter opens with a discussion of the traditional views of initial New World peopling events and then segues into a review of the theories suggested in lieu of the Ice Free Corridor and Clovis First Hypotheses. I suggest that that a Beringian origin and the Kelp

Highway Hypothesis provides the best alternatives for first peopling events and discuss evidence from paleoecology, archaeology, oral history, and genetics that supports this opinion. I use this opportunity to establish the antiquity of human activity in the Northwest Coast at a variety of archaeological sites. Lastly, I look at a several research projects over the last 15 years that have applied the techniques of geospatial analysis to answering question about habitation, site prospection, and migration in pre-contact Cascadia. This chapter synthesizes past scholarship in Paleoamerican, geospatial, and Northwest Coast archaeology to establish a platform on which to place my work.

Chapter 4 establishes the theoretical foundation for my project and begins with a discussion of the major paradigms in landscape archaeology. The concepts of landscape and seascape are reviewed and a new hybrid definition theorized in the context of processual-plus archaeology. The discussion then moves to migration theory and I use this opportunity to offer a formal definition of migration and review its use through time in archaeology. From this foundation I lay out a further theoretical framework in which to view initial peopling events on the Northwest Coast. My approach combines biogeographical landscape learning based on limitational knowledge with a leapfrog transient explorer structure. Push and pull factors and other motivations for migration events as well as scale, distance, and most importantly mode of travel are also discussed. Chapter 4 establishes landscape as both a terrestrial and marine construct representing two ends of the same continuum. This chapter also establishes the pre-contact Northwest Coast environment as quantifiable and systematic, yet simultaneously temporal and dynamic. An emphasis is placed on how this landscape would be experienced by a people with little to no prior knowledge of the areas they were entering.

Chapter 5 outlines the methodology used to answer to my research questions and begins by defining what an archaeological Geographic Information System (GIS) is by briefly reviewing the history of this technology as well as its application to archaeology. The justification behind the selection of the different software used in this analysis is discussed and I review the concept of site prospection modeling while discussing some of the more notable cases of this methodology's use in archaeology. I next review the Principle of Least Cost and how this idea is computationally applied to creating least cost paths. The methodology that I created for this project is broken down step-by-step and each analysis process explained. This includes a review of the types of data that can be used in geospatial analysis and the different sources of data that I used to derive least cost paths. Included in this discussion are the data's resolution, scale, coordinate system, and general preparation process. Lastly, the calculation of friction surfaces including the variables used to calculate different weighting criteria and least cost path analysis process are outlined.

Chapter 6 discusses the results of the least cost analysis. This process involves visual comparison of different paths to identify trends and anomalies in the data focusing on the amount of path overland movement, coastline proximity, directional mean, and clustering pattern. The differences between different study areas, time periods, and in the case of the Prince Rupert Harbour, resolution, are discussed in relationship to scenarios that both allow and eliminate overland travel. The results of each simulation run for each study area at each time period are reported and compared with areas of maximum probability of containing new sites identified. Lastly, suggestions are offered for what locations in my study areas might contain new sites from the late Pleistocene and early Holocene.

The final chapter in this thesis relates the findings from Chapter 6 back to the research questions that were posed earlier in this chapter. These findings are discussed within the theoretical framework of this project and their significance for how we think about migration and landscapes explored. A substantial amount of time is spent discussing how this technique could change Northwest Coast site prospection and how my research impacts the use of least cost analysis in archaeology. The limitations of my work are identified and suggestions offered for how the analysis process improved in the future. Lastly, future research directions are suggested for other applications of this work.

Supplemental material to the main body of this thesis is contained in several appendixes. Appendix A contains the results of path mean direction analysis. Appendix B contains maps showing the comparison of different input data resolutions for Prince Rupert Harbour. The sets of paths created from each weighting scenario for each study area and time period from the model allowing overland movement are contained in Appendix C. Appendix D contains the work flow diagrams for the different sub-models I used generated from ArcCatalogue's ModelBuilder export function and their corresponding Python code. Appendix E contains the results generated from the modeling scenario that disallowed overland travel. Appendix F shows the directional mean results from the same analysis. Appendix G contains maps showing areas identified from my modeling scenarios that allow overland travel with high probabilities of Paleoamerican sites and Appendix H contains maps showing the same information for scenarios that prohibit overland travel. Lastly, Appendix I lists the technical specifications of the different computers used. The seven chapters and nine appendixes of this thesis layout the background, theory methodology, results and findings of this thesis, they provide a record of the research conducted for this project and demonstrate that least cost paths through marine environments can be calculated for early human migrations.

Chapter 2: Study Area

2.0 Physical Boundaries

The areas in which I modeled the movement of Paleoamericans are located on the Pacific Coast of North America. This region is subdivided into both geographically and culturally defined units. From an anthropological perspective, my study falls inside the Pacific Northwest Coast cultural area, which is defined by anthropologists based on the similarity of the Hunter-Gatherer-Fisher peoples that reside within it (Suttles 1990:1-4). This area physically comprises the coastal areas of North America stretching from the Gulf of Alaska down to Cape Mendocino in California (Suttles 1990:1-4). This area is over 2,000 km long as the crow flies and, due to the extremely craggy nature of the coast, the actual length is significantly longer (Ames and Maschner 1999:17). As such this area has been subdivided by researchers into several smaller units. Using these boundaries, my project falls into the Outer Islands-North Coast and Northern British Columbia zones (Shugar *et al.* 2014:5-6) (Figure 2.0). These two areas are comprised of the Alexander Archipelago, Haida Gwaii, the Queen Charlotte Basin, Cook Bank, and the British Columbian coast running from northern Vancouver Island to the border with Alaska (Shugar *et al.* 2014:2). This area encompasses 400,000 km^2 and further subdivision was necessary to create areas that are feasible in terms of scale for least cost path analysis.

Figure 2.0 Sub-Regions of the Northwest Coast (Shugar *et al.* 2014:2)

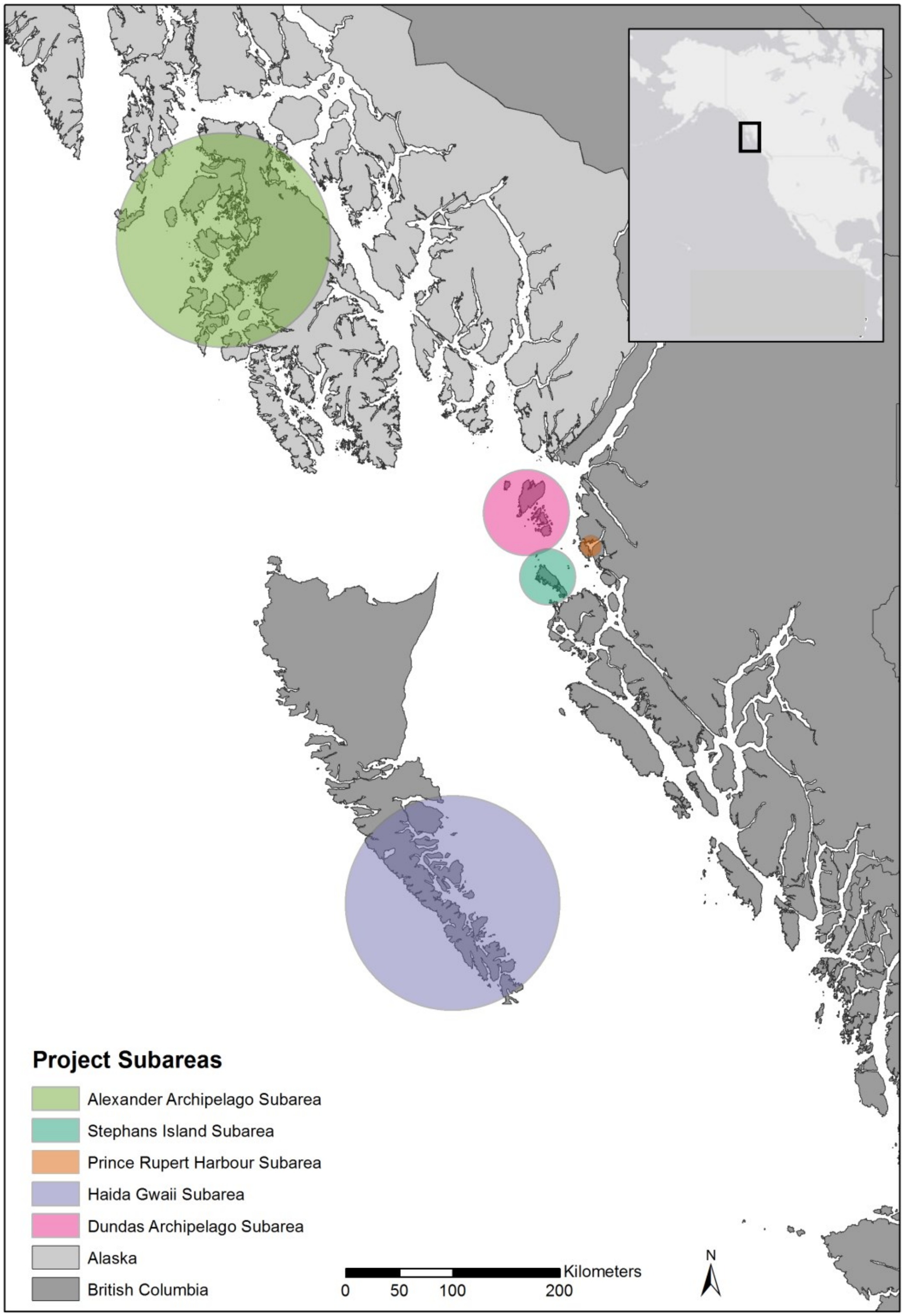
I selected five subareas within the Outer Islands-North Coast/Northern British Columbia area for analysis (Figure 2.1). These subareas are Prince Rupert Harbour, the Dundas Archipelago, Stephens Island, Haida Gwaii, and the Alexander Archipelago (Table 1.0). Prince

Rupert Harbour is one of the world's deepest natural harbours and is located on the coast of British Columbia near the Alaskan border at the city of Prince Rupert. This is the smallest subarea encompassing 315 km^2. The Dundas Archipelago is a collection of islands encompassing 5,000 km^2 located in the Hecate Strait approximately 70 km northwest of the city of Prince Rupert. Stephens Island is also located in the Hecate Strait approximately 50 km southwest of Prince Rupert and encompasses 2,100 km^2. The last two subareas I looked at are composed of major island chains and are much larger that the previously discussed areas. Haida Gwaii is a collection of more than 150 islands approximately 80 km from mainland British Columbia that encompasses 31,415 km^2 and forms the western boundary of the Hecate Strait. Lastly, the Alexander Archipelago is located at the very southern tip of the Alaskan Pan Handle and is the same size as the Haida Gwaii subarea, also covering 31,415 km^2. This group of several hundred islands is located approximately 400 km north of Prince Rupert. These different geographic locations represent a spectrum of locations, allowing movement corridors to be modeled at scales ranging from tens to thousands of kilometres.

Table 1.0 Subarea Locations

Subarea	**Centroid Longitude**	**Centroid Latitude**	**Area**
Prince Rupert Harbour	-14512586.7154 m	7193954.01719 m	315 km^2
Stephens Island	-14552828.5252 m	7165286.97289 m	2,100 km^2
Dundas Archipelago	-14572755.5955 m	7225247.64792 m	5,000 km^2
Haida Gwaii	-14641645.4461 m	6860651.59445 m	31,415 km^2
Alexander Archipelago	-14855650.4404 m	7479657.14343 m	31,415 km^2

Figure 2.1 Analysis Subareas



Subarea locations were picked based on a number of criteria, including the probability of Paleoamerican activity, the quality of the area's sea level curve, and methodological computational limitations. Locations were selected in which sites have been identified to the Early Holocene and earlier, suggesting the potential to yield evidence for earlier occupations (Ames and Martindale 2014:146; Cookson 2013:9; Fedje *et al.* 2011:458; Mackie *et al.* 2011:65; McLaren 2008:iv; Monteleone 2013:171; Sanders 2009:17). Unlike many parts of the world, there has been substantial research into the sea-level and shore-line history of British Columbia, allowing for accurate recreations of what past sea and landscapes would have looked like (McLaren 2008:111; Shugar *et al.* 2014). Exact study area boundaries were set so as to encompass coastal areas in close proximity to known sites as recorded in the Canadian Archaeological Radiocarbon Database (Canadian Archaeological Radiocarbon Database 2015)[1]. Trying to calculate movement paths for the entire Outer Islands-North Coast/Northern British Columbia area is computationally beyond the capacity of most desktop computers. Datasets for some of the subareas contained hundreds of millions of individual data points which took up gigabytes of storage space. For all of these reasons, it was necessary to conduct this analysis on the smaller subarea scale. Exact path positions could be derived for the entire Coast with powerful computers and high resolution data, but the overarching patterns and trends associated with movement events observed in my study areas should be transferable to other parts of the Northwest Coast which have similar sea level histories and geographical configurations[2].

[1] The Canadian Archaeological Radiocarbon Database includes sites from all over North American and is not constricted to purely to Canadian locations.
[2] Further discussion of the trends found in my results can be found in Chapter 6 and discussion on the applicability of Maritime Least Cost Path Analysis to larger study areas can be found in Chapter 7.

2.1 Chronological Boundaries

My thesis is primarily concerned with looking at human activity in North America during the parts of the Pleistocene and Holocene. The Pleistocene was a geological epoch which stretched from 2,588,000 calendar years BP to 11,700 cal. yr BP and was followed by the current epoch the Holocene (Fulton 1989:1; Moss 2011:50). My research looks at the time span stretching from 16,000 to 10,000 cal. yr BP, which includes the end of the Pleistocene and the beginning of the Holocene, which are periods respectively referred to as the late Pleistocene and early Holocene by anthropologists and geologists (Moss 2011:50). Coastal peopling events most likely happened later in this time period, but in order to account for some paleoecological and archaeological evidence that suggests possible earlier dates for migrations, I am using 16,000 cal. yr BP as the beginning date for my period of study (Lacourse and Mathewes 2005:52; Moss 2011:51). Additionally, because of the scarcity of sites predating 10,000 cal. yr BP, I have decided to use this date as the lower chronological boundary for my study (Moss 2011:50). The phrase late Pleistocene/early Holocene (LPEH) will in this context cover the years from 16,000 to 10,000 cal. yr BP, or approximately 14,000 to 9,000 ^{14}C yr BP.

In archaeological terms, the LPEH is alternately referred to as the Paleo-Indian or Paleoamerican period. The phrase Paleo-Indian was originally coined in 1940 by Frank H. Roberts, who applied the term to sites containing the remains of extinct ice age animals found in association with artifacts from cultures adapted to cooler conditions than those that exist today. The term was in widespread use by the late 1950's (Dixon 1999:9; Roberts 1940). Today it is frequently used to describe the founding population from which all indigenous North and South American peoples are descended (Meltzer 2010:5). However, this term has developed a negative connotation with some First Nation peoples and I will use the term Paleoamerican to describe the first inhabitants of New World. In this thesis I use this term in same context as it is used in *Paleoamerican Odyssey* (2013) edited by Graff, Ketron, and Waters.

For analysis purposes I am dividing the LPEH into 3,000 year intervals and calculating the least cost paths through each of the five subareas for each of these chronological periods. This will allow me to explore how the dynamic and changing nature of the landscape of the Northwest Coast affects movement routes. The result of chronologically sectioning my research this way is that three distinct temporal periods of analysis were created for each of the five subareas. In my analysis, the only variable that changes through time is sea level height and I used the sea level curves and associated dates calculated by Shugar *et al.* (2014:2). These researchers used the Calib 7.0 program to apply the INTCAL13 and MARINE13 calibrations with a lab error multiplier of 1.0 to their sample of radiocarbon dates. For marine dates, a regional reservoir correction was applied with a weighted mean ΔR value determined by up to 10 nearest known age samples within 500 km. I report the temporal windows and their associated dates in radiocarbon years before present with this calibration. In order to maintain accuracy, all other dates referenced in this thesis are reported in the format that was used in their original publication. Rough approximations can be made between calendric, calibrated, and radiocarbon dates using Table 2.0, calculated by Fedje and Mathewes (2005:xxi). The difference between these types of dates and their variability over time is result of the differential production of ^{14}C and its uptake in the biosphere via photosynthesis.[3]

[3] Meltzer (2010:6) offers an excellent explanation of how different types of chronological dates are derived.

Table 2. Radiocarbon Calibration (Fedje and Mathewes 2005:xxi)

Radiocarbon years	*Calibrated age*	*Calendar date*
1000 BP	930 cal yrs ago	1020 AD
2000 BP	1,940 cal yrs ago	10 AD
3000 BP	3,180 cal yrs ago	1230 BC
4000 BP	4,490 cal yrs ago	2540 BC
5000 BP	5,730 cal yrs ago	3780 BC
6000 BP	6,820 cal yrs ago	4870 BC
7000 BP	7,810 cal yrs ago	5860 BC
8000 BP	8,870 cal yrs ago	6920 BC
9000 BP	10,190 cal yrs ago	8240 BC
10,000 BP	11,400 cal yrs ago	9450 BC
11,000 BP	13,000 cal yrs ago	11,050 BC
12,000 BP	14,060 cal yrs ago	12,110 BC
13,000 BP	15,630 cal yrs ago	13,680 BC
14,000 BP	16,790 cal yrs ago	14,840 BC
15,000 BP	17,940 cal yrs ago	15,990 BC
16,000 BP	19,090 cal yrs ago	17,140 BC
17,000 BP	20,240 cal yrs ago	18,290 BC
18,000 BP	21,390 cal yrs ago	19,440 BC
19,000 BP	22,540 cal yrs ago	20,590 BC
20,000 BP	23,690 cal yrs ago	21,750 BC

2.2 Cultural Background

Three different types of knowledge, archaeology, oral histories, and ethnography, will be used in my discussion of the aboriginal peoples who live inside my study areas. It is important to include ethnography and oral histories in this conversation because they provide insight about past lifeways that are not available from traditional archaeological sources (Ames and Martindale 2014:153). We can view each of these different sources of information as distinct ways of thinking about the world. To slightly modify the analogy developed by Ames and Martindale (2014:155) each of these perspectives is one strand in the cables of a rope bridge that gaps the divergence between ethnography, oral histories, and archaeology. Individually these strands are not strong enough to bear the weight of a complete cultural history but when twined together they become stronger. When the strings are made to work together they paint a more complete picture of life in the past. It is important that these strands of knowledge remain distinct and that they should be tested against each other instead of synthesised to fill gaps in other forms of knowledge (Ames and Martindale 2014:158). The use of these multiple strands to maintain the integrity of the bridge is crucial for any project looking at distant time periods because these different viewpoints allow for different insights and observations.

Cascadia is home to an amazing diversity of peoples, three of which fall within the geographic boundaries of my study area. Prince Rupert Harbour, the Dundas Archipelago, and Stephens Island are all inhabited by Coast Tsimshian peoples. Haida Gwaii is home to the Haida and the Tlingit live in the Alexander Archipelago (Blackman 1990:240; De Laguna 1990:203; Halpin and Seguin 1990:267). While all these groups share considerable regional affinity these three peoples are culturally distinct and have their own unique oral histories about when and how they came to live in their homelands.

2.2.1 Different Approaches to Understanding the Past

While many lifeways recorded post-contact cannot be projected back into the deep past, the aboriginal groups of the Northwest Coast believe that they have resided on the coast since time immemorial and since they are the direct decedents of coastal Paleoamericans, a review of their culture is warranted (Grier 2007:286; McMillan and Hutchinson 2002:41). One of the fundamental aims of this thesis is to examine the many questions surrounding Paleoamerican culture. In order to fully explore this group of people, I had to work with information from the three previously mentioned types of sources, even though they do not always provide perfect analogs for conditions in the past. Much of my information came from archaeological research; however, ethnography and oral histories played a crucial role in providing information about travel distances, modes of travel, site selection, direction of travel, and other factors used determine movement costs.

Archaeology is the study of the human past through its material remains (Renfrew and Bahn 2010:322). It is a powerful method of learning about past peoples because it allows for direct statements about them based on the physical archaeological record. One of the more significant weaknesses of Northwest Coast archaeology is that some perishable organic materials often do not preserve well and items made from these substances are underrepresented in the material record. Scholarship of items that do preserve allows for statements about subsistence, sedentism, intensification, complexity, and, most importantly in this context, habitation. These observations create a substantial record of human activity in the past on the Northwest Coast (Ames and Maschner 1999; Butler and Campbell 2004; Burchell *et al.* 2013; Cannon and Yang 2006; Moss 2011). We know from Ozette and other sites that cordage, basketry, bentwood boxes, and other items made from organic material were incredibly important and far outnumber items made from materials more impervious to the passage of time (Ames and Maschner 1999:111). The existing record does not give us crucial information about Paleoamerican maritime travel due to the suspected organic nature of their boating technologies (Ames 2002:26-27; Mackie 2011:91). The excavations at Kilgii Gwaii provide a tantalizing but limited view of early material history made from organic material. Excavation Unit 8 at this site produced over 100 artifacts made from wood including wrapped sticks, possible wood projectile points, and a two-part hafts, among other objects that date from between 9,450 and 9,400 ^{14}C yr BP (Fedje *et al.* 2005:199). Oral histories and ethnography become of crucial importance in looking at this aspect of Paleoamerican society because they test archaeological findings to form a better picture of early maritime practices (Wylie 1989:2).

Ethnography is "the study of contemporary cultures through first-hand observation" and is a powerful tool for looking at pre-contact time periods because it provides different types of information than archaeology (Ames and Martindale 2014:152; Renfrew and Bahn 2010:323). The ethnographic work that was conducted from the contact period to the early 20th century is of particular value. Boas (1969), Drucker (1963), Suttles (1990) and other scholars collected an impressive amount of knowledge from their informants about Northwest Coast cultures. I applied three basic rules to the use of ethnography in my research (Grier 2007:291). First, ethnography should be used as an analogy for past lifeways based on relational connections between subject and source. Second, the ethnographic record should be used to form hypotheses about material culture. Third, information from ethnographic sources should not be allowed to block my ability to form novel and new ideas based on the interoperation of the material culture they are analysing.

Oral traditions are intelligible, open-ended systems for assembling and sharing knowledge (Cruikshank 1994:408). They are a useful tool for understanding the past, but as Julie Cruikshank points out, they "are cultural forms that organize perceptions about the world" and are not simply a method for conveying factual information (Cruikshank 1992:40). Susan Marsden (2002:101) adds to this by stating that "The cultural institutions that underlie Northwest Coast oral history … assume cross-generational and cross-cultural communication and include a sophisticated system of encoded knowledge to facilitate it".

The work of McMillan and Hutchinson (2002) is an excellent example of how archaeological data can be used to situate and interpret oral-history. These researchers were able to use archaeological data to chronologically place traditional narratives about earthquakes on the Northwest Coast. Additionally, they recorded Heiltsuk origin stories which describe that "In the beginning there was nothing but water and ice and a narrow strip of shore-line" (McMillian and Hutchinson 2002:60). This description is consistent with a late Pleistocene arrival in a coastal environment. Other stories such as descriptions of early Holocene floods by the Fraser River Salish, which correspond to known sea level rises and Gitksan accounts of early glaciated landscapes demonstrate that oral traditions can accurately capture facts about the deep past (McMillian and Hutchinson 2002:62). When used appropriately, ethnohistory can strengthen the ropes holding up our metaphorical bridge by providing useful analogies for conditions in the LPEH. In particular, ethnohistory is relevant to my project because it informs me about maritime travel into the New World and describes the form of migration and climatic conditions. The logic of dating events from ethnohistory is difficult and just because these accounts recount conditions that seem to describe the late Pleistocene does not mean that they do and I acknowledge this in my work.

2.2.2 The Northwest Coast Deep Past

As very few sites have been discovered on the Northwest Coast which date to the LPEH, there are few definitive statements that can be made about Paleoamerican culture. However, from what little archaeological evidence we do have, there are a few characteristics of these groups of which we can be certain. We know that Paleoamericans had a bifacial lithic tool technology marked by leaf shaped projectile points. This class of tool has alternatively been called the Pebble or Cordilleran tool tradition (Carlson 1996:8; Matson and Coupland 1995:68). Excavations at the Richardson Island site have revealed that sometime after 8,750 ^{14}C yr BP a microblade tradition was added at this location, a development in lithic tool sequences that is also frequently seen in the technologies of the surrounding areas (Magne 2004:91; McLaren and Smith 2008:45). Extensive maritime technology must have existed as well at this time because faunal assemblages from this time period contain elements of species that can only be obtained through deep-sea fishing. Further evidence for marine adaption is provided by the location of some old sites that were on islands in the past meaning that the boating technology must have been available to establish these sites (Mackie *et al.* 2011:68). Additionally, excavations at the Kilgii Gwaii site have revealed that cordage, wedges, and wood stakes were being used at least 10,000 ^{14}C yr BP (Fedje *et al.* 2005:198). All of this evidence suggests that there are lithic and organic materials being used by Paleoamerican peoples consistent with marine adaptation.

Based on zooarchaeological research, we have some idea about the subsistence practices of Paleoamerican peoples. From the excavations of K1 and On-You-Knees caves, it is apparent that humans were hunting bears (Mackie *et al.* 2011:65; Dixon 2013:63). At both of these sites projectile points have been found in association with the remains of black bears (*Ursus americanus)*. Additionally, tools associated with deep water fishing have been found such as fishhooks, indicating that Paleoamericans could have been able to access resources such as halibut (*Hippoglossus stenolepis)* that can only be caught in the ocean (Fedje *et al.* 2005:203). It is a reasonable inference that the first inhabitants of the Northwest Coast would have had had lithic, cordage, and wood working traditions that would have allowed them to make use of a variety of different animal species.

2.2.3 The Haida, Tsimshian, and Tlingit

Significant ethnographic information that is useful to my work has been collected about the Haida, Tsimshian, and Tlingit peoples. These cultures are part of a group of over 30 different autonomous peoples speaking 45 languages that reside on the Northwest Coast (Suttles 1990:4). All of these peoples belong to the same overarching culture classification frequently referred to as complex Hunter-Gatherer-Fishers[4] and while these peoples are similar in many respects there are some important differences between these groups (Ames and Maschner 1999:18; Moss 2011:12-13; Suttles 1990:1-4). Much of our knowledge of these peoples comes from post-contact ethnography and it is important to review these records because they are the best proxies that we have for some aspects of Paleoamerican culture and can inform how we think about and model this group's activity (Grier 2007:297). Ethnography is never a perfect analog for past cultural conditions and the interpretation of this form of knowledge is always incomplete and open for discussion (Moss 2011:24-25). I use ethnographically recorded patterns of long term cultural continuity to gain insight about the deep past by looking at the gaps between the strands of my rope bridge.

The Tlingit live in Southeast Alaska and are divided into three different dialects: Gulf Coast, North, and South. These linguistic divisions to a degree also represent cultural subgroups (De Laguna 1990:203). The Southern Tlingit traditionally inhabited the Alexander Archipelago and are the primary group of interest to my research (De Laguna 1990:205). Many Southern Tlingit believe that they came to their current territory over 10,000 years ago through Northward migrations events from the Tsimsean Peninsula (De Laguna 1990:206). These beliefs establish the possibility of reverse migration and large scale movement events along a north to south axis.

Tlingit villages were semi-sedentary with groups moving to the location of different resources throughout the year according to the seasonal round (De Laguna 1990:204). In selecting sites for these villages, the Tlingit picked areas that were in sheltered bays and provided access to ocean resources (De Laguna 1990:206). In terms of my geospatial analysis, the Tlingit favoured locations that were sheltered from ocean currents on sinuous coastlines. During the

[4] As discussed in Moss (2011:27-46) the use of the Hunter-Gather-Fisher classification has become complicated by recent research and I use it here for lack of a better term that acknowledges Northwest Coast peoples fisheries management, plant cultivation, dog husbandry, and mariculture practices.

spring, the hunting of terrestrial mammals was the primary subsistence activity followed in the summer by salmon fishing and storage. In June and July the Tlingit would take advantage of calm sea conditions to engage in trade and hunt sea otters before moving back to a permanent camp in the fall and laying in for the winter (De Laguna 1990:209). These subsistence activities demonstrate the importance of maritime technologies to the Tlingit.

Several different types of boats are recoded as having been used by the Tlingit for a variety of purposes including trade, warfare, and subsistence. Most relevant to my research are accounts of the use of the Umiak and the heavy prowed ice canoe. These two types of watercraft demonstrate the use of skin boats and the ability of mariners to navigate a frozen environment around the time of the contact period and suggest that the use of such technology and knowledge could extend further back in time (De Laguna 1990:208). Ethnographic accounts of Tlingit culture provide important information for my analysis on boating technology, site selection, and movement events.

There are four subdivisions of Tsimshian peoples with the Coast Tsimshian inhabiting Prince Rupert Harbour, the Dundas Islands, and Stephens Island (Halpin and Seguin 1990:267). Traditionally for the Coast Tsimshian, February to April marked eulachon season (Halpin and Seguin 1990:269-270). In May women gathered seaweed while the men fished for halibut. June and July were dedicated to gathering sea gull eggs and shellfish while the salmon runs and the associated catching and preserving of the fish began in August and continued all the way to October. During the winter months large amounts of shellfish were harvested over time that resulted in the construction of the large shell middens that are the defining feature of many Tsimshian sites. These resources share the common connection of originating in aquatic environments marked by highly sinuous shorelines, emphasising the importance of marine technologies and protected site locations to the Tsimshian (Cookson 2013:100; Mackie and Sumpter 2005:350-351). The anthropogenic construction of middens takes a significant investment of labour and time, which, when viewed with additional archaeological evidence, demonstrates that the Tsimshian used Prince Rupert Harbour for at least 5,500 years providing a measure cultural continuity (Ames and Martindale 2014:145)[5]. While this history does not stretch all the way back to the start of the late Pleistocene, it does support the consideration of these factors in my analysis especially when they are combined with our archaeological knowledge of site selection and technology use from the deep past (Fedje *et al.* 2005:199; Mackie *et al.* 2011:69) [6].

The Haida people who inhabit the islands of Haida Gwaii are culturally similar to the Tlingit in many respects (Blackman 1990:240). One of the most striking of these similarities is in how the Haida picked their village locations. Village sites needed to offer protection from storms, to be in close proximity to halibut (*Hippoglossus stenolepis*) banks and shellfish beds, and to offer large beachfronts on which to beach canoes. In terms of variables that can be used in geospatial analysis, the Haida preferred areas near protected waters, with flat beaches, in close proximity to productive marine environments.

The Haida seasonal round is very similar to the one that was practised by the Tlingit except they placed more of an emphasis on the fishing of halibut and the hunting of sea mammals (Blackman 1990:246). Trade was crucial for these peoples and canoes, slaves, and shells were all exchanged to the Tlingit and Tsimshian for mainland resources. The Haida were skilled boat makers manufacturing at least seven styles of canoe, which were widely sought after (Blackman 1990:246). Despite the importance of trade the Haida are recorded as having engaged

[5] It is also possible for middens to form due to natural depositional processes not related to human activity.
[6] See Chapter 3 for further discussion of late Pleistocene site placement and material culture.

in extensive warfare against their neighbours (Blackman 1990:246). The location of many Haida sites on islands, especially those on Kilgii Gwaii, demonstrate the importance and antiquity of maritime technology to this culture. When combined with knowledge of how they picked their sites the ethnographic record helps legitimate the reconstruction or maritime travel routes and provides insight on variables to include in analysis.

By looking at these three cultures, I was able to gain valuable information about the actions of small mobile groups of people moving by boat through a coastal environment that in turn influenced my decisions about what variables to include in my modeling scenarios. Evidence of return migration events oriented along a north to south axis was also provided creating support for the form, scale, and type of migration I am hypothesising in the deep past. The use of ethnography reinforced the importance of incorporating flat beaches, proximity to other inhabitable areas, and environmentally productive sinuous coastlines in my analysis. It also demonstrated that maritime technology and lifeways have been a corner-stone of Northwest Coast cultures for thousands of years. The people who have inhabited my study areas are fundamentally connected to the ocean and the role of maritime transportation is an understudied aspect of their culture. No study of boat based travel can begin without a review of how climate and geology have affected ocean conditions through time on the Northwest Coast.

2.3 Paleoclimate

The contemporary climate of the Northwest Coast is heavily influenced by its position on the Pacific Ocean and is characterized by heavy rainfall with year round cool temperatures (Clague 1989:27). However, the climate has been variable through time and was very different during the LPEH than it is today. The most recent climatic cycle in North America to affect the Northwest Coast was the Wisconsin Glaciation, which began circa 80,000 ka. During this period the climate was generally cooler and punctuated by short warm periods called interglacials (Clague 1989:3). The Fraser Glaciation was the last glacial event of the Wisconsin Glaciation on the Northwest Coast and lasted from approximately 25,000 to 16,000 ^{14}C yr BP (Clague 1989:52). The last two thousand years of this period are called the Last Glacial Maximum (LGM) and the end of this event forms the upper chronological boundary of the LPEH (Clague 1989:57; Kennedy *et al.* 2010:1288).

Cool conditions during the Wisconsin Glaciation led to the formation of the Laurentide ice sheet that covered all of Canada east of the Rockies and the smaller Cordilleran ice sheet that was centered on the Canadian Coast Range and reached all the way to the Pacific Ocean (Barrie and Conway 2002:172-173). The extents of both of these sheets varied through time depending on global conditions, with maximal coverage occurring as late as 16,000 ^{14}C yr BP in outer coastal areas and as early as 18,000 ^{14}C yr BP at the southwest end of the Cordilleran sheet (Lian and Hickin 1993:841). Deglaciation began earlier on the coast and both ice sheets had fully retreated by 9,500 ^{14}C yr BP (Clague 1989:57). The overall trend was one of warming temperatures and receding ice during the LPEH (Sarnthein *et al.* 2006:141). Reconstructing climates is a central piece of evidence in arguments about different avenues of Paleoamerican migration and ecological conditions during this time period are thoroughly reviewed in Chapter 3. One the primary effects of the formation and thawing of glaciers is the rise and fall of sea levels, which is of crucial importance to understanding Northwest Coast prehistory.

2.4 Geology and Sea Level Change on the Northwest Coast

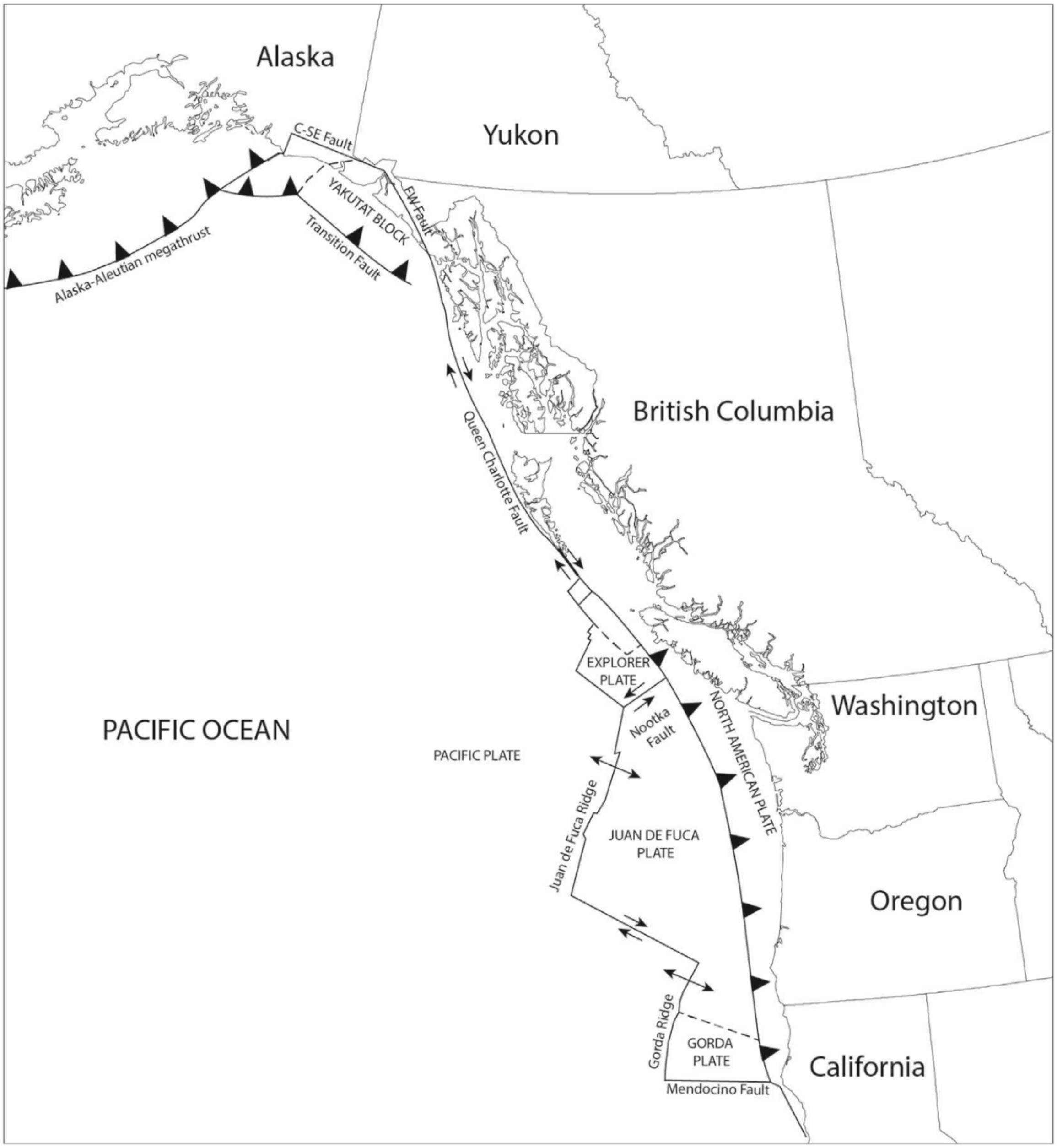
The Northwest Coast has a long record of geological instability caused by the meeting of several large tectonic plates. This, combined with fluctuations in global temperature has resulted in drastic sea level changes through time (Shugar *et al.* 2014). The history of these changes have been studied using soil coring to recover samples that can be analyzed for the presence of different diagnostic microflora such as pollen, phytoliths, seeds, and diatoms (McLaren 2008:89-110). The presence of different species indicates different environmental conditions; in this case the presence of saltwater and freshwater environments. The stratigraphic layers from the core containing these specimens are then radiometrically dated to form a timeline of climate change for a given location. By repeating this process in different areas of the Northwest Coast, scientists have been able to recreate the fluctuation of sea levels for many locations. However, the accuracy of these curves is not the same in all locations; for example, the Prince Rupert Harbour interpretations were made from a small number of samples, casting doubt on the accuracy of the curve (Shugar *et al.* 2014:Supplemental Data). Research is currently underway to refine the Prince Rupert Harbour curve.

2.4.1 Northwest Coast Geological Setting

The geological composition of the Northwest Coast is complex (Shugar *et al.* 2014:2-5). The North American landmass rests on the very large North American tectonic plate and the majority of the Pacific Ocean is on top of the Pacific Plate. In between these two plates are a series of smaller ones that interact with these two behemoths, making this area very seismically active (*Shugar et al.* 2014:4). The Gorda Plate is located off the coast of Northern California (Korma *et al.* 2011:809). Immediately north of this is the Juan Del Fuca Plate, which runs from the California Oregon border all the way to approximately half way up the coast of Vancouver Island (Korma *et al.* 2011:809). This series of geological features is capped by the Explorer Plate, which ends just off the southern tip of Haida Gwaii (Mazzotti *et al.* 2013:2). This arrangement effectively sandwiches these smaller plates between the larger North American and Pacific Plates. The boundaries of these features form a subduction zone and strike slip faults that give this area its extreme seismicity. Three of these fault features in particular are predominate in shaping the Northwest Coast landscape (Mazzotti *et al.* 2013:829; Shugar *et al.* 2014:4-6).

The Cascadia Subduction zone is the meeting place of the Pacific, North American, and Juan De Fuca plates which has resulted in the interaction of powerful subduction and strike slip faults in close proximity (Shugar *et al.* 2014:2-5) (Figure 2.2). The uplift caused by this tectonic activity is raising parts of the North American Plate between one and three mm per year (Mazzotti *et al.* 2003:16) (Figure 2.2). Just to the north of Vancouver Island the subduction zone ends and the Queen Charlotte Fairweather strike slip fault begins. This fault runs north all the way to the north end of the Alaskan Panhandle. Here the Pacific Plate is slowly moving south and the North American Plate is slowly moving north at a rate of 43-55 mm per year (Elliot *et al.* 2010:15). Lastly, there is a transitional strike slip underthrust fault located off the coast of eastern Alaska called the Yakutat Block. This chunk of the earth's crust is moving between 45 and 50 mm north-northwest per year (Elliot *et al.* 2010:16).

Figure 2.2 Tectonic Plates of the Pacific Northwest Coast (Shugar *et al.* 2014:5)



It is also worth mentioning that the extremely powerful Alaskan megathrust subduction zone runs under the Aleutian Islands and has the capacity to produce earthquakes and tsunamis that could affect the Northwest Coast (Shugar *et al.* 2014:5). The result of this tectonic activity is that Northern British Columbia is characterized by landforms caused by strike slip action

(Shugar *et al.* 2014:6). Namely these are steep slopes, high peaks, and deep fjords composed of granite and other igneous rocks, though metamorphic and sedimentary rocks are not completely absent. The Outer Islands North Coast area is composed entirely of islands with coastal plains formed from glacial outwash and reworked by aeolian and littoral processes (Clague 1989:36). This area is tectonically active and complex with features that have greatly modified this landscape over time and any research in this area must be cognizant of this change.

2.4.2 Mechanisms of Sea Level Change

The changes in relative sea level (RSL) on the Northwest Coast have been highly localized due to the glacial and tectonic history of individual areas. In general, sea level changes have been caused by oceanic and crustal factors working at a range of temporal and spatial scales (Nelson *et al.* 1996:8). For example, Washington and Oregon remained largely untouched by glacial ice but were affected by eustatic sea level rise and earthquake events that significantly changed their shorelines. In British Columbia, change in RSL has been observed as a result of isostatic forces that are temporally and spatially heterogeneous. Alaska presents some of the fastest rates of crustal up lift in the world due to its isostasy and neotectonics (Shugar *et al.* 2014:1).

Eustasy is defined as change of RSL as a result of changes in tectonic setting, sedimentation process, or the density and volume of sea water (Farrell and Clark 1976:648). These changes are not uniform over the entire area of an ocean basin and vary in accordance to sterics, neotectonics, sedimentation, and isostasy. Steric processes cause changes in sea levels due to the thermal expansion or contracting of seawater. Changes in the earth's temperature can cause ocean water to warm and expand raising sea levels or cool and contract lowering the RSL.

It is likely that steric processes had little to no effect on LPEH sea level changes on the Northwest Coast (Milne *et al.* 2009:472).

Neotectonics is the process of crustal deformation caused by coseismal subsidence and uplift (Nelson 2007:3076-3078). This is the process of one tectonic plate sinking below another at their junction. The result of this constant strain is that over the centuries, energy is accumulated at the boundary between plates and released during earthquakes. These events can cause instantaneous and dramatic changes to the landscape in from of scarps and embankments. Additional less dramatic surface deformation also occurs between quakes because of compaction that manifests on the landward side of faults on the Northwest Coast in the form of a forebulge raising landmasses. Conversely, the crust on the ocean side sinks as it is stretched out.

Perhaps the greatest factor to influence sea level change on the Northwest Coast is isostasy (Shugar *et al.* 2014:6). This is the change to RSL caused by the freezing and melting of glacial ice. When water is captured as ice in a glacier it reduces the amount of water available in the ocean. Additionally, the weight of the ice presses down on the crust on which it resides. The effect of this is that the water level drops and the landmass sinks. When the ice melts, the trapped water is released causing both sea levels and landmasses rise. How these changes manifest is extremely heterogeneous with areas in close proximity being affected in different ways by the same glacial events. During the LGM the isostatic depression of British Columbia may have been as much as 300 m (Clague and James 2002:77).

In short, the sea level history of British Columbia and South East Alaska has been governed by isostatic crustal displacement. In British Columbia, a forebulge feature formed off the west coast of the Dundas Archipelago (McLaren *et al.* 2011:87). The result of this has historically been lowered sea levels on the Outer Shore Islands and raised levels on the British

Columbia coast. However, along the path of the geological hinge effect that runs the length of the coast under the Dundas Archipelago and Stephens Island, sea levels have remained fairly static over the last 18,000 years (Carrar *et al.* 2007:234).

2.4.3 Northwest Coast Sea Level Histories

Sea level histories for areas of the Northwest Coast that are physically close can be very different from each other and are determined by a locations unique combination of eustasy, isostasy, sedimentation, and neotectonics. Sea level curves are based on anywhere from tens to thousands of samples which are statically analyzed to fill in the gaps between measurements and the result of the differing amount of input data is that the accuracy of some curves is greater than others. For my study areas there are sufficient data to model the changes in RSL with a reasonable level of certainty. During the Late Quaternary worldwide sea levels rapidly rose over a period of 21,000 years by approximately 120 m (Fairbanks 1989:637). Within this overall rising trend are the localized sea level histories of the Dundas Archipelago, Prince Rupert Harbor, Haida Gwaii, Stephens Island, and the Alexander Archipelago.

The Dundas Archipelago straddles a geological hinge, minimizing RSL change at this location (McLaren *et al.* 2011:86). Between 14,100 and 13,800 cal. yr BP the sea level was 12 m above present. At 12,200 – 12,000 cal. yr BP the local sea level had dropped to 9 m above current conditions and at 8,200 cal. yr BP it was only 5 m above present. Over the last 8,000 years the RSL has gradually retreated to its current position (McLaren *et al.* 2011:86). At no time in the LPEH was the RSL lower than it is today and there is no need to factor in currently submerged areas in movement corridor models.

A sea level history has not been assembled for Stephens Island; however, due to its geological similarity to the Dundas Islands, the data from this location will be used for both subareas (McLaren *et al.* 2011:88). Stephens Island is located along the geological hinge that runs along the Northwest Coast and sea levels are likely to resemble those at the Dundas Islands. This lack of a sea level history for Stephens Island presents a less than ideal situation and hopefully the increasing academic realization of the importance of accurate sea levels curves will spur the creation of data for this area in the future. Sea level curves are only accurate over short distances increasing the difficulty of creating new curves; however there are regional patterns across axes parallel to and perpendicular to the glaciated ice margin from which larger trends can be interpreted (Andrew Martindale, personal communication 2015). As previously mentioned, at no point were currently underwater areas exposed and no bathymetric data is needed for this area.

Currently only the crudest of sea levels curves exists for Prince Rupert Harbor. The sections of the curve that are older than 8,000 cal. yr BP are based on ~10 radiocarbon measurements which is an insufficient sample for creating an accurate and detailed sea level history for this study area (Shugar *et al.* 2014:12). However, based on this information, the Harbour sea levels were 50 m above present 15,000 ^{14}C yr BP (Fedje *et al.* 2005:36). One thousand years later they had dropped to 15 m above present and have continued to fall to their current levels (Shugar *et al.* 2014:12). Currently a much more comprehensive curve is in development at the University of British Columbia and until its completion, the existing curve must suffice[7].

Haida Gwaii sits on the western side of the geological hinge and has had a much more dramatic sea level history than the previously discussed areas. At 17,000 – 15,500 cal. yr BP the RSL was 32 m below present. Sea levels continued to drop over time and by 11,200 – 10,600 cal. yr BP the sea level had fallen to 68 m below modern levels (Shugar *et al.* 2014:11). At this point

[7] Bryn Letham is developing sea level curves as part of his PhD dissertation under the direction of Dr. Andrew Martindale at the University of British Columbia that he hopes to publish in the near future.

the trend reverses and waters begin to rise. By 9,600 cal. yr BP the ocean had risen to 5 m above current levels and continued to quickly rise, reaching a height of 15.5 m by 8,200 cal. yr BP (Fedje *et al.* 2005:27; Wolfe and Huntley 2008:5). Since then sea levels have gradually fallen to their current levels. This complicated sea level history necessitates the integration of both terrestrial and marine topographic data into movement corridor models.

The Alexander Archipelago, much like Haida Gwaii, was affected by a tectonic forebulge, causing sea levels to rise and then fall dramatically (Shugar *et al.* 2014:18). At 15,800 cal. yr BP the sea level was 56 m above present and from this high point has gradually fallen to its current position. The process and data necessary for modeling paleolandscapes in the Alexander Archipelago is essentially the same as Haida Gwaii.

In conclusion, my analysis will be conducted for five specific study areas along the Pacific coast of British Columbia and Southeast Alaska. These areas were chosen due to previous scholarship suggesting that they have a high likelihood for containing very old sites and the computational limits of running a least cost path analysis on geographical extensive areas. Each study area was examined in 3,000 year increments during the LPEH from 16,000 to 10,000 cal. yr BP. This approach provides a more nuanced view of this constantly changing landscape. Within this study area live several different aboriginal peoples who have a direct connection to Paleoamerican peoples. Our knowledge of these groups comes from a variety of sources, each of which has their individual strengths and weakness. By looking at all of these, I gained valuable insight into the perishable and social culture of the Paleoamerican groups that are at the core of my research. Additionally, an understanding of the dynamic climate and geology of each study area is essential for any kind of modeling of events in the deep past. A combination of several factors has significantly influenced sea levels on the Northwest Coast and this is a crucial variable in my analysis, the importance of which cannot be overstated. The Northwest Coast is an incredibly diverse area that is equally defined by its unique and dynamic environment and the people that inhabit it.

Chapter 3: Paleoamerican History of the Northwest Coast

3.0 Introduction

In comparison to other parts of the world, the continents of North and South America have a relatively short history of human inhabitation (Ames and Maschner 1999; Mandryk *et al.* 2001:301; Moss 2011:8). The antiquity of anatomically modern humans can be traced back hundreds of thousands of years in Africa and tens of thousands of years in Europe, Asia, Australasia, and Near Oceania. The Americas were one of the last places in which humans established a presence (Steckley 2011:182-183). The search for the reason why it took so long for humans to reach this area provides some of the most interesting scholarship and research in North American archaeology. The series of events that led to the arrival of the first inhabitants of this continent is commonly referred to as the peopling of the New World. However, for as much progress as has been made in understanding these events, there is still a huge amount that we do not know and many questions that remain unanswered (Graf *et al.* 2013). For every artifact that is recovered, DNA sequence unravelled, and language history established, dozens of new questions are generated. Central among these are those that deal with how and when the first Paleoamerican peoples arrived in the Americas (Dixon 1999:19, Erlandson *et al.* 2007:162, Fladmark 1979:55, Meltzer 2010:10-18).

Before beginning to discuss the findings of my research, it is necessary to situate my thesis in the contemporary conversation and associated history of the peopling of the New World. First I will outline the traditional theories explaining Paleoamerican migration and how they have changed over time. Next I will review the evidence for alternative theories focusing on the Kelp Highway Model (Erlandson *et al.* 2007). I will also talk about the known archaeological sites in Cascadia that date to the LPEH period. This will be followed by a discussion of the various projects that have made use of geospatial modeling on the Northwest Coast. This review provides the necessary context and background in which to understand the significance and impact of least cost path modeling of Paleoamerican migration events.

3.1 The Clovis First and Ice-Free Corridor Hypotheses

For much of the twentieth century, the archaeological community thought that it understood the process and timing of initial human migrations into the New World. These explanations took the form of the Clovis First and Ice-Free Corridor theories (Adovasio and Pedler 2013:512; Arnold 2002:437; Beck and Jones 2013:273; Mandryk *et al.* 2001:301). These hypotheses stated that as the Cordilleran and Laurentide ice sheets retracted, a narrow ecologically viable corridor into North America was available, through which ancient peoples were able to travel (Dixon 1999:30; Ives *et al.* 2013:150). These migrations started in Beringia moving through Southern Alberta into the North American continental interior. Motivation for these migrations, particularly those following the LGM, was frequently attributed to the pursuit of Pleistocene fauna, with these events taking place approximately 11,000 ^{14}C yr BP (Arnold 2002:437; Fladmark 1979:56; Ives *et al.* 2013:162; Sauer 1944:531; Waters and Stafford 2007:1122). These theories are based around assumptions and observations primarily derived from geological and paleoecological research, as well as the study of Clovis and Folsom artifacts. It was long assumed that humans armed with specialized hunting technology and an advanced familiarity with animal behavior were the first to enter the continent and would have rapidly spread throughout North America (Kelly and Todd 1988:234).

Another theory has been articulated that suggests a pre-LGM migration into the New World. This idea dates back fifty years and is still popular with some archaeologists (Müller-Beck 1966:1210; Holen and Holen 2013:429) The most current version of this idea, the

Mammoth Steep Hypothesis, suggests that the environment of Eurasia during Oxygen Isotope Stage 3 would have allowed humans with the right tool kit to successfully travel into the New World (Holen and Holen 2013:429; Ives *et al.* 2013:150). These migrations would have taken place approximately 22,000 ^{14}C yr BP and would have ceased during the LGM (Holen 2005:41; Holen and Holen 2013:430). However, because my project focuses on later time periods, the rest of this section will focus on theories involving later migration events.

The Clovis First and Ice-Free Corridor theories are constantly changing as new evidence is uncovered. In recent years there have been major modifications to these ideas in response to findings that show little linkage between Clovis sites and the hunting of mammoths, mastodons, and other Pleistocene megafauna. Additionally, new genetic and skeletal evidence from various very old skeletons discovered in the Americas suggests a Eurasian origin for Paleoamericans via Beringia (Brace *et al.* 2014:463; Chatters *et al.* 2014:753; Rasmussen *et al.* 2014:225). Lastly, the Clovis cultural time period has been refined to a shorter chronologic window (Waters and Stafford 2007:1122). An understanding of these theories and their history is essential to any conversation about Paleoamerican history.

3.1.1 The Chronology and Ecological Viability of the Ice-Free Corridor

The ecology of the Ice-Free Corridor and Beringia has been modeled using a variety of techniques. What these reconstructions suggest is that Canadian potion of the corridor route would have been covered with ice for much of the late Pleistocene. Only during the Bølling-Allerød interstade, which lasted between 16,000 and 10,000 ^{14}C yr BP, would this area have been capable of supporting human populations. This has led to the suggestion that during the Holocene and possibly the late Pleistocene, the Corridor may have served as biological refugium (Grosswald 1999:37). Additional research has produced evidence that as the Corridor opened, the periglacial areas created would have been capable of supporting large mammals, as "the lee side of glaciers, melt water, loess and silt, katabatic winds, and sunshine produce young, productive, pulse-stabilized ecosystems" (Geist 1999:78). These are environments very similar to those that can be found in the ice fields of the St. Elias mountain range where 13 species of large mammal currently live. By analogy, this has led to the conclusion that humans could have lived in these types of environments. This argument is further supported by evidence of anatomical features that evolved in humans during the Pleistocene to help cope with lowered temperatures, such as a reduction in canine tooth size, large fat reserves, and variable body size (Geist 1999:83). Additionally biome reconstruction has suggested that as early as 12,000 ^{14}C yr BP that shrub and tundra grass land would have dominated the corridor, providing an environment capable of supporting grazing mega fauna (Dyke 2005:223). Thus we see a body of evidence that some archaeologists use to suggest that as the Corridor opened it would have provided an environment capable of supporting human movement. There is a significant debate as to when exactly chronologically the Corridor would have become capable of supporting a human population, a topic that will be discussed later in this chapter.

3.1.2 Clovis Technology in the New World

The Clovis cultural group is frequently identified by the distinctive fluted projectile points that they used to hunt large mammals (Ellis 2013:127-128; Miller *et al.* 2013:208). These artifacts were first excavated in the American Southwest in the 1930s and have since been found across much of North America (Dixon 1999:10; Miller *et al.* 2013:213). These first Clovis points discovered were found in association with *Bison antiquus* bones, which indicated that these points must date to a time period when this species was present in North America. In an era before radiometric dating, this association with Pleistocene megafaunal remains provided conclusive evidence that humans must have been in the Americas before mammoths went extinct approximately 10,000 years ago. These findings refuted ideas popular during the early 19th century about very recent and very ancient Paleoamerican migrations and provided the first chronologic insight into these events (Dixon 1999:10). Since 1933 and the publication of the seminal *The American Aborigines, Their Origin and Antiquity* (1933) by the Fifth Pacific Science Congress, there has been a consensus among scholars for the existence of human populations in the Americas for a minimum of 10,000 years. Many archaeologists have interpreted this as evidence to mean that Clovis peoples were the first to arrive in the New World (Beck and Jones 2010:81-82; Dixon 1999:13).

The Pleistocene Megafauna Overkill Hypothesis is a framework for explaining the distribution and presence of Clovis technology in North America. In this interpretation of North American history, Clovis peoples traveled down the Ice-Free Corridor and, upon arriving in the North American continental interior, encountered extensive populations of large land mammals who had no experience with human predation. This allowed for these animals to be easily hunted, and by following herds, human populations were able to spread quickly over the continent in a period as short as 1,000 years (Martin 1973:969). This theory was further expanded to include the idea that Clovis peoples were technologically based hunters as opposed to the geographically oriented hunter-gatherer cultures that we see today. Clovis peoples would have used the combination of their fluted point technology and a familiarity with animal behavior to facilitate rapid movement and selective predation of animal populations (Kelly and Todd 1988:231, Haynes 2006:257).

The Clovis First paradigm has been supported by a large corpus of knowledge developed over the last 80 years. Following the application of radiocarbon dating methods to Clovis sites in the 1960s, the Clovis period was conservatively estimated to have lasted from 11,500 to 10,800 ^{14}C yr BP (Haynes 2006:256). Recent scholarship has demonstrated that this date range, which was unquestioned for the latter half of the 20th century, is inaccurate. The conservative estimate for the Clovis period in North America has been modified in recent years. An estimate age of 11,050 to 10,800 ^{14}C yr BP based on new radiometric dating calibration curves was derived from dendrochronological analysis produced by Waters and Stafford (2007:1122) and an age range of 13,400 to 12,700 cal. yr BP was produced by Miller *et al.* (2013:210) who incorporate dates from the Aubrey site. The creation of Waters and Stafford short chronology is partially the result of a push for increased hygiene in dating Clovis sites. Their changes to how sites are dated potentially increases the accuracy of the Clovis chronology but also drastically decrease the number of recognized Clovis sites (n=14) and introduces issues with sample size (Waters and Stafford 2007:1123). Regardless, all of these chronologies suggest that this technology was spread between preexisting human populations and not spread during initial colonization events.

Work by Miller and his associates (2013) has also suggested that the Clovis technology may not be as uniform as previously thought and that this technology may have distinct Classic Clovis and Proto Clovis periods. Additionally several lithic technologies have been identified which predate the Clovis period most notably including Western Stemmed and Western Fluted points (Beck and Jones 2013:280; Collins *et al.* 2013). Modern studies of Clovis sites also demonstrate a lack of correlation between the geographic location and date of Clovis sites suggesting this technology originated south of Beringia and then spread north (Beck and Jones 2010:86; Beck and Jones 2013:275; Ives *et al.* 2013:163; Waters and Stafford 2007:1123). These conclusions have resulted in an ongoing reimagining of the Clovis First hypothesis to explain these new findings.

New interpretations of Clovis site assemblages have caused traditional interpretations to change significantly in recent years. A reanalysis of Clovis sites and their faunal remains have revealed that there is insufficient evidence to suggest that Clovis peoples are the reason for the rapid extinction of megafauna in North America (Grayson and Meltzer 2002:347). Of 76 Clovis sites reviewed, only 14 showed a definitive association with mastodon or mammoth bones. If Clovis culture was dependent on large game hunting, we would expect to see a stronger correlation between the remains of these animals and Clovis sites. Disease and climate change have been suggested as alternative explanations for the drastic reduction in animal populations and the ultimate demise of American megafauna (Grayson and Meltzer 2002:347).

3.2.0 Landmark Pre-Clovis Sites

Over the last 40 years, the academic supremacy of the Clovis First theory has gradually eroded. This is largely due to the discovery of archaeological sites that have been proven to predate the opening of the Ice-Free Corridor (Table 3.0). Due to paleoecological research, we can predict when the Corridor would first have become a viable route for human movement (Dixon 2013:58). Research has determined that the Corridor could have physically opened as early as 13,500 cal. yr BP, and yet sites have been discovered that are older than this in Chile, Pennsylvania, and Oregon (Catto *et al.* 1996:30; Kennedy 2010:1296; Shapiro *et al.* 2004:1563). Monte Verde was the first site to be widely accepted as concurrently dating to the Clovis occupation of the Americas. This site is located on the banks of Chinchihaupi Creek in the southern part of Chile and was discovered when a local woodsman cutting an oxcart trail along the creek uncovered prehistoric mastodon bones, lithic artifacts, and wooden fragments (Meltzer 2010:117). These artifacts were brought to Dr. Thomas Dillehay, who determined that further investigation was warranted. His initial exploratory work quickly turned into a major research project conducted from 1977 to 1985. Due to a unique series of flooding events, the site has excellent preservation. Using a combination of archaeological, botanical, and faunal evidence, Dillehay and a slew of collaborators were able to demonstrate that the MVII layer of Monte Verde was deposited by humans and may date to 12,450 ± 150 ^{14}C. yr BP (Dillehay 1989:141). The findings from this site represented a revolutionary challenge to the Clovis First theory and were subject to intense scrutiny (Adovasio and Pedler 2013:514; Dillehay 1984:106; Dillehay and Collins 1988:150). In response to the general academic skepticism about the chronology of the site, a number of prominent archaeologists were invited to visit in 1997. Upon completing their site tour, these scholars reached a consensus that the site dated to at least 12,000 ^{14}C yr BP (Adovasio and Pedler 1997:576).

In addition to Monte Verde, a small number of sites have been discovered that also appear to predate the Clovis period (Meltzer 2010:131). Meadowcroft Rockshelter is a landmark site that sits above Cross Creek in southwest Pennsylvania. This site is composed of a sandstone overhang in which a rich assemblage of artifacts has been found and radiocarbon dated to between 16,000 and 13,000 cal. yr BP (Adovasio *et al.* 1990:353). This site was excavated by Dr. James Adovasio between 1973 and 1978. Adovasio, a researcher famous for his use of cutting-edge methodologies and fastidious attention to detail, found that this site contained 11 distinct stratigraphic layers (Adovasio and Pedler 2013:513). The oldest of these, Stratum IIa, has been conservatively dated to 12,800 ± 870 ^{14}C yr BP using a series of radiocarbon dates which were independently analyzed by several different laboratories (Adovasio *et al.* 1990:352; Adovasio and Pedler 2013:512). This layer contains over 400 pieces of debitage and 13 tools, clearly demonstrating human occupation of this layer and by association a human presence in Pennsylvania thousands of years before the opening of the Ice-Free Corridor (Meltzer 2010:111).

Table 3.0 Archaeological Sites from the LPEH

Site Name	Location	Earliest Date (Calibrated)	Earliest Date (Uncalibrated)	Date Source	Citation
Monte Verde	Puerto Montt, CHL	14,872 – 14,210	12,450 ± 150	Wood and Charcoal	Dillehay 1989
Meadowcroft Rockshelter	Pennsylvania, USA	20,476 – 18,110	16,165 ± 975	Charcoal	Adovasio and Pedler 2013
Paisley Cave	Oregon, USA	14,958 – 14,280	12,400 ± 60	Coprolite Macrofossils	Jenkins *et al.* 2013
On-You-Knees Cave	Alaska, USA	11,247 – 11,347	9,880 ± 50	Human Pelvis	Dixon *et al.* 1997 Kemp *et al.* 2007
K1 Cave	British Columbia, CAN	10,685 – 10,505	9,376 ± 50	Animal Bone	Ramsey *et al.* 2004
Gaadu Din 1	British Columbia, CAN	11,957 – 11,760	10,150 ± 25	Bone Point Fragment	Fedje *et al.* 2011
Gaadu Din 2	British Columbia, CAN	12,110 – 12,035	10,295 ± 25	Hearth Remains	Fedje *et al.* 2011
Werner Bay	British Columbia, CAN	10,200	9,150	Sea Level Modeling	Josenhans *et al.* 1997
Stave Lake	British Columbia, CAN	12,382 – 12,124	10,370 ± 40	Charcoal	McLaren *et al.* 2008
Manis	Washington, USA	13,860 – 13,765	11,975 ± 35	Bone Collagen	Gustafson *et al.* 1997 Waters *et al.* 2011
Ayer Pond	British Columbia, CAN	12,019 – 11,796[8]	11,990 ± 25	Bison Bone	Kenday *et al.* 2011
Anzick	Montana, USA	12,707 – 12,556	10,705 ± 35	Human Skeleton	Rassmussen *et al.* 2014
Chetwynd	British Columbia, CAN	11,324 – 11,030	11,240 ± 70	Bison Bone	Shapiro *et al.* 2004
Gault and Friedkine	Texas, USA	15,000 – 13,500	14,360 ± 90	OSL Samples	Waters *et al.* 2011
Wally's Beach	Alberta, CAN	13,300	11,470 ± 35	Bone Samples	Waters *et al.* 2015

[8] Shapiro and colleagues do not provide a calibration age from their radiocarbon dates from Chetwynd so I calibrated the date reported in Table 3.0 using the Calib 7.1 program with the IntCal13 curve.

Claims about the antiquity of this site have been met with resistance by many archaeologists. These objections focus on the possibility of the contamination of radiocarbon dates by natural coal sources, a lack of Pleistocene environmental indicators, and that the recovered artifacts do not clearly fit into existing typologies (Sturdevant 1999:34). However, independent analysis has uncovered no signs of any type of contamination in the radiocarbon samples. It is also possible that when most of North America was affected by cooler climatic conditions, this area was not explaining the presence of unexpected floral and faunal remains. Lastly, the uniqueness of the artifact assemblage could possibly be explained as the result of the discovery of an entirely new technology distinct to this site. Even considering these worries, conservative estimations of the site's age still place its occupation at least partially before the Clovis period (Waters and Stafford 2007:1122).

Another location that is important to this conversation is Paisley Cave. This site is composed of a wave-cut shelter that sits on the shore of Lake Chewaucan in Oregon. Inside the cave several human coprolites, which have been dated to 12,400 ± 60 ^{14}C yr BP, have been discovered (Jenkins *et al.* 2013:223; Thomas *et al.* 2008:786). Currently these are some of the oldest signs of human habitation in the Americas, possibly predating all skeletal material. DNA was successfully extracted from the coprolites and its analysis revealed that the humans that produced the coprolites can be traced to the Native American-founding genetic markers. The dates associated with the coprolites were calculated and crosschecked by two different laboratories and stringent measures were taken to prevent genetic contamination in both the field and the lab (Meltzer 2010:117). Paisley Caves provides a very different kind of direct evidence for human occupation of Oregon prior to the opening of the Ice-Free Corridor which supports the evidence found at other sites across the Americas.

The Gault and Friedkin sites located along the Buttermilk Creek in Texas are also relevant to this conversation. These sites are part of the same locality and are within a few hundred meters of each other. Both locations contain artifact material that has been dated to between 13.2 and 15.5 ^{14}C yr BP (Waters *et al.* 2011a:1599). These dates were obtained from 18 Optically Stimulated Luminescence (OSL) dates. While not as accurate as radiocarbon dates, the OSL dates are in the correct stratigraphic order and internally consistent (Waters *et al.* 2011a:1601). The artifacts that have been found are representative of Clovis and Pre-Clovis technologies. The oldest projectiles have been described as looking similar to the stemmed point tradition (Collins and Bradley 2008:70-72). These artifacts dating over 15,000 in number demonstrate that humans have been in the New World for at least 15,500 years and provide some of the best evidence for Pre-Clovis human activity in the Americas (Collins *et al*. 2013:526).

The last archaeological site that needs to be discussed is Wally's Beach. This site is located at the base of the route of the Ice Free Corridor in Alberta and provides the oldest evidence for human activity in the Corridor (Waters *et al* 2015:4263-4267). This location has produced the butchered remains of 7 horses and 1 camel as well as 29 non-diagnostic lithics. 27 radiocarbon dates were taken from XAD-purified collagen sample from these skeletons and they place this sites average age at 13,300 cal. yr BP. which is slightly older than the previously reported date of 11,350 ± 80 ^{14}C yr BP. This site anchors Pre-Clovis people in the Americas providing some of the earliest dates for proven a biotically viable passage through Canada.

3.2.1 North West Coast Sites with Early Holocene Material

There are also a number of sites located in Alaska and British Columbia that appear to contain material culture concurrent with or postdating the Clovis period. These sites do not have the same body of research supporting their antiquity as the previously mentioned locations, but do provide enough evidence that there is a strong probability that they date to at least the early Holocene. On-Your-Knees Cave is located on Prince of Wales Island in Southeast Alaska. A surface tool collection here has been dated using a single sample to 9,880 ± 50 ^{14}C yr BP and the remains of a young man discovered at the site were dated to 9,200 ^{14}C yr BP (Dixon *et al.* 1997:703). Also located at this site is a karst cave, which contains a lithic assemblage from the same time period, further establishing the antiquity of the site (Mackie *et al.* 2011:65). Another karst cave site, K1 Cave, is located on the west coast of Haida Gwaii. Here faunal remains and two dart points have been dated to 9,376 ± 50 ^{14}C yr BP (Ramsey *et al.* 2004:108). The site profile is consistent with that of a bear den and does not show any signs of human use. Most likely humans were hunting near the cave and the points were carried into the cave by a wounded animal (Mackie *et al.* 2011:65-66). Another very old site providing evidence for bear hunting can be seen at Gaadu Din 1 on Huxley Island in southeast Haida Gwaii. At this site a bone point and charcoal flakes were recovered and dated to 10,615 ± 30 ^{14}C yr BP and 10,150 ± 25 ^{14}C yr BP (Fedje *et al.* 2011:457; Mackie *et al.* 2011:66). Approximately 300 m to the north of Gaadu Din 1 is the Gaadu Din 2 cave site, at which four bifacially flaked lithics were discovered and dated to 10,295 ± 25 ^{14}C yr BP (Fedje *et al.* 2011:457; Mackie *et al.* 2011:66). The samples used to derive this date were obtained from fish and black bear bones found in association with the lithics (Fedje *et al.* 2011:458).

Bucket dredge sampling in Werner Bay off of Moresby Island in British Columbia was conducted as a result of site prospection modeling using digital elevation models of prehistoric landscapes and recovered a single stone tool. Based on sea level histories and the artifact's location on the tidal plain, this tool should date to 10,200 cal. yr BP (Josenhans *et al.* 1997:7). Stave Lake in British Columbia has been periodically surveyed during periods of drought and 56 surface scatters have been identified; 23 of these have been excavated in some form and two yield dates from the Pleistocene (McLaren 2008). At the Cardinal Creek Mouth site charcoal located directly under a biface was dated to 10,370 ± 40 ^{14}C yr BP, and at the Devil's Point site charcoal overlaying a flake tool were dated to 10,290 ± 50 ^{14}C yr BP (Mackie *et al.* 2011:68; Fedje 2011; McLaren 2008).

In 1977, Emanuel Manis of Sequim, Washington began to dig a small pond on his property. In the process of doing this he discovered the remains of both bison (*Bison antiquus)* and mastodons. One of the several hundred faunal remains he found had what appeared to be a bone projectile point embedded in it and a possible flaked cobble spall was later discovered (Gustafson *et al.* 1979:157). This attracted the attention of archaeologists who investigated the find. Samples for calculating radiocarbon dates were collected and after analysis returned an age of 13,800 cal. yr BP for the bones. The point has been extensively studied with high-resolution x-ray computed tomography and DNA and protein sequencing and proven to be a projectile point 27-35 cm in length made from mammoth bone (Waters *et al.* 2011:351).

3.2.2 Northwest Coast Sites with Possible LPEH Material

Several sites have been identified on the Northwest Coast that suggest possible LPEH human activity, but that have not produced conclusive evidence of human occupation. These locations include the Ayer Pond and Charlie Lake sites. Here I will review the Ayer Pond site, as it is the best example of this type of possible site.

Similar to the discovery at the Manis Mastodon site, nine partially articulated *Bison antiquus* skeletons were found during the creation of a wetland preserve at Ayer Pond on Orcas Island in British Columbia (Kenday *et al.* 2011:140). These skeletons show evidence of greenstick fractures, percussion impact scars, and cut marks of a type that could have been caused by human butchering. The skeletons were found under a metre of peat at the bottom of the lake, and it has been suggested that the skeletons were butchered on the lake while it was frozen and then left to sink to the bottom upon the thawing of the ice. The age of the skeletons has been placed between 12,200 and 6,730 ^{14}C yr BP based on dates directly from the bones and materials in the associated stratigraphic layers. Researchers have not ruled out taphonomic processes and geological forces as an explanation for the positioning and damage to the bones, and no other evidence for human activity at this location has been discovered. Therefore, we cannot conclusively say that these animals were killed or butchered by humans. This site suggests possible human activity but does not provided definitive evidence of human occupation.

The purpose of listing all of these sites and their respective dates is that they clearly demonstrate the presence of human populations on the Northwest Coast during the LPEH. Sites such as Monte Verde, the Meadowcroft Rockshelter, Gault, and Friedkine prove a Pre-Clovis human occupation of the Americas. The oldest sites in the continental interior demonstrate a possible Pre-Clovis human presence and the oldest sites on the Northwest Coast suggest that this area was inhabited concurrently with or immediately following to the opening of the Ice-Free Corridor. These revelations have caused scholars to consider new initial peopling hypotheses that explain how the dates from these sites fit into the larger chronology of North American prehistory.

3.3 Alternative Peopling Theories

Significant new archaeological work has been done that suggests that several different cultural patterns may have already been in place in North America at the time of the introduction of Clovis technology (Collins *et al* 2013:521). This assertion is largely based on the discovery of lithic items that are morphologically distinct from and predate Clovis points in North America

(Beck and Jones 2010:106). The process of describing the disparate types of items that have been identified into unified technologies and typologies is ongoing. These examples show that there may be material culture in North America that is at least concurrent with and possibly older than the Clovis culture.

Linguistic evidence has also been found that suggests human occupation in the Americas before the arrival of Clovis peoples. Linguists have created models that allow for the estimation of the spread of cultures based on the degree of change between languages. The Americas have an unusual amount of linguistic diversity, based on known language spread rates, with over 300 distinct languages. Research has projected that this variety could only arise if humans have been living in the New World for longer than 10,000 years, and some models suggest migration dates as early as 30,000 ^{14}C yr BP (Nichols 2008:1113). However, at this time there is no definitive archaeological evidence to corroborate human arrival prior to 14,000 ^{14}C yr BP.

The combination of archaeological and linguistic evidence that refutes the Clovis First theory has led to the suggestion of two counter-theories to explain the method and chronology of the initial Peopling of the New World. The Atlantic Ice Bridge theory suggests that peoples descended from European Solutrean cultures that migrated across a frozen Atlantic ice sheet into the Americas. This theory is strongly disputed within the archaeological community and most scholars do not consider this a viable explanation for peopling events (Bradley and Stanford 2004; Straus *et al.* 2005). The strongest of these criticisms are based on evidence from very early human skeletons recovered across North America. Genetic and skeletal morphological analysis conducted on these remains have revealed that these individuals are related to Eurasian peoples who migrated to the New World via Beringia (Chatters *et al.* 2014:753; Rasmussen *et al.* 2014:226; Rasmussen *et al.* 2015:3). These findings collectively suggest that both Clovis and modern North American aboriginal groups are descended from populations migrating east through Beringia; not west along the Atlantic Ice Bridge.

One of the more widely accepted and better supported counter-Clovis First theory is that of the coastal migration-based Kelp Highway Hypothesis (Erlandson *et al.* 2007). This idea claims that the coast would have been ecologically viable for human populations at 16,000 cal. yr BP and that the continuous kelp ecosystem of the Pacific Rim would have allowed maritime travel from Siberia into the Americas via a series of boat trips over hundreds or thousands of years. Here I will briefly review all the major lines of evidence used to support the idea of a coastal migration.

3.3.1 Paleoecology

Archaeological, palynological, and geological research have determined when the Ice Free Corridor would have first become passable for humans. There is little evidence to suggest that humans would have been able to travel through this route prior to 12,000 ^{14}C yr BP (Arnold 2002:446, Dixon 2013:51, Dyke 2005). The corridor was mostly deglaciated by at least 13,500 ^{14}C yr BP but the resulting landscape would have been marginal and biotically incapable of supporting a human population. The Chetwynde site in British Columbia sits at the mid-point of the Ice-Free Corridor and *Bison antiquus* remains found there have been dated to 11,240 cal. yr BP, providing some of the oldest evidence of an environmentally viable corridor (Ives *et al.* 2013:151; Shapiro 2004). In short it would have been several millennia after the opening of the corridor before humans would have been able to travel through it, as it would have taken at most hundreds of years for the necessary plant and animal populations to establish themselves (Dyke 2005:222).

It has been suggested that as the Last Glacial Maximum (LGM) ended, isolated coastal refugia for plant and animal species, including humans, would have been accessible (Fladmark 1975:55). Evidence suggests that the coast would have been passable by as early as 15,000 ^{14}C yr BP. This deglaciated landscape would have taken the form of discrete promontory lobes that would quickly have been biologically productive, unlike the continental interior (Mandryk *et al.* 2001:305). Ice retreat would have been transgressive, with southern Alaska being the first area to open up at approximately 16,000 ^{14}C yr BP and southern British Columbia the last at 13,000 ^{14}C yr BP. This would have allowed for the gradual southward advancement of Paleoamerican peoples along the coast (Mann and Hamilton 1995:449). Unlike the Ice-Free Corridor, these coastal areas would have been home to a robust community of plant and animals species.

Extensive paleoecological research has been conducted on Haida Gwaii and this area provides the majority of our information on what the coast would have been like between 16,000 and 10,000 ^{14}C yr BP. The oldest plant microfossil remains on the northern Pacific Coast are from Kodiak and Pleasant Islands in Alaska and have been dated to approximately 15,000 ^{14}C yr BP. Actual floral remains from herbs, grasses, and ferns which date to 14,700 ± 700 ^{14}C yr BP have been found at sea-cut cliff exposures at the Cape Ball site on Graham Island (Lacourse and Mathewes 2005:52). The overall vegetation trend is a transition from tundra to forests with definitive evidence from pollen counts for widespread forests by 10,500 ^{14}C yr BP (Lacourse and Mathewes 2005:44). However there is evidence from the tidal flats of Haida Gwaii, areas which are now underwater but which would have been above sea level during the late Pleistocene, that they would have been capable of supporting forests as early as 12,200 cal. yr BP. A paleosol in the Juan Perez Sound contains a tree stump that has been dated to this period and provides direct evidence for tree growth (Lacourse and Mathewes 2005:42). Most importantly a variety of plant species including Alpine Bistort (*Bistorta vivipara*), Soapberry (*Shepherdia canadensis*), Lupin (*Fabaceae*), Northern Rice Root (*Fritillaria camschatcensis*), and various ferns have all been proven to exist on the coast at this time. All of these are plants that are known from the ethnographic record to have been consumed by Northwest Coast peoples, proving that food sources would have been available (Lacourse and Mathewes 2005:55). In addition to floral resources, invertebrate animals were also present on the coast during the late Pleistocene.

A combination of paleontological finds and archaeological excavations have provided the majority of evidence about the faunal species present during the LPEH. There is some disagreement in the interpretation of the robustness of animal communities. Rebecca Wigen (2005) finds insufficient evidence for faunal refugia on the Northwest Coast during the LGM. However, within a few thousand years of the end of the LGM there is sufficient evidence to suggest populations of sea otters (*Enhydra lutris*), foxes (*Canidae*), bear (*Ursidae*), caribou (*Rangifer tarandus*), cervids, sea birds, and numerous fish species (Wigen 2005:99-102). Wigen's analysis is of faunal remains from archaeological sites and her conclusions may be distorted by the lack of sites that predate 10,000 ^{14}C yr BP. Other researchers, such as James Dixon (2013), have suggested that coastal refugia must have been capable of supporting humans because remains from brown bears and Arctic foxes have been found on the Alexander Archipelago in contexts that chronologically bracket the LGM (Dixon 2013:53). This assertion is strengthened by genetic analysis of modern bear populations that suggest their continuous uninterrupted habitation of the coast (Heaton and Grady 2003:47). Radiocarbon dates from ringed seal (*Pusa hispida*) skeletons, an established food source species, demonstrate that these animals were present on the coast continuously throughout the LGM as well. Two archaeological sites, K1 Cave and Port Eliza Cave, contain brown bear remains which date to ~14,500 cal. yr

BP, suggesting that humans could have survived on the coast at this time as bears are strong proxies for humans in their environmental needs (Dixon 2013:54).

The drastic rise and fall of sea levels during the LPEH has greatly complicated the search for early sites (Mackie *et al.* 2013:137). Many places that in the past were drowned are now above the tideline and many locations that would have been accessible are now underwater creating a discontinuous ecological record for this area that has resulted in certain degree of uncertainty in environmental and habitation reconstructions (Wigen 2005:99). However, despite this limitation there is sufficient evidence to state that portions of the Northwest Coast were viable environments for human occupation in the late Pleistocene.

3.3.2 The Kelp Highway Hypothesis

John Erlandson and his collaborators (2007) believe that the Kelp High Way hypothesis provides the best explanation for the Peopling of the New World. Their hypothesis states that a similar suite of ecological resources stretching from Japan all the way to the tip of South America would have facilitated the movement of people into the Americas (Erlandson *et al.* 2007:164). This entire stretch of coastline, with the exception of short tropical patches at the equator, is home to members of the Order kelp (*Laminariales*), which are the keystone species of a very rich resource base. This ecological similarity would allow for Paleoamerican peoples to travel along the coast without having to learn new subsistence practices and would facilitate easy and quick dispersal into North America. While no direct evidence for ancient kelp forests has been discovered along the coast of Beringia, remains of species known to live in kelp beds have been recovered such as Sea Cow (*Hydrodamalis gigas*), Abalone (*Halliotis*), Sea Urchin (*Echinoderm*), and Rockfish (*Sebastes)* (Erlandson *et al.* 2007:167). Modeling of the change in Kelp forests over the last 20,000 radiocarbon years suggests that during the LPEH, these plants would have been even more prolific than they are today and that they would have had an even broader geographic range (Erlandson *et al.* 2007:166).

3.3.3 Oral Histories

The last line of evidence that supports coastal migration is the oral histories of the aboriginal peoples who inhabit this area. There is a long history of the telling of history through narrative on the Northwest Coast and significant research has been done on the *Adawx* of the Tsimshian and the *K'aayang.nga* of the Haida. The *Adawx* is a form of narrative that "purports to relate significant events in the history of specific families, lineages, clans, and village groups." (Martindale 2006:159). The work of Susan Marsden (2002) individually and with her collaborator Andrew Martindale (2003) has explored how the format and method of this type of narration works to preserve the integrity of the story being presented. By looking at the recursivity of different elements of a specific narrative, a measure of accuracy can be made for events in a story, and by marking different chronological events and tying them to genealogies, an absolute timeline for the story can be formed (Martindale 2006:160). The *Adawx,* and the *K'aayang.nga* to a lesser extent, have been demonstrated as being capable of recording significant geological, and to a lesser extent historical, events with a high degree of accuracy; therefore, it and other oral traditions may be able to shed light on the Peopling of the New World. A *K'aayang.nga* entitled *Tl'guuhlga Gan Xaayda Gwaayaay* (Creating Haida Gwaii) makes repeated references to the Haida people as coming from the ocean and looking for a place to live. It is possible that these elements of the story might have their origin in maritime migration events (Kii7iljuus and Harris 2005:125). Alan McMillan and Ian Hutchinson (2002) have discovered more explicit mentions of possible peopling events in Heiltsuk origin stories that describe that "in the beginning there was nothing but water and ice and a narrow strip of shore-line" (McMillan and Hutchinson 2002:60). All of these examples demonstrate how the oral histories of Northwest Coast peoples also provide evidence for coastal migration. It is worth noting that the study of oral histories as tools for recreating past events is an emerging field and these sources of evidence should be recognized for what they are: descriptions of possible events and not literal truths.

The previous sections of this chapter have established that there was a Pre-Clovis human population in the Americas. While unproven due to a lack of archaeological evidence, one of the strongest theories we have to explain how these people arrived in the New World is the Kelp Highway Hypothesis. The key to finding evidence of Northwest Coast Paleoamerican peopling events is identifying sites that would have been used during LPEH migrations. The best tool we have for accomplishing this is geospatial site prospection modeling. Many projects have been conducted using digital tools to find early sites and they play an important role in shaping the course my research has taken.

3.4 Geospatial Modeling of the Peopling of the New World

Several research projects have made use of a variety of geospatial analysis techniques to contribute to our understanding of the peopling of the New World. These projects use a variety of methods that look at combinations of paleoshorelines, digital elevation models, aerial photography, topographic data, and bathymetry as input for predictive analyses that try to identify the areas of the Northwest Coast most likely to have been inhabited by Paleoamerican peoples. These studies range in complexity from simple analysis of site selection criteria to more advanced path-of-least-resistance calculations of movement across the landscape of the New World. Here, I will briefly review these different studies to establish the academic environment in which this thesis is placed.

An excellent project was conducted by Adrian Sanders (2009) which used LiDAR, geographic information systems (GIS), and remote sensing technologies as well as more traditional survey methods to test for archaeological sites on North Graham Island in Haida Gwaii. Sanders's research made use of an interdisciplinary multi-logical framework that tested how geospatial technologies can be balanced against phenomenological methods for survey and site discovery. Sanders found that by incorporating GIS modeling with an experiential and ethnographic knowledge of his study area, he was able to create a methodology for successfully ranking the probability of different areas on Northern Graham Island containing sites. His work is a good example of how environmental and cultural inputs can be combined in computer-based modeling and demonstrates how this type of analysis can recognize both the importance of environmental inputs and a firsthand knowledge of the study area (Sanders 2009).

Another excellent study, which came out of the University of Victoria, was the dissertation of Duncan McLaren (2008). His project recreated Holocene and late Pleistocene sea level fluctuations and paleoecology of the Dundas Islands in very precise detail. This was done by taking lake sediment and soil core samples from around the islands and testing them for the presence of different diatoms, pollens, and other environmental indicators. The presence of these microbotanical remains and their position in the core sample's stratigraphy was recorded. The associated layers were radiocarbon dated to determine when different locations would have been covered in seawater. This work helped to demonstrate how a tectonic hinge running down the Northwest Coast has been one of the principal forces affecting sea level change and helps to explain why geographically close areas can have very different sea level histories. This sea level data was combined with shoreline slope and aspect, freshwater proximity, sheltered location, salmon stream location, and shore zone type information to create a site prospection model for raised coastal terraces. This site identification modeling was proven successful as five new sites were discovered which predate 5,000 ^{14}C yr BP. These are the first sites of this age in Coast Tsimshian territory and demonstrate the applicability of geospatial site prediction modeling on the Northwest Coast. McLaren's work also shows the importance of accurate sea level curves and multi-criteria evaluation in site prospection (McLaren 2008).

Perhaps the most recent application of geospatial science to site prospection modeling is the work of Kelly Monteleone (2013) who asked similar questions to McLaren but applied her research to a study area in Alaska. In her dissertation research, digital elevation models and bathymetric data were combined to create site prospection models for three areas of the Alexander Archipelago. Monteleone looked at the landscape of the archipelago in 500 year intervals from 16,000 to 10,500 cal. yr BP. Her model merged bathymetrical and terrestrial elevation data to create elevation models of the archipelago for each time period. The site prospection process was divided into three stages; the first of these was the gathering of paleoclimate, geological composition, hydrology, glacial extent, and archaeological information. These inputs were then used in the analysis stage to calculate slope, aspect, distance from freshwater bodies, tributary junction location, distance from known sites, distance from the coastline, and sinuosity so as to determine areas of high and low site probability for the study area. The final stage of the project was a rigorous statistical assessment of the results using spatial auto-correlation techniques such as Kvamme's Gain and Getis-Ord General-G tests. These analyses proved the model was more likely than random selection to identify areas containing previously discovered very old archaeological sites, and by extension undiscovered sites as well (Monteleone 2013:107-132).

The most promising areas identified by the model were located in now submerged parts of Southeast Alaska. Extensive underwater testing was done at these locations to identify new sites. This testing process was conducted using a combination of sonar imaging, drop bucket sampling, and remote-operated vehicle surveys. These efforts resulted in the discovery of several possible rock shelters and stone features in Shakan Bay and the Gulf of Esquibel. Survey in Keku Strait correlated the location of a previously discovered ground slate point to an underwater sonar anomaly, though it is still unknown if this anomaly is related to the point (Monteleone 2013:149-169). This dissertation demonstrates the applicability of statistical analysis in testing the accuracy of geospatial models. It also shows that bathymetric and elevation data can be successfully combined to create elevation models for Pleistocene landscapes.

Daryl Fedje and Quentin Mackie are two of the foremost experts on early Northwest Coast archaeology and they published a book chapter in 2011 that detailed their use of and experience with predictive modeling techniques in Haida Gwaii. Their research compared the use of high-accuracy topographic maps, high-resolution photogrammetric contour mapping, multibeam swath bathymetry, and LiDAR. They found that existing techniques for identifying sites in terrestrial areas were very effective, particularly the photogrammetry contour-based methods. With this approach, several sites predating 9,000 ^{14}C yr BP were identified. However, their experience with trying to locate sites on drowned landscapes has been largely unsuccessful, with less than 1% of their attempts to identify these areas having recovered any archaeological material (Mackie *et al.* 2011:81). The largest impediments to finding sites in submerged contexts are poor sampling techniques and inaccurate site prospection models (Mackie *et al.* 2011:80). The cost of conducting underwater archaeology is very high in comparison to terrestrial archaeology and new methods of discovering sites need to be developed with higher rates of success (Fedje *et al.* 2011:461).

Least cost path modeling has been previously applied to the Northwest Coast for trying to understand Peopling Events. In 2000 David Anderson and Christopher Gillam published an article in *American Antiquity* where they used least cost path analysis to compare multiple routes of movement through the New World during the late Pleistocene. Their study used the location of lakes and glaciers as barriers to travel and slope as its sole determinant of movement cost. Lakes and glaciers were positioned to their extents as of 12,000 cal. yr BP, meaning that both the coastal and Ice-Free Corridor routes were viable for inclusion in their study. The slope was calculated from a GTOP30 world DEM at 30 arcsecond resolution. No bathymetric data was incorporated due to a lack of data for the entire Americas at a suitable resolution. Additionally none of the North American landscape that was inundated 12,000 years ago was considered in the creation of least cost paths.

Three different starting points were used in Anderson and Gillam's study. They calculated paths from western Alaska, the mouth of the Columbia River, and the Isthmus of Panama (Anderson and Gillam 2000:47). From these origin points paths of least resistance were calculated to 45 early sites spread across the continent (Anderson and Gillam 2000:47). The Alaskan origin scenario created paths that followed the Mackenzie River before branching out across North America and spreading down to the tip of South America (Anderson and Gillam 2000:48). The scenario that uses the mouth of the Columbia River as its origin point created paths that immediately pushed east before branching to the north and south (Anderson and Gillam 2000:49). The Isthmus of Panama scenario was run as two separate simulations, the first modeled southward movement and created routes which moved west across the top of South

America before travelling south through the middle of the continent and then deviated east down the coast (Anderson and Gillam 2000:51). The second model projected northward movement and is essentially identical to the results of the Pacific Coast origin point scenario. Anderson and Gillam did not include areas of the coast which are now submerged but that would have been accessible during the late Pleistocene in there simulations (Anderson and Gillam 2000:46). As such there is a need for least cost path analyses, such as the one undertaken in this thesis, which incorporate this variable. It is also worth noting that Anderson and Gillam included a temporal element to their project where they determined, based on the paths they calculated, that the spread of humans across the American continent could have happened in a little as 2,000 and as much as 5,000 years (Anderson and Gillam 2000:54). Their least cost path research demonstrates that this technique can effectively be applied to answering questions about the method of the peopling of the New World. It also shows that previous analyses of the Northwest Coast have not accounted for the dynamic and changing nature of this environment. Anderson and Gillam's work forms an excellent jumping-off point for the research that I conducted.

The peopling of the New World is an event that remains almost as enigmatic today as it was at the discovery of the first Folsom and Clovis points. While we now know with a high degree of certainty that people arrived in the Americas prior to the opening of the Ice-Free Corridor, how and exactly when this was accomplished still remains a mystery. Archaeological sites both in the continental interior and on the coast demonstrate the antiquity of this human activity. Alternative theories to the traditional Clovis First approach have been suggested which range from the highly implausible to those such as the Kelp Highway Hypothesis, that are supported by a solid body of evidence. Geospatial research has provided important insight into the peopling of the New World and from this research comes a solid foundation for my implementation of prospective modeling and least cost analyses.

Chapter 4: Theoretical Framework

4.0 Introduction

Theory, simply put, consists of a series of fundamental premises, postulates, or assumptions that specify certain entities, processes, or mechanisms, suggesting different phenomena (Schiffer 1988:462). The understanding of the world adopted by a scholar serves as the backbone of their research. In my research on the movement corridors used during the initial peopling of the New World, the questions I ask are viewed through the contexts of landscape and migration. Landscape is the scale at which this analysis takes place and migration is the method for situating human movement. These two frameworks provide the basic structure for least cost analyses of the peopling events of the New World by allowing me to make use of a specific set of tools for answering my research questions. Applying digital archaeological methods to research questions of human movement requires the hybridization of these different theoretical paradigms. The results of digital archaeology are highly dependent on the assumptions about past cultures that specific theories allow me to make, and a well-developed theoretical foundation is essential to my research methodology.

This chapter discusses the history and evolution of landscape and migration archaeology, highlighting the different elements of these fields that are combined in my thesis to create its theoretical framework. Here landscape is defined in terms of scale, type, temporality, and composition. This constructed depiction of the natural world is then viewed through the lens of human migration theory. In this chapter, migration theory is interpreted in a historical context, which looks at landscape learning, migration models, structure, type, scale, motivation, impact, distance, and mode of movement. My understanding of the scale and method of early peopling events provides the theoretical foundation for the least cost analysis at the heart of this research and structures how the proposed research questions are answered.

4.1 Landscape Archaeology

Over the years, many different subfields of archaeology have emerged and in this project I draw heavily from elements of several of these, including landscape archaeology along with migration theory. Landscape archaeology is best defined as

> An archaeology of how people visualized the world and how they engaged with one another across space, how they chose to manipulate their surroundings or how they were subliminally affected to do things by way of their locational circumstances [David and Thomas 2008:38].

In short, how did the interaction and perception of people with their physical world affect the development of different cultures? In my study of landscape I have taken this definition and combined it with the approach of Julian Thomas who states by "considering the ways in which the significance of the landscape gradually emerged, through practices of building, maintenance, tending, harvesting, and dwelling, we are constructing in the present an analogy for past worlds of meaning" (Thomas 2012:182). The central question here is how can looking at modern landscapes inform us about how past people would have assigned significance to their physical world?

Landscape first entered the archaeological lexicon in the 1970s and quickly grew in popularity. Immediately it was adopted by processual archaeologists who made use of ecological frameworks that looked at the impact of humans on their environment. The next major development in this field was the differentiation between settlement patterns and systems. Here a line was drawn between the placement of sites and the organization of people on the landscape. Processualists were also very interested in looking at how collectors and foragers used landscape, particularly in regard to the spatial patterning of resources, features, and artifacts (David and Thomas 2008:23-25). With the rise of post-processual archaeology in the 1990s the focus turned to sourcing studies and concepts of style. Additionally, cultural resource managers began to make increasing use of landscape in predictive modeling and other compliance activities (David and Thomas 2008:33-35). Today much of the current discussion in landscape archaeology focuses on how indigenous groups are using this field to critique traditional colonial conceptions of landscape in scholarly work (David and Thomas 2008:35).

4.1.1 Definitions of Landscape

The word landscape itself is a relatively recent addition to the English language, as it was first used to describe a specific style of 16th century Dutch painting which depicted rural scenes (David and Thomas 2008:27). However, the origins of this word can be traced further back to the German *landschaft* which describes a unit of human occupation on the land. From these origins, the use of the word has evolved to describe a particular vista or view (David and Thomas 2008:27; Strang 2008:51). There has long been a discontinuity that reverberates to this day between the historical definition that describes human activity and the modern use that describes topography and view. In this thesis I use the modern definition, which forms the basic framework upon which the rest of the research is placed. Many theoretical approaches have been used to explain landscape, the most traditional of which is scientific and abstract. In this school of thought landscapes are “quantifiable, universal, objective, neutral, a-temporal, static, and absolute (among other things)” (Hu 2011:80). This approach defines landscape as the surface on which an act becomes meaningful through routine occupation and “the material manifestation of the relation between humans and the environment” (Barrett 1991:8; Crumley 1994:23).

Another approach to landscape is a “humanized” view, which sees landscapes as qualitative, experienced, contextual, relative, temporal, and dynamic (Hu 2011:80). My research combines both the scientific and humanized perspectives and treats landscapes as being quantifiable but also as social, dynamic, and changing through time. Landscapes can be reduced to metrics like distance, area, count, distribution, and frequency that can provide insight into human interaction in and with these places. The world, especially during the LPEH on the Northwest Coast, was amorphous, radically dynamic, and constantly changing through time. Different groups traveling through these areas would have had very different experiences. The world was warming, ice was retreating, and sea levels were fluctuating, meaning that Paleoamerican migrants would have had inherently reflexive and contextual experiences (Dixon 2013:57).

Any place navigated by of boats also needs to be seen in terms of the aquatic environment in addition to terrestrial areas. Seascape is a concept which can have many different meanings. It has been described as constructed from factors that allow an individual to determine their location on water without reference to terrestrial features (Ford 2011:4). Additionally, seascape has been used to explain ideology and the cultural relationship of different peoples to the ocean (Van de Noort 2003:405). However, in the context of this project, the definition offered by McNiven (2008:150): “views from land to sea, views from sea to land, views along the coastline, and the effect on landscape of the conjunction of sea and land” is the most appropriate. This is an approach that is implemented to great effect by Hein Bjerck (2008) in his study of the development of Scandinavian and Patagonian maritime relations. Due to the nature of the methodology and types of data used to reconstruct maritime migration routes, his definition is the most useful for expanding the boundaries of the study area to include marine environments that are frequently not factored into landscape analysis.

In my project, the term landscape is expanded to include both terrestrial landmasses and near-shore areas covered with water that are visible from land. This allows areas such as tidal zones, passages, bays, deltas, and other transitional places to be included in my definition. The junction of water and land is a key element of my study and this hybridized approach allows for the tenets and principles of traditional landscape archaeology to be applied to the parts of this study area that are aquatic and often seen as empty or unimportant places in traditional studies of landscape. Conversely, the dual nature of this definition is also important in thinking about how to treat the inland areas of my study areas. Are these empty places of no significance to people traveling by boat or are they viable paths for seeking specific resources and avoiding difficult watercourses? My definition of landscape allows for all of these scenarios to be explored.

4.1.2 Landscape Scale

Scale is an important consideration in any discussion of landscape. Scale can be viewed through two different lenses, both of which are relevant to this conversation. Geographic scale is defined as "the dimensions of a specific landscape" (Johnston and Smith 2000:725). For this project the geographic scale is the Northwest Coast. This is the area of the Pacific Ocean that falls between Cape Mendocino in Northern California and Icy Bay in Alaska (Ames 1994:209). While having a clearly defined geographic scale is crucial, more important in developing the theory for this project is the methodological scale of this research.

The methodological scale is the scale at that the actual analysis or research is conducted (Johnston and Smith 2000:724-725). This form of scale is determined by the types of techniques and methods used by a researcher. There are two methodological scales in this thesis. The first is the project study area, which is a rectangle of coastline stretching from the southern tip of Haida Gwaii to the Alexander Archipelago in the north. Within this larger area are the five sub-study areas which are areas of particularly high probability of human activity during the LPEH. The larger methodological scale allows for trends and overarching patterns to be explored such as coast-wide migration while the sub areas facilitate a finer-grained approach.

4.1.3 Types of Landscapes

There are several different ways of categorizing landscapes. The traditional contemporary approach is as constructed or built. This is a view that sees the environment as made by human activity; however. this is an approach that is not appropriate when working in the context of this research. Mobile cultures, like those peopling the New World, most often classify their landscape by "projecting ideas and emotions onto the world as they find it – on trails, views, campsites and other special places" (Ashmore and Knapp 1999:10). There is no evidence at this time to suggest construction or building on the landscape scale during the LPEH on the Northwest Coast that is the product of sedentary peoples. This understanding of Paleoamerican movement is useful as a starting place for looking at the archaeological situation I am studying.

Wendy Ashmore and Arthur Knapp (1999) have developed several categories of landscape classification that are useful here. *Conceptual landscape* is the most appropriate of these categories and is defined as a landscape interpreted and given meaning through localized social practices and experience. These landscapes are mediated and constituted through social processes that lead to their reproduction through time (Ashmore and Knapp 1999:11). This category is useful because it allows for a dynamic and evolving understanding of the Northwest Coast that also factors in the physical elements of this location. When combined with Ashmore and Knapp's idea of the *ideational landscape*, these two categories of landscape provide a framework that is suitable for my analysis. Ideational landscapes are places that are given meaning through "the formation of ideas or mental images of things not present to the senses and culture based on spiritual values or ideas" (Ashmore and Knapp 1999:12). The ideational category focuses on the lived experience of people in a place and is a useful way of approaching landscape considerations because it accounts for human agency and other phenomenological elements of landscape in an explicit way.

In this thesis, the various approaches previously discussed are hybridized to create a theoretical landscape model. Migration events on the Northwest Coast during the LPEH would have been a continuum moving from a strictly naturally evolved landscape devoid of human meaning or manipulation to an increasingly ideational and conceptual landscape. Prior to the arrival of first peoples, my study area would not have been associated with any social practices or processes. However, as people began to live in this area their understanding of it would change. This framework is useful because it allows me to better model and subsequently understand how peoples' interactions with the landscape would have changed during the 6,000 year time span I am investigating. The combination of the different conceptions of landscape allows for both the social and environmental aspects of Northwest Coast environments to be incorporated into my analysis.

The glaciation of the Northwest Coast and the presence of small refugia mean that movement through this area would have been similar in some respects to island movement and colonization (Dixon 2013:63). Joe Crouch (2008:134) discusses the idea of canoes as mobile sites and this is an aspect of the landscape that cannot be overlooked. Crouch's work demonstrates that a site does not have to be a fixed location and that canoe and other boating technologies allow for normally fixed resources such as water sources to become mobile. This influences my understanding of landscape in that a mobile conception of landscape creates places that are very difficult to map in the traditional static sense. My hybridized approach allows for things like the risk management strategies employed by mariners to be considered; for example, the use of protected waterways to avoid strong ocean currents (Crouch 2008:131-137).

4.1.4 Landscape Temporality

Landscapes are inherently temporal places; they are continually shifting and changing as a result of both human and natural processes. Both of these types of change are relevant to my research. Social aspects of landscapes are often overlooked and are very important to any study involving human decision making processes. Frontiers are a social construct established by people and are zones from which settlers looked outward from their established territory with further colonization in mind. Boundaries, on the other hand, are inner-oriented and mark the division between different sovereign units (Kristof 1970:134-135). On the Northwest Coast, Paleoamerican peoples would have been crossing established boundaries, and as they moved south, frontiers would have transitioned into bounded territory. As such, there would not have been one stable home range. This concept ties in closely with the models of migration that are discussed later in this chapter.

Several natural processes are important to consider when talking about change on the Northwest Coast. Most of these are connected to sea-level and global temperature trends (Rowland 2008:386). Modern global warming has spurred new interest in the effects of past climate changes, a topic that has its origins in uniformitarian and gradualist thought. Climate change is a process driven by internal tectonic forces and external climate factors. These processes are not slow moving ones that would have little immediate effect on past peoples. The

LPEH Northwest Coast is just one of many places where we see rapid environmental change that would have affected peoples' daily lives. The rapidity of this change can be seen in the work of scholars like Quentin Mackie (2011) and Daryl Fedje (2011) who demonstrate that sea level change would have been noticeable during an individual's lifetime. Understanding a paleolandscape is a crucial element in understanding the people that lived in it and this is why running analyses of sea level change for different chronological windows is so key to this study (Stern 2008:364-365).

4.1.5 Paradigms of Landscape Theory

Processual or "New Archaeology" has been popular since Lewis Binford's *Archaeology as Anthropology* (1962) first brought this approach to the attention of the archaeological community. His method included treating archaeology as science, focusing on temporal cultural processes, and the primacy of a principally explanatory discipline. Between the early 1960s and the late 1980s this was the dominant mode of thought in archaeology (Johnson 2004:14-16). The advocates of the processual approach believed that adherence to the scientific method and the search for universal principles was the only way to move beyond the spatial and temporal limits of the historical and antiquarian-based traditional methodologies of the early twentieth century (Martin 1971:3).

In the 1980s innovations in computer technology resulted in new methods of investigating human interaction with the landscape, opening entirely new branches of archaeological research (Evans and Daly 2006:3; Wheatley and Gillings 2012:1). Many modern scholars, as illustrated by the examples assembled in Surface-Evans and White's (2012) volume, believe that the digital representation of ancient landscapes and material culture is a legitimate and valuable tool for understanding the actions of humans in the deep past. A further extension of this view is that the thinking and decision making of these peoples can be interpreted and inferred using these techniques (Llobera 2012; Lock 2009). Today many archaeologists continue to do work grounded in the same processual tradition.

4.1.6 Post Processual Landscape Archaeology

In the 1980s, critiques of processual analysis of landscape were articulated, focusing on the environmental determinism and lack of human agency in these methodologies. From these criticisms, the post-processual school of thought was created (Fleming 2006:268). The central tenet of post-processual landscape archaeology is that human agency and the social aspects of human life need to be considered in the analysis of the interaction of humans and the landscapes they inhabit. This theoretical shift is expressed in neo-Marxist, post-positivist, praxis, hermeneutic, and most importantly to landscape archaeology, phenomenological approaches (Renfrew and Bahn 2010:28).

The concept of phenomenology was pushed into the archaeological discourse by Christopher Tilley (1994) and others who advocated an empathetic approach in which a landscape is traveled and experienced so as to inform researchers about a culture's interaction with their physical world (Brück 2005:50; Thomas 1996:89; Tilley 2004:219-228). Tilley's theoretical view states that a digital representation or model cannot adequately explain the interaction that ancient peoples would have had with the landscapes within which they lived (Tilley 2008:271). Specific criticisms by phenomenologists of digital archaeological modeling include that these methods are environmentally driven and do not account for human activity on the individual or community levels. Phenomenologists argue that processual techniques fail to account for human decisions that are influenced by cultural variables that have nothing to do with the environment; and that these processes, when removed from their historical context, do not make sense to a modern audience (Bender 1998:40; Ingold 1993:152). According to these scholars, post-processual archaeology is the only way to counter the lack of human agency that they see as the major failing of the processual method (Fleming 2006:268).

4.1.7 Processual-Plus Landscape Archaeology

In the last fifteen years some scholars have called for a combination of the processual and post-processual method (Hegmon 2003:216; Llobera 2001:1013, 2003:25; Pauketat 2001). This new framework is called processual-plus archaeology and it is a blending of the empiricism of processualism with the humanistic theory of post-processualism. The work of Marcos Llobera exemplifies the application of processual-plus work in digital landscape archaeology. He and other processual-plus researchers focus their work on the individual and community scale so as to account for human agency and to not overly preference environmental factors. Work by these individuals attempts to incorporate decision making based on cultural factors into digital forms of analysis (Llobera 2001:1097, 2007:52, 2011:215, and 2012; McEwan and Millican 2012:491). Processual-plus research represents a spectrum of approaches. Some are grounded heavily in processual theory, such as Gillings's (2009) work on megalith visual affordance in the United Kingdom and others have a much more phenomenological orientation, such as Janowski and Ingold (2012:12) who focus on the hopes and dreams of past peoples as connected to the physical world.

4.1.8 Landscape Theory for Northwest Coast Migration Route Prediction

My project makes use of the processual-plus approach because it accommodates GIS analysis, but allows me to account for the dynamic and social nature of the study area. The definition of landscape presented earlier is only tenable in a processual-plus theoretical framework because this approach allows for the quantification of a landscape and simultaneously acknowledges the rapidity of landscape change, as well as the differing experiences of migrating Paleoamerican groups. My use of a hybridized marine/terrestrial landscape definition requires the use of the post-processual approach because this framework supports my research in ways other paradigms cannot.

My methodology heavily draws on elements of the post-processual toolbox by recognizing human agency and that different migratory groups would conceptualize the world very differently as they passed along the same narrow, ecologically viable paths into the New World. The use of techniques like multiple-weighting criteria in deriving movement costs allows for different conceptions and experiences with the landscape to be modeled. By working on a relatively fine temporal scale, the variability of the landscape can be incorporated into analysis by looking at the changes to movement routes over time. Lastly, the social aspects of landscape are incorporated into my methodology by working at high levels of spatial resolution. This allows for more of the micro-interactions of populations to be modeled.

4.2 Migration and Movement

Migration is a topic which has a well-developed theoretical foundation in archaeology and that has been studied extensively in the greater field of social science. The migration of Paleoamerican groups into the New World is notable because the circumstances of these movements were significantly different from any other migration that had happened in the previous 30,000 years. These peoples moved into a culturally empty landscape about which they would have known very little because of the lack of previous human populations (Rockman 2003:12). Looking at Australian and Polynesian migration events can be helpful in understanding the series of events seen in the New World, as they too deal with long-distance ocean travel and movement into culturally empty landscapes (Beaton 1991:209). On the

Northwest Coast it is likely that a founding population moved from refugium to refugium down the coast using maritime transportation eventually settling into a landscape that did not have an indigenous population (Dixon 2013:63). The pattern of movement used in this circumstance is best described using Anthony's (1990:902) "Leapfrog" and Beaton's (1991:223) "Transient Explorer" frameworks placed within a biogeographical approach as described by Rockman (2003:14).

4.2.1 What is Migration?

Migration has been extensively studied in anthropology and archaeology and a large body of research has been compiled on this topic (Brettell and Hollifield 2000; Clark and Cabana 2011; Rockman and Steele 2003). For the purpose of my research, migration is defined as "one way residential relocation to a different environment by at least one individual" (Clark and Cabana 2011:5). This definition has been selected from the many that have been developed in the study of this phenomenon because it best fits our current understanding of LPEH coastal migrations. Here I assume that groups of people of unknown size would have moved out of Beringia and into the Northwest Coast, an environment that theoretically was not so different from what these people were used to (Erlandson *et al.* 2007:164-165).

Migration is a social act in any context and fundamentally is the movement of individuals from one social and economic context into a new one. Moving to a new place is both a process and an agent of change and is not as simple as just relocating to a different geographic location. Migration also involves changing social relations within the social network the group is leaving, within the group of travelers undertaking the migration, and with new groups of people encountered along the journey (Clark and Cabana 2011:4). In many cultures, identity is fundamentally linked to location and migrations can have large impacts on how groups perceive themselves (Nuttall 2001). The key element of a migration is that it is a transgressive event. A geographic, social, or linguistic boundary must be crossed. It is this act that separates a migration from mere relocation to a new geographic location (Clark and Cabana 2011:9). On the Northwest Coast, these earliest migrations would have crossed multiple types of boundaries, each of which would have had its own unique degrees of permeability, meaning that barriers must be individually considered (Rockman 2003:15). Groups would have moved between land and water, from inland tundra to coastal forest, and from colder northern latitudes to increasingly warmer southern areas (Erlandson *et al.* 2007:170, Dixon 2013:62). Groups would have initially crossed social and linguistic boundaries as they moved from relatively densely populated areas past existing borders to a continent without a pre-existing human population. This is a change that would involve a certain degree of isolation which would have had ramifications for kinship, subsistence, and trade (Beaton 1991:224).

4.2.2 History of Migration

The history of migration theory, like landscape analysis, is heavily tied to the continually changing paradigms of thought in archaeology in general. At the inception of modern archaeology in the early 1900s, migration was a key concept of study. This was because great significance was placed on culture change and the movement of peoples was assumed to be one of the primary drivers of this change (Anthony 1990:896; Clark and Cabana 2011:17). The cultural historical approach was championed by the likes of Bruce Trigger and Gordon Childe who thought that the migration of peoples would result in abrupt changes in culture (Rockman 2003:3). This was the dominant paradigm in archaeology, along with diffusion, for explaining the effects that the movement of people had on culture until the rise of processual method.

During the processual period the discipline of archaeology saw an increased interest in universal laws and general processes. The result of this was a movement away from the study of migration. The perception of the localized regional cultural history of migrations as interpreted in the cultural historical movement stood in opposition to the New Archaeology's focus on cultural processes. The study of human movement in the deep past fell out of popularity and migrations were largely ignored until the 1990s where interest was rekindled with David Anthony's 1990 article "Migration in Archeology: The Baby and the Bathwater." However, this is not to say that the processual method was not applied to migration: it was just not a popular area of study. Paul Martin (1973) famously looked at the migration of Paleoamerican peoples through the ice-free corridor into North America. From his analysis of the probable biomass of early Holocene North America, he developed the concept of a megafauna-fueled rapid expansion of Paleoamerican peoples through the continent. By estimating the amount of faunal material available to hunters, calculating rates of extinction, and looking at the radiocarbon dates associated with known Clovis sites he estimated that the expansion of people throughout the Americas occurred in as little as 1,000 years (Martin 1973:973). Martin's model has come to be called the overkill or "blitzkrieg" model and is a foundational element of the Clovis First school of thought.

With the rise of post-processual archaeology and its focus on case-by-case analysis of human action, migration studies again became of interest in archaeology. This school of thought focused on human agency, social landscapes, and interpretation, meaning that new kinds of questions could be asked. In his seminal article Anthony (1990:895) greatly expanded the way archaeologists thought about migrations by calling for analysis with an understanding of "migration as a patterned human behavior". In his article he outlines several key concepts, first among which is that social organization, trade, and transportation technology must be considered in the study of migration. Likewise, a distinction must be made between long and short-distance migrations. Long-distance migrations are easier to detect in the archaeological record due to the scale of these movements. Lastly, the form of a migration often fits into one of several different models. The previously mentioned work of Martin is a classic example of a “Wave of Advance” model. A more current example of this theory can be seen in the work of Robert Kelly and Lawrence Todd (1988).

Kelly and Todd (1998:232), like Martin before them, believe that the Americas were very rapidly filled with people who spread like a wave across the continent from an initial entry point. However, their theory is not contingent on the hunting of large megafauna mammal species. Instead it is based on several different lines of reasoning focusing on the technological ability of these peoples, as opposed to geographic orientation as suggested in Martin’s model (Kelly and Todd 1988:231). The apparent rapidity of inhabitation suggested from radiocarbon dating, the selective use of high-quality stone for tool making, the similarity of point typologies in dispersed geographic areas, the prevalence of bifacially flaked lithics in early assemblages, and elements of site taphonomy at these sites suggestive of heavy use of caves and rockshelters are the keystones of this interpretation of peopling events. All of these factors suggested to Kelly and Todd that America’s first inhabitants possessed a very flexible subsistence system that would have allowed for their spread quickly throughout the diverse environments of the Americas, like ripples before the bow of a ship (Kelly and Todd 1988:234). The Wave of Advance model is one of the more popular the traditional and historic approach for explaining the peopling of the New World.

Anthony (1990:92) also discusses return and stream migrations. In many instances of migration, once the route and method of movement is established people begin to flow continuously along that path from a specific origin point, thus forming a stream of people.

People who migrate tend to have migrated recently in the past, and migration along a route does not have to be unidirectional. In many cases people will, in whole or part, retrace their past steps and return to familiar locations in return migrations. Perhaps Anthony's most relevant contribution to the method of migration discussion is his "Leap-Frog" form of movement. This is a type of long-distance migration where people move considerable distances via geographically dispersed stopping points before establishing a new permanent home.

Anthony's movement patterns have been applied to Paleoamerican migrations on the Northwest Coast by David Anderson and Christopher Gillam (2000:56). These researchers further subdivided this form of migration into the "String of Pearls" and "Leap-Frog" types, where the latter is characterized by movement and settlement into spatially adjacent areas and the former by travel to discontinuous locations. I have adopted the Leap-Frog form of movement for my study as it best fits our understanding of the conditions during the LPEH, where the landscape was composed of small, spatially distant, deglaciated refugia (Dixon 2013:63). Paleoamerican peoples would have left Beringia and hopped along the coast by boat, crossing vast distances in a situation that fits the Leap-Frog scenario. A group of people upon moving into any new and different environment encounter a learning curve that must be mastered for successful habitation (Rockman 2003:4). Next, I look at how Leap-Frog type migration is connected to different types of landscape learning and the effect this has on our view of migration.

4.2.3 Landscape Learning and the Biogeographical Approach

Landscape learning is "the social response to situations in which there is both a lack of knowledge of the distribution of natural resources in a region and a lack of access to previously acquired knowledge about distribution" (Rockman 2003:4). Three different forms of knowledge can be used in acquiring landscape learning; (1) locational knowledge deals with the locations of physical resources and their characteristics; (2) limitational knowledge deals with environmental boundaries and the cost of acquiring resources: and lastly, (3) social knowledge is the transformation of a landscape into units of information which can be transmitted between people. In Paleoamerican migrations, there is a distinct lack of social and locational knowledge as no one in the migrating population had ever traveled into the Americas before. The bulk of what people would have known would have come from limitational knowledge. It has been suggested that the coast of the Pacific Basin would have been almost continually composed of kelp- (*Phaeophycea)* based ecosystems between Japan and the tip of South America (Erlandson *et al.* 2007:171). This ecological similarity would not require substantial shifts in the subsistence practices of travelers moving down the coast and its presence means that limitational knowledge would most likely have been dominant with the potential for limited locational knowledge.

The presence of limitational knowledge lets me adopt a biogeographical approach to modeling migration. I cannot assume that people will live everywhere it is physically possible to survive, but instead that they will live in places that they categorize according to their cultural values as desirable for habitation. This selection process is going to be shaped by various barriers to movement. Population can form a barrier in that a given refugium will only have the ability to sustain a population of a certain size. Once the population threshold is reached, the area is no longer a viable target for inhabitation. Social barriers are only minimally present in the landscape being studied because the only social interactions present would have been with other various migrating parties. The types of knowledge a group has access to can be a limiting factor in their interaction with the environment. For migration into an area without a resident population, knowledge forms the largest barrier, with population and social barriers playing less of a role in landscape learning (Rockman 2003:15-17). How a group of people learn to live in a new area is only one small part of the migration process. In all migration events, as well as the specific context being studied here, migration structure, scale, motivation, impact, distance, and mode of transportation must be considered (Clark and Cabana 2011:6-8).

4.2.4 Maritime Northwest Coast Migration

Leap-Frog migrations during the LPEH down the Northwest Coast would have been composed of two stages. The first of these would have been a pioneer phase. In this phase, social knowledge would have been limited, but not nonexistent because of scouting activities where individuals ventured out ahead of the main group. These scouting activities would have allowed for the accumulation of some knowledge about the environments that would be encountered during the latter trip. It is possible that these journeys would have been connected to rites of passage where young people ventured into the wild for a set period of time before returning to the community (John Ives, personal communication 2014). Additionally scouting would have been an essential contribution to the wayfinding process which is heavily dependent on landmarks, paths, and tracks (only the first two of these are relevant to marine travel) (Golledge 2003:33). The establishment of pathways would facilitate travel and routes would be created from the accumulation of knowledge about the landscape (Zedeño and Stoffle 2003:62). Given the benefits of these activities I assume that some kind of scouting would have been necessary to undertake migration down the Northwest Coast.

The settlement or second phase of a migration event would be composed of the movement of the main group of people. Moving out of an established and populated social landscape would have the effect of isolating the migrating group, which would have had major ramifications for survival in a new landscape. Groups participating in initial migrations that did not benefit from well-established paths and a solid knowledge base would probably have been smaller in size, meaning that random chance would have played a larger role in their success (Meltzer 2003:553, Ives 2014:3, Golledge 2003:37). When a migration was unsuccessful and a group was not able to establish itself in a new area, it may have been forced to backtrack to a previous stopping point or even the origin of its migration. It is probable that during these initial migration events site abandonment and return migration events took place (Anthony 1990:898). This would have had the effect of increasing social knowledge due to the transmission of information from the retuning group to other groups. The key concept here is that within the greater southward trend of movement, migration probably was bidirectional with groups of people traveling back and forth across any given area. This means that modeling of migration must take counter-flow events into account and that unidirectional movement cannot be assumed (Anthony 1990:904).

The transient explorer framework best provides a plausible logic of migration that could have been used by Paleoamerican peoples. Transient explorers have most prolifically been studied in Australia and can be viewed as highly mobile groups traveling to resource patches inhabiting areas just long enough to fully exploit the available resources before moving on. Group size would have been small and marriage relationships would have been limited to a very small pool of people (Beaton 1991:216). Additionally, small splinter groups would have formed frequently as couples and their immediate family struck off on their own. However, small group size means that these peoples would have been more susceptible to accidents, disease, and other phenomena that groups with a larger population would have been able to survive. The flow of information would have been sparse to nonexistent between groups, again providing support for a biogeographical migration framework. Group composition would have been stable with childbirth quickly replacing members who had left as a result of splintering action (Beaton 1991:223).

In Beaton’s examination of the economy of the transient explorer form of migration, it is clear that these groups would have had a high tolerance to different ecological zones and would have freely moved between resource patches. The concepts of bounded territories or a “home range” is not applicable. He also expects that the assemblages of sites created by these peoples would be very similar across large geographic areas. Within sites, the types of tools seen should consist of generalized technologies, which would allow environmental and economic fluidity when needed. It is likely that this flexibility would have not been initially necessary for Paleoamericans due to the similarity of kelp resources until groups began to move inland away from the coast or to areas where kelp may not have been plentiful such as at the equator at which point the transient explore framework explains there movement through these areas.

The colonization logic used by transient explorers in Australia and other places would have been particularly effective on the Northwest Coast. Jon Erlandson and associates’ (2007) Kelp Highway model describes how coastal migrations might have taken place and fits cleanly into Beaton's logical framework as the types of resources available for subsistence would have been narrowly constrained. This makes sense when considering the assertion that kelp ecosystems would have been one of the principle factors making long-distance migration on the Pacific Rim possible. The generally linear nature of coastal movement (as opposed to a Wave of Advance migration) is also popular with transient explorers. Lastly, these groups favor routes that allow them to access similar resource patches. This is another defining element of the Kelp Highway hypothesis, which is constructed around the similarity of coastal ecosystems in Northern Asia and the Americas.

The scale of migration is important for choosing factors relevant to modeling these events. The number of people in a migratory event would likely have been small. Additionally, the number of sites they made use of would have been very small initially but would have increased through time as the climate warmed and glaciers retreated (Dixon 2013:63). The only viable stopping points for a group of any size would have been select coastal refugia. This means that as time passed it is possible that the size and scale of migration events could have increased.

The motivation of these migrations could be caused by a variety of 'push' factors. These could include internal conflict between subgroups within the Paleoamerican populations of Beringia. It is well established that conflict was prevalent in later time periods on the Northwest Coast and it is possible that such conflict existed in earlier times (Moss 2011:128-129). This is a common motivation for migration that is seen widely throughout space and time (Tsuda 2011:316). Genetic evidence also suggests that populations may have begun to expand during the late Pleistocene in Beringia and this may have been a driving factor for southward movement (Mulligan and Kitchen 2013:174). The climate in Beringia at the end of the Last Glacial Maximum would have made for a difficult place to live and it is possible that resource scarcity may have acted as a motivation for migration events (Dixon 2013:62). Additionally, there is little known about the religion and ideology of Paleoamerican groups and this may have been a factor in convincing people to move into the New World. As seen in various pilgrimage events over the course of human history, this can be a powerful motivator. Lastly, there may not be an environmentally logical reason for these migrations as humans are random beings and a sense of wanderlust or curiosity may be the driving force behind colonizing events (Tilley 1994:78).

Due to the lack of established landscape knowledge for the Northwest Coast, it is likely that 'pull' factors attracting people to the Americas were less of a factor in the decision to move southward. However, as the climate warmed through time, resources would have become more plentiful in the New World and the fertility of the kelp-based ecosystem may have attracted people to the coast (Erlandson *et al.* 2007:164). The southward movement of people may have created a social pull for later migrations as familial relations have also been documented as a source of motivation for migration events (Tsuda 2011:320).

The impact of these migrations would have been extremely significant. During the LPEH the New World was the only unpopulated area of the globe outside of Polynesia and Antarctica (Beaton 1991:209). The cultural origins for the first indigenous groups in the Americas are born out of these initial migrations. The effect here is that an empty landscape was quickly filled with a large human population (Martin 1973:970; Meltzer 2005:3; Mulligan and Kitchen 2013:174). The effects of this new population may have included significant changes to the landscape and the environment of the New World. Perhaps most famous of these is the role that humans may have played in the extinction of Pleistocene faunal species (Martin 1973:969). The degree to which humans contributed to these events is still debated, but it is almost certain that humans accelerated the extinction process to some extent.

Lastly, the mode of migration needs to be considered. In order to access the parts of the coast that would have been capable of supporting human population, early migrations would have had to have been conducted by boat (Ames 2002:26; Coupland 1998:41; Erlandson and Braje 2011:29). Maritime travel means that archaeological sites could be separated by vast geographic distances. This is one reason that the inclusion of seascapes in my understanding of landscape is so important. Access to boat technology greatly changes the way the landscapes were navigated. With boating technology, what was once an insurmountable barrier to movement becomes a highway offering a direct route between livable areas (Ames 2002:20-21). However, access to this technology does not mean that the ancient people would have known about or chosen to use the most direct routes between coastal refugia. Human agency and the unpredictability of individuals have to be considered, especially as this relates to the use of boats. This is one reason why the use of multiple movement logic weighting scenarios that capture different ways of thinking about travel is crucial. Maritime travel allows for bulk goods to be easily transported, easing the initial stages of a group's efforts to establishing itself in a new area.

Early Northwest Coast migrations can be reduced to a few fundamental points. Paleoamerican migrations likely fit the model of linear Leap-Frogging movements of people between coastal refugia along a band of similar ecological resources. This movement most likely would have been conducted by means of watercraft and would have covered long distances. These trips would have been part of a southward trend of movement in which bidirectional movement was possible. Paleoamerican populations would have been traveling into a culturally empty landscape about which little was known. They would have had to rely on their locational and limitational knowledge of coastal environments as well as limited social knowledge that results from scouting and return migration events to facilitate landscape learning. These actions would have fit the patterns of transient explorer groups composed of small bands of individuals quickly moving over the landscape subject to natural stochastic forces. It is with this understanding of migration and the definition of landscape discussed earlier that a unified theory for my thesis can be formed.

4.3 Integrating Landscape and Migration Theory

The integration of landscape and migration is possible through the use of a processual-plus approach. By looking at the landscape as simultaneously dynamic, social, quantifiable, and temporal, past human action can be understood through the social nature of humanity and empirical analyses conducted. Here human movement decisions are seen as primarily driven by environmental factors, which can be described quantitatively. However, these decisions were made in unique spatial-temporal contexts by each group of travelers. The decision-making process would not solely have been based on environmental factors. Social dynamics and human agency also would have affected these processes to a large extent. The exact form of these influences can only be understood in the broadest terms, given our current knowledge of Paleoamerican culture. Thus the research questions proposed for my project must be answered using the finest spatial and temporal resolutions possible, as this allows for modeling that more closely approaches movement at the individual and group levels. The re-creation of various movement costs should not commit to pursuing a single universal line of logic. Different decision-making scenarios must be considered where different factors are afforded primacy as different groups traveling through the same landscape may have used different criteria in deciding where to travel.

I have created a definition of landscape that expands the traditional use of the term from purely terrestrial areas to include marine areas, with a focus on the places where the land and the sea meet. The scale of my analysis must enclose the entire area to which humans would have had access. Thus the study area in my analysis is in fact all the possible different combinations of time, space, and unique experience compressed into one palimpsest of human history on the Northwest Coast.

The theoretical schema which is used here can be best described using the analogy of a prism refracting a beam of light. How Paleoamericans calculated the cost of moving through a landscape is bounded by the scale, motivation, impact, structure, mode, and landscape learning curve of the migration. This is the beam of light in our analogy. This beam is then passed through the prism of landscape archaeology. The refraction of the light is based on our view of landscape as temporal, radically dynamic, and constantly changing through time. This process produces a spectrum of possibilities of time, space, and place, each of which must be considered. Therefore, how I scale the analysis and the assumptions I make about causality determine what kind of inferences I can draw about the method of analysis.

The theoretical paradigm presented here seeks to combine the strengths of several past schools of thought and create a framework for an analysis based on understanding of a past which is explored through the scientific method and quantitative analysis, but which is cognizant of the reflexive, contextual, and social realities of human culture. This approach allows me to develop the most accurate understanding of how ancient Paleoamerican peoples moved through the New World.

Chapter 5: Methodology

5.0 Introduction

This chapter outlines the specific process and approach that I used to calculate least cost paths through the Northwest Coast in the deep past. The application of least cost analysis to a maritime context has never before been attempted and, in order to understand how I derived my results, the principals behind GIS analysis, the process for preparing my data, and the specific techniques I used need to be discussed. This includes defining exactly what a GIS is and what software programs were used. Understanding these aspects of my project is important because these factors determined the types of tools and data available to me, which in turn influenced many of the methodological details of the analysis, which produced the final results. Each step in the analysis process is highly influenced by those that preceded it.

The hybridization of two different GIS techniques forms the methodological backbone of my work. The first of these is site prospection modeling. This a field of study that looks at our ability to deduce the decision-making and thought processes of past peoples so as to figure out how and where they would have interacted with their physical landscape (Wheatley and Gillings 2012:148). This concept is important to my project because it is the basis of my reconstruction of movement events in the LPEH. The second technique on which my research is based is least cost analysis. This is the mathematical process that I used to determine how people in the past may have moved through the physical world they inhabited (Surface-Evans and White 2012:4). Understanding the operation, limitations, and strengths of each of these techniques is essential for interpreting the results they produce.

Exactly how both of these techniques are implemented is strongly shaped by the use of specific GIS analysis programs and datasets. Different programs include different toolsets and each of these tools requires that the input data that drives them be prepared in certain ways. This preparation is composed of two steps. First, topographic data must be processed so that elevation surfaces can be created depicting the landscape at various points in time. Then non-topographic data must be prepared in a process that includes the modification and creation of new datasets from existing information so that it can all be integrated together. Then this information is passed through a workflow, which does the actual modeling of routes through the creation of friction surfaces and calculating cost distance from this information. All of the steps leading to this point influence what the results of the analysis will look like and minor changes along the way can have significant ramifications. As such understanding the entire process is necessary for meaningful discussion and analysis of results.

In this chapter I review what a GIS is and how this technique was applied to tackling my research questions. This is followed by a discussion of how least cost analysis can be used for site prospection through the application of specific computer programs. Then I discuss the three separate stages of my analysis. The first of these was the process of generating and collecting datasets for use in the analysis. The second stage was the creation of elevation surfaces for different areas at different points in time and the calculation of movement cost friction surfaces. The final stage consisted of determining least cost paths through landscapes from origin and destination points. Each of these steps played a specific role in the analysis process for deriving the final product of this study. The rest of this chapter will review each of these steps.

5.1 Geographic Information Systems

One of the most significant recent advances in archaeology is Geographic Information Systems (GIS) technology (Wheatley and Gillings 2012:1-3). A GIS is defined as “a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes" (Wheatley and Gillings:8). Another helpful definition is offered by Wheatley and Gillings that further describes a GIS as:

> An information system that is designed to work with data referenced by spatial or geographic coordinates. In other words a GIS is both a database system with specific capabilities for spatially-referenced data as well as a set of operations for working (analysis) with the data [Wheatley and Gillings:8].

GIS has allowed archaeologists to approach questions about the spatial relationships of archaeological sites, features, and artifacts in ways that were beyond the capacity of researchers in the past.

The first basic GIS programs were created in the mid-1960s and the first fully functional operational integrated GIS software was developed by the Canada Land Inventory for the purpose of digitizing hardcopy maps in 1972. Following the success of this GIS, many other fields quickly realized the value of this technology and created their own GIS systems. Archaeologists first began to use GIS programs in the 1970s and software manufacturers quickly took notice and began to develop applications with functionality specifically targeted to their needs (Lock and Harris 1992:81; Meher 2006:ix). The use of GIS in archaeology has been largely focused in North America where it has seen extensive application to site prospection modeling as well as more traditional uses. This being said the use of GIS in archaeology is not constrained to North America and it is increasingly being used all over the world (Wheatley and Gillings 2012:16). As the technologies for gathering the spatial data that drives GIS programs such as GPS, total stations, LiDAR, remote sensing, geophysical survey, etc. have improved, more and more archaeologists are incorporating this technology into their work. Today most projects include at least a very basic level of geospatial science and GIS analysis (Wheatley and Gillings 2012:17). Mirroring the increased use of GIS in archaeology is the prolific creation of GIS software programs, each of which have their own specific functions and can be used to accomplish different types of tasks.

5.2 GIS Programs

A large number of different GIS programs have become commercially available since the advent of this technology. Most of these programs provide the same basic functionality however some software has features that are tailored to specific fields of study. Advanced users are even beginning to write and program their own analyses in Python and other scripting languages (Surface-Evans and White 2012; White and Barber 2012). As such, some programs are better suited to certain kinds of analysis than others because they are able to access different kinds of tools and logical structures. This relates to my project in that some software is much better at handling the very large datasets that I worked with. Differences in performance comes largely from the fact that programs are written using different software languages and coding approaches, the result of which is that some programs are able to handle different types of tasks more efficiently (i.e. more quickly) than others (Wheatley and Gillings 2012:8). Functionality and speed were the major considerations I looked at when deciding what GIS programs to use for my analysis.

I used ArcGIS 10.3 Desktop and ArcGIS Pro 1.0, both produced by ESRI (Earth Science Research Incorporated), for the majority of my analysis. These programs provided all the necessary processes and tools to create digital elevation models, develop frictions surfaces, and run least cost analysis. Some data transformations were completed using the open source software QGIS Desktop 2.6.0 Brighton that allowed for files to export to a wide variety of formats such as comma separated value (CSV). This software served to bridge a gap between the initial format that some data was recorded in and formats that could be read by ArcGIS. Each of these programs played a key role in the analysis process. QGIS was used to prepare the data, and ArcGIS to process and display the data. Both programs were necessary to create usable results.

5.3 Site Prospection Modeling

As mentioned, one of the primary applications of GIS technology in archaeology has been for site prospection modeling. This is a technique that has been extensively used in North America due to the brevity of the historic period and the general lack of knowledge about prehistoric events relative to Old World contexts. This type of modeling is "an assignment procedure, or rule, that correctly indicates an archaeological event outcome at a land parcel location with greater probability than attributable to chance" and is ideal formulated against known data (Wheatley and Gillings 2012:148). This technique is commonly used to try to determine where a particular type of site or feature is more likely to occur on a landscape. Predictive modeling uses the absence or presence of different environmental and cultural features for a given area to determine the likelihood of human activity at that particular location. The versatility of this method has been demonstrated by its application in archaeological contexts all over the world (Carrer 2013, Maschner 1995, Surface-Evans and Alan 2012, Verhagen 2007, White and Barber 2012). The extensive application of these models has shown that they yield results that are significantly better than using random or chance-based classification methods (Wheatley and Gillings 2012:165). This technique is relevant to my work because I can use these principles to hypothesize areas that are more likely to have been used for movement by humans in the past. Site prospection sits at the methodological heart of my project and my analysis moving forward is predicated on the assumption that we can accurately hypothesize where humans would have physically been located in space at a given time (Wheatley and Gillings 2012:148).

5.4 Least Cost Analysis

Least cost analysis is a geospatial analysis technique closely related to site prospection modeling because it is assumed that areas with easy access have a higher chance of containing evidence of human activity than areas that are difficult or undesirable to access (Wheatley and Gillings 2012:142). The theoretical backbone of this technique is the Principle of Least Effort, which was developed by George Zipf (1949:7) in the late 1940s. This principle states that when interacting with different areas, humans will most often choose the area with the greatest accessibility. Specifically, this concept states that humans will move from point A to point B over the path with the lowest accumulated cost (Surface-Evans and White 2012:2). Cost in this context can be defined in three different ways: time, distance, and energetic expenditure (Mitchell 2012:177; Surface-Evans and White 2012:4). The cost of movement must also consider directionality or anisotropy (Surface-Evans and White 2012:3). For example, it is significantly easier to move down a gradient than it is to move uphill. There are several different types of formula used to calculate movement cost. For this thesis, Dijkstra's approach was used instead of A*[9] (Mitchell 2012:195). This method was developed by Dutch computer scientist Edsgar Dijkstra in 1959 and it determines the lowest-cost route between an input location and every other location on a surface. The algorithm performs a search of the entire surface regardless of other mitigating factors such as cumulative distance. It is computationally more intensive, but easier to implement than other approaches (Surface-Evans and White 2012:3-4). In

[9] A*, pronounced "A star," is a distance-plus-heuristic function which is computationally faster but less accurate than the Dijkstra method. For more information on the specific differences between least cost algorithms see Surface-Evans and White (2012:4).

my least cost analysis, landscapes were divided into square shaped cells. Each of these cells was analyzed to determine the difficulty or desirability of moving through the real world area it represents. These movement cost values were then recorded as numeric values for each cell in a raster dataset called the friction surface or cost surface layer (Mitchell 2012:225). In order to create least cost paths, origin and destination points of the movement event that is be recreated are placed on top of the friction surface. ArcGIS then calculates the path of least resistance between these points using the values recorded in the friction surface (Mitchell 2012:214). These paths are then recorded in a raster dataset and converted to polyline features.

The friction surface is an integral component of least cost path analysis (Mitchell 2012:225-230). This is the dataset that records the difficulty of moving through a cell inside the study area. The friction surface is derived from a series of inputs that represent the different types of movement cost variables that are being calculated for each cell in the study area. These inputs are then reclassified based on criteria set by the researcher and summed together, again for each unique cell. Movement costs can be determined from physiological, environmental, or cultural variables (Surface-Evans and White 2012:4). Finding the right balance of these three types of inputs is necessary to avoid over-emphasizing a particular type of knowledge.

The math behind cost distance calculations is conceptually straightforward. The distance between cell centers is measured. Cells that are not on a direct vertical, horizontal, or diagonal line from the origin cell are measured in a stair step pattern (Mitchell 2012:219). The GIS then calculates the average movement cost between adjacent cells and this value is multiplied by the geographic distance between the cell's centers. This number is multiplied by any specified weighting factors, which would be used to make specific cells more or less difficult to travel through (Mitchell 2012:230). For calculating vertical and horizontal movement, it is assumed that movement is split equally between both the cell in question and its neighbour being analysed. The horizontal or vertical factors for each cell are multiplied, added together, and then divided by two (Figure 5.0). If no horizontal or vertical factors are specified, a value of one is used (Mitchell 2012:248). This new cost distance between the two cells is added to the cumulative value of costs to reach that location from the origin cell as previously assigned by the cost distance algorithm (Mitchell 2012:249). If a new path should be calculated later in the cost distance analysis to reach the same cell, which is less costly, the old value is replaced by this new more efficient one. The process is repeated moving outward from the origin cell in all directions (Mitchell 2012:250).

Figure 5.0 Least Cost Distance Formula

$$\text{"}Cost\ Distance = Distance * ((From\_Cost * From\_Horzontal\_Factor) + (To\_Cost * To\_Horizontal\_Factor) / 2) * Vertical\ Factor\text{"}$$

As is demonstrated by case studies compiled by White and Surface-Evans (2012), least cost analysis has been very successfully applied to answering many different questions about the movement of past peoples in terrestrial contexts. Simple studies incorporating topography have been done looking at resource procurement in Palaeolithic and Paleoamerican contexts, demonstrating at a fundamental level the applicability of this technique to archaeological questions (Rademaker *et al*. 2012; Rissetto 2012). More complex models looking at multi-criteria analysis have been created by Nolan and Cook (2012), who looked at the interaction of ecology and social evolution in the Middle Ohio River Valley during the Late Prehistoric. While inputs for cost analysis are frequently environmental in nature, several archaeologists have successfully done more advanced studies which incorporated cultural knowledge into their analysis (Hudson 2012; Richards-Rissetto 2012; Ullah and Bergin 2012). An especially notable application of this technique is the work of White and Barber (2012), who developed the From Everywhere To Everywhere method to look at the movement of Maya between polities in Columbian Oaxaca, Mexico. Their study does not assume that the travelers had a predefined destination point in mind at the onset of their travel and as such is very relevant to conversations about initial peopling events where a similar lack of landscape knowledge existed. Anderson and Gilliam (2000), whose work was discussed at length in Chapter 3, have shown that least cost analysis is a methodology that can be applied to modeling the movement of Paleoamerican peoples and provide a strong foundation for the work of this thesis (Anderson and Gilliam 2000).

Despite the temporal, chronological, geographical, and thematic variation in previous archaeological applications of least cost analysis, these studies all share one common factor. This commonality is that all of this research examines movement events over terrestrial landscapes. No one has yet attempted to apply this methodology to open water maritime movement. Some tangential work has been done that factored in travel along rivers by Patrick Livingood (2012), who looked at movement along the Mississippi River by Southern Appalachian Mound cultures in relation to the extent of polities. However, his research just looked at energetic expenditure for paddling up or down a river. Additionally water bodies have been used as barriers to overland movement in some least cost path analyses (Surface-Evans 2012:136; Livingood 2012:178). As such my work is the first to apply least cost analysis to open water movement. This is an important distinction, as different considerations of movement cost must be considered for this type of landscape. At its most basic level, least cost analysis is based on the features of a landscape that fall within a given cell (Wheatley and Gillings 2012:142). To take these attributes of the real world and make them understandable to a computer program, this information needs to be translated into the digital world of 1s and 0s. The details of how this is accomplished in combination with the inherent characteristics of the data have significant ramifications on the analysis process.

5.5 Geospatial Data

Geospatial data is either vector (data represented by points, lines, and polygons) or raster (data values recorded in cells) in which each object or cell is located in space using either a projected or geographical coordinate system. Information recorded in this way can be used as the impetus to drive spatially aware analysis (Longley *et al*. 2006:65; Wheatley and Gillings 2012:28). It is now common practice in disciplines that make use of geographic information to digitally record data using coordinate systems that allow features within a dataset to be analyzed internally in relationship to each other and externally to other features on the earth's surface (Connolly and James 2006:16-24). The Internet has facilitated easy access to this GIS data and the sharing of information between various entities is rapidly becoming more common in academia and government (Wheatley and Gillings 2012:218). Data for this project was supplied by a variety of government and academic organizations. As my study area falls across the international border between Canada and the United States of America, it also was necessary to coordinate with institutions in both of these countries. The most important data inputs in this project were elevation and bathymetric data which were used to create digital elevation models (DEMs) of LPEH landscapes (Table 5.0)[10].

[10] "Bathymetry is the study of the 'beds' or floors of water bodies, including the ocean, rivers, streams, and lakes" (National Ocean Service 2015). It can be treated as submarine topography and refers to the shape and depth of underwater terrain. This data represents the landforms that lie under the surface of water bodies and is the backbone of hydrography (National Ocean Service 2015).

Data was collected whenever possible as points containing latitude, longitude, and elevation information. However, some agencies were only able to provide their data as rasters and elevation points had to be extracted from these files by placing a point storing the elevation data at the center of each cell. Elevation data for British Columbia was provided by the Terrain Resource Information Management Program II (TRIM). Elevation data for the terrestrial portions of South East Alaska was obtained from the U.S. Geological Survey's National Elevation Dataset (NED). While both of these datasets are relatively coarse in resolution, they represent the highest quality data that is publically available for the entirety of my study area (Data Maintenance Unit 1997; U.S. Geological Survey 2015). For the Prince Rupert Harbour, high resolution LiDAR data was available through the Prince Rupert Harbour Archaeological Project (PRHAP)[11]. Informal ground truthing activities, which I participated in during the summer of 2014 with PRHAP, demonstrated that this data is of very high quality and as such provided me with a very accurate understanding of this area's topography.

[11] LiDAR data for the Prince Rupert Harbour area was graciously provided by NEXEN to the PRHAP for the purpose of furthering anthropological research in this area.

Table 5.0 Project Data Sources

Dataset	Source	Resolution / Scale	Citation
Canadian Elevation	DataBC Terrain Resource Management Program	1:20,000	Province of British Columbia 1997
Canadian Bathymetry	CHS Hydrography Data Center	Varies by Survey	Canadian Hydrographic Service 2014
Alaskan Elevation	USGS National Elevation Dataset	2 Arc-Second	U.S. Geologic Survey 2014
Alaskan Bathymetry	NOAA National Geophysical Data Center	Varies by Survey	National Ocean and Atmospheric Agency 2014
Alaska Hydrography	Alaska Department of Natural Resources	1:63,360	Alaska Department of Natural Resource 2007
Canadian Hydrography	Natural Resources Canada – CanVec+	1:20,000	Natural Resources Canada 2013
Prince Rupert Harbor LiDAR	Prince Rupert Harbour Archaeology Project	1 m	Prince Rupert Harbour Archaeology Project 2014

Bathymetric data for Canadian waters was obtained from the Canadian Hydrographic Service (CHS), who provided me access to parts of a new data product that they are in the process of developing, which is a compilation of all their data from single beam and multibeam sonar systems. Bathymetric data for Southeast Alaska was obtained from the National Ocean and Atmospheric Agency (NOAA) in the form of digital sounding survey point data. Both of these datasets were compiled from hundreds of surveys spanning the history of the CHS and NOAA and the resolution of this data varies considerably. All of the bathymetric data products used here contain gaps where NOAA and the CHS ships have not yet been able to map the ocean floor and there is no way to compensate for this deficit until more complete surveys are undertaken. At this time this information represents the best data that is publically available for the coastal waterways of the Northwest Coast (David Rodziewicz, personal communication 2014; Tony Dill, personal communication 2014).

Vector watercourse data also had to be prepared for use in this project. This process consisted of filtering these datasets, which recorded all hydrographic features in British Columbia and Alaska, to just river, stream, and lake data and merging these features into one file (Alaska Department of Natural Resources 2007; Canada Centre for Mapping and Earth Observation 2014). The data was sorted in this way because the dataset included many modern manmade features that would not have been present in pre-contact times. It is important to note that lakes less than 20 acres are not included in this data and no additional public information is available to fill this gap at this time (Canada Centre for Mapping and Earth Observation 2014).

Watercourse data does not exist for landscapes that are currently inundated by ocean waters. This necessitated the use of digital elevation surfaces to predict the location of water sources for parts of Haida Gwaii and the Alexander Archipelago (ESRI 2015a). The first step of this process was to create depressionless DEMs of the study areas. This is a DEM free of Sinks, which are cells with invalid flow directions. Flow direction is the direction that a drop of water that is spilled on to the center a cell will run out of that cell (ESRI 2015a). Sinks are places where the flow input cell is higher in elevation than the processing cell or pairs of cells that pour into each other. As flow direction computation assumes that water will always run downhill, sinks represent logical impossibilities that will create erroneous results if not corrected. These locations are identified using a process that determines the cardinal direction water will run off of a given input cell. This is calculated by dividing the change in elevation between two cells by the distance between them and then multiplying this value by 100 (ESRI 2015a). The watershed for each sink is then derived using flow direction and the sink locations as pour points. Pour points are the places where water exits a watershed. These hydrological boundaries are then passed through tools that determine the minimum elevation in each watershed (ESRI 2015a). The lowest elevation along the boundary of each watershed is determined to create a dataset displaying the elevation at which water will overflow the basin after filling it to the rim. The product of this process is a dataset that identifies the maximum depth of sinks in a raster. This information is then used to set an elevation difference limit that removes sinks from the DEM. Flow accumulation or the number of upslope cells that feed into a given cell is then calculated and this data is then the threshold used to identify stream networks (ESRI 2015a). This analysis produces results recorded in the raster format and the last step is to convert these findings to polylines.

I ran a series of iterations using different thresholding values for both the Alexander Archipelago and Haida Gwaii. I then took the results of each of these tests and compared them to the water features recorded in the existing data for both of these locations. This comparison revealed that a value of 7,000 input cells should be used as the threshold to determine stream locations in Haida Gwaii and a value of 20,000 cells for the Alexander Archipelago (Table 5.1). These cut-off values were chosen because they correctly identified known major water bodies and minimized creating erroneous stream locations. This form of stream location modeling is a technique that tends to overestimate the number of water sources in a landscape and as such I took a conservative approach when selecting my threshold values to minimize creating erroneous low movement costs.

Table 5.1 Hydrology Modeling Threshold Values

Subarea	**Number of Contributing Cells**
Alexander Archipelago	7,000
Haida Gwaii	20,000

The data used in this project was provided at a variety of resolutions and accuracies that had to be combined in order to produce usable products for this analysis. Due to the varied nature of the sources for this data the analyses performed have a lower than ideal level of internal accuracy. However, the input data represents the highest quality products that are currently available and is more than sufficient for testing my methodology and predicting Paleoamerican movement routes. Once data is ready for analysis it can then be passed through the many steps for determining least cost paths.

5.6 Elevation Surfaces

Due to the frequent and dramatic sea level change that has affected the Northwest Coast over the last 16,000 radiocarbon years, it was necessary to calculate elevation surfaces that reflect the landscape's topography at different times (Shugar *et al.* 2014:1). Elevation surface creation for different time periods was accomplished by gathering topographic and bathymetric point data for each study area and merging these datasets into one big point cloud in order to interpolate surfaces. These point clouds represent the topography of the landscape as it would exist if completely drained of water. For each subarea, elevation point data was collected and projected into a geographic coordinate system[12]. This data was then clipped to the extent of the subarea to remove extraneous points. All of these datasets were then merged into one feature class and data points with elevations equal to or less than -150 m were deleted. These points were dumped from the data because sea levels within my study area never dropped below this elevation (Shugar *et al.* 2014:13-14).

The point elevation data was then run through an Inverse Distance Weighted (IDW) interpolation algorithm in ArcGIS Pro 1.0.1 to create an elevation surface for each subarea (ESRI 2015c). IDW is a technique that determines cell values for areas between input points by using a linearly weighted combination of sample input points that represent the locations of discrete variables. In this case, the variable being used for the interpolation was elevation. IDW assumes that a variable decreases with distance and is calculated by raising the inverse of a distance to the *n* power where *n* is set by the analyst. The higher the power the more influence nearby points will have in determining a cell's value. IDW was used instead of other interpolation methods such as Spline or Kriging because previous work in recreating drowned landscape in Southeast Alaska has demonstrated that IDW produces near identical results and is computationally less intense (Monteleone 2013:111)

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[3]All data used in this analysis was projected into the WGS84_Universal_Mercator (EPSG:32633**)** coordinate system. This coordinate system was used because my study area straddles two UTM zones (8N and 9N) and this system allows for the easy comparison of data amongst all the areas I looked at.

In my analysis a variable radius of 12 was used, meaning that each cell's value was determined based on the values of the 12 nearest points (ESRI 2015c). No barriers were designated and a search power of 2 was used. Barriers are features that limit the extent of the interpolation process within the dataset and represent real world features that cause extreme changes in elevation, such as a cliff faces or large bodies of water.

Surfaces were only calculated at the 30 m cell size for all study areas, except Prince Rupert Harbour where datasets at the 5 m and 10 m size were also calculated. The production of these additional surfaces was possible due to the presence of high quality LiDAR DEMs and the small size of this study area. These more accurate datasets allow for comparison of how different spatial resolutions affect project results. These drained landscapes were processed to account for the sea level that would have been present at each chronological period. In this process, the contents of all cells with a value greater than the sea level are copied and cells that would have been underwater are reassigned a new value of zero (Table 3). This creates a DEM showing the LPEH landscape. At this point the topographic data is ready for use in the analysis.

5.6.1 Non-Topographic Data Preparation

An analysis extent was set for each study area by selecting a center point for the analysis based on the location of known old sites, and then buffering this to include as much of the contemporary landmasses within the study area as possible. These buffers were capped at a 100,000 m radius for Haida Gwaii and the Alexander Archipelago. Some prehistoric landmasses fall outside analysis areas because it was methodologically necessary to delineate subarea boundaries prior to creating DEMs of paleolandscapes that would show exactly what the past landmasses would have looked like. Only contemporary landscape features could be used to set extents for constricting distance calculations and determining the location of origin and destination points for movement events.

Origin and destination points were placed at 20° intervals along each study area perimeter, resulting in 18 unique points for each subarea. These points were occasionally manually adjusted to by a few metres towards the study area's interior in order to accommodate their use with data in different formats. This modification had negligible impact on the results and was caused by using both raster and vector data in the same analysis. The square shape of raster cells and their cardinal orientation means that the perimeter of a raster dataset can never be perfectly circular (ESRI 2014b). Raster data approximates curves by using a stair step orientation and sometimes origin points fell along the circular smoothed vector perimeter of study area extents outside the raster's coverage between cells. The same locations were used as both origin and destination points so as to allow for travel in any direction across the landscape to be modeled (Anthony 1990:989; Mitchell 2012:217).

The landmass for each study area through time was calculated by iterating through lists containing the sea level height values in relation to modern levels for each chronological window (Table 5.2)[13]. Each time the model was run, a new value representing a new time period was selected from the list and used to determine which cells in the IDW surfaces were equal to or greater to these values. Cells with values that were identified as meeting this criterion were preserved and all other areas were reset to 0 m (sea level). This created new DEMs representing the landscape for each time period. Contour lines were then created for these landscapes and the lines equal to the sea level height representing the shoreline were selected and converted to polygons to delineate the landmass present for each time period. These polygon features were

[13] All sea levels are reported relative to present mean sea level and were converted to a common datum by Shugar *et al.* (2014:2).

clipped by the study area extent because it is possible for features to extend beyond the study area perimeter.

Table 5.2 Sea Levels by Time Period and Study Area

Area	Sea Level 10,000 cal. yr BP	Sea Level 13,000 cal. yr BP	Sea Level 16,000 cal. yr BP
Prince Rupert Harbour	+3 m	+20 m	+50 m
Stephens Island	+9 m	+12 m	+14 m
Dundas Archipelago	+9 m	+12 m	+14 m
Haida Gwaii	+15 m	-140 m	-150 m
Alexander Archipelago	+10 m	-125 m	-150 m

5.6.2 Friction Surface Creation and Weighting

Movement costs for each cell in a study area were calculated from five different variables and then summed together in a series of weighted friction surfaces. This summation allows for the difficulty of moving through each cell to be represented by a single numeric value (Mitchell 2012:229). Summations add the values of cells from different data layers that represent the same geographic area. The creation of different weighting scenarios allows for different movement logics, each of which emphasize different types of factors to be modeled. For example, a scenario that emphasises environmental movement costs might represent the thought process of a group of people that placed great importance on the attributes of the physical world relating to energy expenditure, such as the greater exertion associated with increased slope when deciding where to travel. This can be contrasted against a culturally weighted scenario, which models the actions of people for whom passing by socially important places at the expense of ease of movement was important. The five movement cost variables I considered fell into three general categories: environmental, physiological, and cultural (Surface-Evans and White 2012:4). Environmental movement costs are those associated with the inherent features of the terrain such as topography, hydrology, and vegetation. Cultural movement costs are determined by how specific peoples would experience traveling through a landscape and may include territorial borders, significant locations, and other costs that are socially constructed. Physiological movement costs are determined by the limits of human biology such as the maximum storage and expenditure of caloric energy. My analysis incorporates each of these variables through the inclusion of multiple types of movement cost.

The environmental movement costs considered in my research take three different forms, each of which were identified as being important to site selection on the Northwest Coast by Herbert Maschner in his 1995 study of sites on Kuiu Island in Southeast Alaska. The first landscape characteristic used to determine environmental movement cost was coastline slope (ESRI 2012d). Slope was calculated for every cell and areas with slopes equal to or less than a 2 percent incline were classified as conducive to travel and reclassified with a movement cost of one. All other cells in each study area were assigned a value of two. As defined by ESRI, reclassification is "the process of taking input cell values and replacing them with new output cell values. Reclassification is often used to simplify or change the interpretation of raster data by changing a single value to a new value, or grouping ranges of values into single values" (ESRI 2014c). Beach aspect was also included and areas with an eastward exposure between 1 and 180 degrees were ranked as more desirable stopping points in maritime movement events based on the work of Maschner (1995:179) and Mackie and Sumpter (2005:350) that identified that sites on the Northwest Coast were most likely to face this direction (ESRI 2012c). These areas were given a movement cost of one and all other locations a value of two (Table 5.3).

Table 5.3 Movement Cost Reclassification Criteria

Category	**Variable**	**Movement Cost 1**	**Movement Cost 2**	**Movement Cost 3**
Environmental	Beach Slope	≤ 2%	> 2%	NA
Environmental	Beach Aspect	1° - 180°	181° - 360°	NA
Environmental	Freshwater Proximity	≤ 200 m	> 200 m	NA
Physiological	Travel Distance	≤ 5760 m	> 5760 m	NA
Cultural	Sinuosity (> .5)	≤ 1000 m	1000 m - 2000 m	> 2000 m
Cultural	Visibility[14]	Most Visible	2nd Most Visible	3rd Most Visible
Cultural	Protected Waters	Highly Protected	Medium Protection	Least Protected
Cultural	Inland Waters	181° - 360°	0° - 180°	NA

Proximity to sources of freshwater was also included in calculating environmental movement costs. The Euclidean distance was calculated between each water source in a study area and these values were then reclassified to give cells within 200 m of a water source a value of one and all other areas a value of two (Table 5.3) (Maschner 1995:181).[15]

The physiological cost of moving through each landscape was factored into my analysis by looking at the distance that can be traveled by Umiak skin boats. Currently no artifacts

[14] Break points were determined by Jenk's Method of classification. Break values were not recorded due to the iterative nature of the work flow which overwrote these values each time the model was run. Visibility reclassification never exceeded five classes.
[15] Euclidean distance is the straight line distance as calculated by the Pythagorean Theorem between two points (ESRI 2012b).

associated with LPEH watercraft have been discovered, and it has been suggested that the dugout canoes and other similar boat types reported by early ethnographers probably do not date beyond the Holocene (Ames 2002:26). The Umiak is a very old maritime transportation technology and provides the best analog for the boats that would have been available to Paleoamericans (Ames 2002:26; Montenegro *et al.* 2006:1324; Moss 2008:48). Experimental archaeology using Umiaks to travel from Skokomish, Washington to Dungeness at the eastern end of the Straits of Juan de Fuca has determined that the maximum average distance that could have been traveled by a fully loaded Umiak is 57.6 km/day based on 12 hours of paddling at a of speed of 4.5 km/hour (Ames 2002:30-31). In my analysis using the 57.6 km travel distance gave every cell in the smaller study areas the same value. So instead I used 10% of this value, or 5,760 m, as my reclassification threshold because tests using different values for Prince Rupert Harbour demonstrated this value created the most diverse results. I believe that this diversity translates into more accurate results because it provides a broader spectrum of area accessibility values.

In order to incorporate movement costs into the analysis, the Euclidean distance from each origin point was calculated and then reclassified based on this travel distance threshold. These eighteen different values were summed together for each cell into one dataset. These new cell values were again reclassified using equal intervals so that areas with the most overlap had the lowest movement cost and areas with less amounts of overlap became more expensive to move through. This has the result of giving a movement cost of one to areas accessible from the highest number of origin sites and progressively higher movement costs to areas that could be reached from correspondingly fewer origin points (Table 5.3). Hence areas that would have been more easily accessible are preferred through low movement cost values in the friction surface. The range of reclassification values changed depending on the size of the study area with Prince

Rupert harbour having a greater amount of accessibility between origin points and the larger study areas having less overlap.

Cultural variables were more difficult to incorporate into the analysis given the general lack of knowledge about Paleoamerican culture. However I was able to identify four different factors suitable for the creation of a nearshore travel corridor that reflects the culturally based movement decisions of early mariners. The first of these factors was the location of waters that are on the inland side of islands, peninsulas, and other landmasses. These waters are subject to weaker wave action than the open ocean and are subsequently easier to travel through, as demonstrated by the work of Madonna Moss on voyaging through the Hecate Strait (2008:39). As all the areas in my study are on the West Coast of North America, the eastern side of features would most frequently be the protected side of landmasses and these areas are identified and incorporated into friction surface creation as discussed in the following paragraph.

Euclidean distance and direction measurements calculated from the shoreline were combined to identify protected waters (Table 5.3). These distance calculations were reclassified into three classes using the Jenks Natural Breaks method because this simplifies reclassification and summation operations later in the analysis (ESRI 2014a). The Jenks method is useful here because it breaks the data up based on statistical trends in the data itself instead of using arbitrary values by finding naturally occurring clusters in the data (Jenks 1967:186-190). The direction data was reclassified to assign cells to the east of the landmasses, those between 0 and 180 degrees, a value of one and all other cells a value of two. These two sets of data were then summed together and reclassified so that cells on the eastern side of landmasses got progressively higher movement cost values as they moved further from the coastline (Table 5.3).

The second input into the Near Shore Corridor was the location of straits and passages. These are locations where ocean currents are less severe and Northwest Coast sites are prevalent, as demonstrated by the Prince Rupert Harbour which contains 271 recorded sites within an area of 180 km^2 (Ames and Martindale 2014:142). Identification of these areas was accomplished by calculating the Euclidian distance from landmasses and then reclassifying these values to identify areas within 2,000 m of the shore. Identified areas were assigned a value of one while all other locations got a value of two (Table 5.3). The 2,000 m reclassification value was used because I was not able to identify a universally agreed upon geographic measure that defined the size of a strait. I took measurements of straits and passages in my study areas and determined that none was wider than 4,000 m. The Euclidean distance tool in ArcGIS counts out radially from the perimeter of an input feature until it encounters the boundary of the analysis extent or cells that have already been assigned a distance measurement (ESRI 2012b). As such any cell more than 2,000 m from the shoreline cannot be located in a passage or strait. This is not an ideal method for identifying these waters; however the topological logic necessary to form better identifications are beyond the capacity of all the off-the-shelf GIS software that was used in my analysis.

Another input variable that was included in the Near Shore Corridor was coastline sinuosity. Sinuosity is the measure of the cragginess of the coast and represents the amount of coastline available from a location. Areas with greater sinuosity provide greater access to intertidal and subtidal resources with greater biodiversity and increased habitation suitability (Mackie and Sumpter 2005:350-351; Monteleone 2013:15). Mackie and Sumpter (2005) demonstrated with geospatial modeling that Early Holocene sites were more prevalent on complex shorelines and their work establishes a precedent for the use of sinuosity in site prospection modeling. To calculate sinuosity I used a variation of Kelly Monteleone's (2013:125) technique. In my approach landmass polygons were converted to line features and points were placed at 1 km intervals on these lines. The points were used to cut the lines into smaller segments (1 km in length) that were then passed through a script that calculated the deviation of the line segment from the shortest line between its end points (Monteleone 2013:127; TeamPython 2011). This variation was expressed as an index value between 1 and 0, where a straight line between endpoints is equal to 1. Shoreline segments were selected that had sinuosity index values greater than .5 and the Euclidean distance from each of these segments was calculated. This distance was reclassified into three classes where waters within one km of highly sinuous shores were assigned a new value of one, those between one km and two km a value of two, and those further than two km a value of three (Table 5.3).

The visibility of the shoreline from the ocean was also determined. Based on preliminary viewshed analysis I ran for the Dundas Islands and Prince Rupert Harbour, I determined that it is highly unlikely that the shoreline would be visible at distances in excess of five km from the shore. Mountains and other larger geographical features would be visible from distances much further out to sea, but these types of landform are not relevant in visually determining the qualities of beach for landing a boat. Landmasses were buffered at one km intervals to a distance of five km and points were placed along these lines at five km intervals. These locations were used as observation points to determine viewsheds for a person sitting in a boat. When computing viewshed, observation point height normally is adjusted to represent the eye level of an average size individual. However, this type of modification does not affect the computation of results from 30 m cells and was not implemented (Wheatley and Gillings 2012:183). The results of the viewshed analysis were cumulative identifying how many observation points could view a given cell. These values were reclassified to assign low movement cost values to more visible cells and higher movement cost values to cells with lower visibility (Table 5.3).

All of the reclassified results for the four different near shore corridor inputs were summed together. This dataset was then reclassified to assign the lowest value in the summed raster a new value of one with each progressively higher input value getting an incrementally high reclassification value. The reclassification increment interval was set to one. All of the reclassified cultural movement cost layers where then summed together to identify near shore movement corridors representing areas with the lowest cost of travel.

All of the output layers representing the final movement costs for each type of variable were then combined together using a weighted overlay. This is a process by which the input cell values from each movement cost layer are multiplied by a weighting factor and summed together (ESRI 2011). For my analysis, four different weighting criteria scenarios were used, which emphasised the unweighted, cultural, environmental, and physiological costs of moving through a landscape. These weighting scenarios are displayed in Table 5.4. The specific values used in each weighting scenario were created by me and at this stage are fairly arbitrary given the lack of concrete knowledge about Paleoamerican movement patterns. Weightings were assigned by giving half of the total weight of a category to the inputs associated with the variable being emphasised and then splitting the other half between the remaining inputs. However, the use of different scenarios has the effect of allowing for the examination of how different ways of thinking might affect the paths that Paleoamerican mariners might have taken in their travels. As more research is done into initial New World peopling events, weighting values can be refined, perhaps with the help of regression analysis.

Table 5.4 Weighting Scenario Values

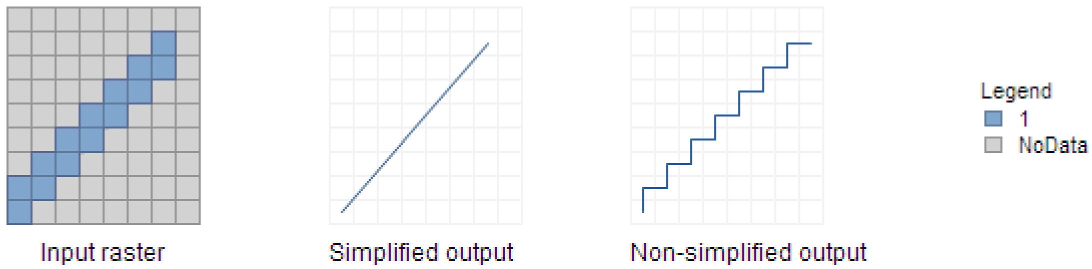
Variable	Physiological Scenario	Cultural Scenario	Environmental Scenario	Unweighted Scenario
Beach Slope	.125	.125	.25	.2
Beach Aspect	.125	.125	.25	.2
Freshwater Proximity	.125	.125	.25	.2
Maximum Distance	.5	.25	.125	.2
Near Shore Corridor	.125	.5	.125	.2

The methodology described above allows for travel through terrestrial areas. I decided to not completely disallow overland movement because voyagers frequently portage their boats in order to navigate impassable marine obstacles (Moss 2008:38). In my initial tests of the methodology for Prince Rupert Harbour, overland travel was minimized in comparison to routes crossing marine areas. However, once I applied this technique to all my study areas and began analysing the results, I decided it would be worthwhile to run an analysis that made terrestrial travel extremely difficult. I noticed that for the other study areas, paths with a much higher degree of overland travel were generated which is not helpful in looking at boat-based journeys. To address this problem, I created new friction surfaces for Prince Rupert Harbour, the Dundas Islands, and Stephens Island in which I identified the landmass at each time period and added 1000 to their movement cost values while leaving the marine cell values untouched. This manipulation had the effect of making it 100 times more costly to move through terrestrial landscapes, mostly constricting routes to marine areas. Due to the position of origin points located on landmasses and the manner in which least cost analysis works, in some cases overland travel still exists; however, it is greatly minimized. I used the three smallest study areas because they don't become dominated by drained landscapes in the deep past and were the easiest to compute new results for. All other aspects of these analyses such as weighting scenarios, time periods, origin points, etc. remained the same as described for the analyses allowing overland movement.

5.6.3 Least Cost Paths

Once the friction surfaces were derived they were then used to determine the cost distance from each origin point in a study area to every other cell (ESRI 2015b; Mitchell:219). This process also produced backlink information that records the route of the path of least resistance from each cell to the origin point (ESRI 2012c). Both the backlink and cost distance information was used to calculate the least cost path from a given origin point to all the other origin/destination points in the study area. The backlink information specifies the path of least resistance between locations. The cost distance layer records the cost value for each cell and the backlink data records the exact route of the path. These paths are recorded as a raster dataset in which cell value records the number of paths that travel through a cell. Hence if the paths to five different destination point's travel through a cell it is assigned a value of 5. If no paths travel through a cell, which is the majority of cells in the cost path layer, the cell is assigned a value of Null. The next analysis step is to convert the raster results to unsimplified polylines (Figure 5.1). These line features represent the least cost paths for that modeling scenario and are at this point ready for visual analysis as discussed in the next chapter.

Figure 5.1. Raster to Polyline (ESRI 2015f)



5.7 Methodology Summary

GIS has drastically changed the way we look at movement in the deep past. The creation of predictive modeling, site prospection, and least cost analysis techniques emerged as powerful tools for looking at past human behaviour, as has been demonstrated by projects all over the world. It is in this body of work that I situate the methodology that I have created. The calculation of least cost paths through Northwest Coast marine environments can be simplified to three primary steps. The first of these is the acquisition and collection of topographic, bathymetric, and hydrographic data from various agencies which is then prepared for analysis by converting layers to a common coordinate system, simplifying rasters to point data, merging datasets, and removing unnecessary information. The second stage involves processing data to provide the inputs for determining movement costs, which when summed form friction surfaces used to derive four different movement cost scenarios. Finally, least cost paths were created for each of these scenarios for three different time periods in each study area and used to produce line density maps. This methodology provides a new approach to determining the paths that humans may have taken through landscapes incorporating large bodies of water and is driven by a variety of different inputs that allow for various different ways of thinking about movement and landscape to be modeled.

Chapter 6: Analysis Results

6.0 Comparing Results

My analysis of least cost paths through the Northwest Coast during the LPEH resulted in the generation of 1,824 individual paths. Deriving and analyzing this data was a multistep process, which began by determining the appropriate data resolution for calculating model routes. This analysis was accomplished by comparing least cost paths created at three different spatial resolutions for Prince Rupert Harbour. Once an appropriate analysis resolution had been selected, the next step was to calculate and compare the paths produced from modeling scenarios that permitted both overland and maritime travel. The results of these analyses were merged into datasets showing all the paths for each movement cost-weighting scenario in each study area at each time period. For example, the 18 individual paths generated from running the cultural weighting scenario model for Haida Gwaii at 13,000 cal. yr BP were gathered into one dataset and viewed as a group. This manipulation of the data allowed for the comparison of path clustering pattern, average orientation, coastline proximity, and amount of overland travel. Looking at these attributes of the paths created a large-scale perspective that shows spatiotemporal patterns and trends of possible migration events. The next step in the analysis process was to perform the same calculations and assessments for paths created from modeling scenarios that made overland travel prohibitively expensive. Lastly by looking at the density of paths areas with the highest likelihood of containing new site from the LPEH were identified. This chapter is loosely arranged into four sections, each corresponding to one of these tasks, and capped off by a summary section integrating the results from all the analyses together.

The first quality of the least cost paths that I looked at was route location patterns. I observed whether paths pass along the perimeter of the study area or primarily through interior areas. Additionally I noted any hotspots showing a particular nexus of activity within these larger patterns. The patterns I observed fell into several categories. Grid-like patterns are characterized by linear paths positioned at right angles and can be clustered in a geographic quadrant or interior area. Additionally gird patterns can mirror the boundary of the study area in a parallel to perimeter pattern. Dispersed path layouts are those where routes are equally distributed through the study area without clustering. The overall cardinal direction of each set of paths was established by passing merged results through the ArcGIS Desktop Linear Directional Mean tool. This script identified the mean direction, length, and geographic center for each set of lines (ESRI 2015e). For the analyses that were not constricted to movement through marine landscapes, the degree to which a path moves over terrestrial areas was also established by visual comparison of the routes created from different weighting scenarios. Another measure used to compare weighting scenarios was how closely routes follow the coastline. I chose to look at these attributes of the paths because they are factors that allow me to gauge which paths would be best suited to site prospection and which ones most closely represent what maritime migration events would have looked like. I believe that early mariners would have traveled close to the coastline, along a north-south axis, and would have minimized their overland travel especially given the difficulty of portaging a skin boat (Table 6.0).

Table 6.0 Analysis Criteria

Attribute	Real World Phenomena	Type of Measurement
Coastline Proximity	Distance of traveler from landmass	Most commonly occurring weighting scenarios
Amount of Overland Travel	Amount of distance portaged vs. rowed	Most commonly occurring weighting scenarios
Clustering Pattern	Areas with higher human activity	Clustered or dispersed with notation of hotspots
Directional Mean	Average direction of travel	Average cardinal direction of path segments

6.1 Input Data Spatial Resolution Comparison

Analysis of Prince Rupert Harbour was conducted at three different spatial resolutions using 5 m, 10 m, and 30 m cells all interpolated from the same original elevation point data. There are distinct and significant differences between these datasets. The aim of running the same analysis at multiple resolutions was to determine where the appropriate balance between computational requirements and result accuracy lies. I wanted to keep this methodology within the capability of a modern desktop PC and did not consider supercomputing options (for computer specifications used in my analysis, please see Appendix G).

In reviewing the data from Price Rupert Harbour from all four weighting scenarios at the 16,000 cal. yr BP time period, it is apparent that there is a significant difference between the paths created at different resolutions. The 5 m and 10 m data are significantly different as the 10 m data avoids passing through the center of the study area and closely follows the coastline. These paths are geographically spread out showing a more dispersed pattern. In contrast, the 5 m data has large tightly clustered open water segments that cut through the middle of the Harbour frequently running through the same locations. In comparison to both of these datasets the 30 m data shows characteristics that are more similar to results produced from the 5 m data than the 10 m data (Figure 6.0)[16].

The data from 13,000 cal. yr BP shows many of the same trends as the data from the earlier chronological period. Here the 5 m data is more similar to the 30 m data than it is to the data calculated at the 10 m resolution. The 5 m paths and 30 m paths cross through the middle of the study area whereas the 10 m paths move around the periphery of the Harbour. Additionally, the 10 m data has a larger amount of overland travel. Perhaps most importantly, the 10 m data does not spend as much time following the coastline as the 5 m and 30 m paths do. There is also a great deal of physical overlap between the 5 m and 30 m paths. In areas where the routes do not overlap, the 30 m paths are located in closer proximity to the 5 m paths than to the 10 m paths. In conclusion, in my opinion for this chronological window, the 5 m data is most accurate followed by the 30 m data and then the 10 m data (Figure 6.1).

The sea levels in Prince Rupert fell quite drastically between 13,000 and 10,000 cal. yr BP and the paths generated for this time period are substantially different from those for the earlier landscapes. Despite this drastic change, the previously observed overarching patterns are also true for these least cost paths. During this time period each dataset is more uniquely different from what has been previously observed: the datasets do not match up well in terms of the areas that they cover. The 5 m data is largely characterized by horizontal and vertical paths moving through the landscape in a grid pattern. These paths are very linear without the zigzagging seen in other time periods. The 10 m data is largely constrained to moving over the landmasses and is almost completely devoid of segments that pass through marine areas. These paths are not linear and tend to move in a circular fashion around the edges of the study area in a

[16] The appendixes contain maps showing all of the data generated in this thesis, while individual examples of particular note will be shown in this chapter.

parallel to perimeter pattern. The 30 m paths show characteristics that are a mix of those displayed by the 5 m and 10 m data. These paths are similar to the 5 m paths in that they travel through the middle of the study area and have long marine segments. They also have more of a vertical/horizontal movement trend than the 10 m paths (Figure 6.2). The 30 m paths are similar to the 10 m paths in that they travel closer to the study area perimeter than the 5 m paths.

Figure 6.0 Prince Rupert Harbour Least Cost Paths 16,000 cal. yr BP

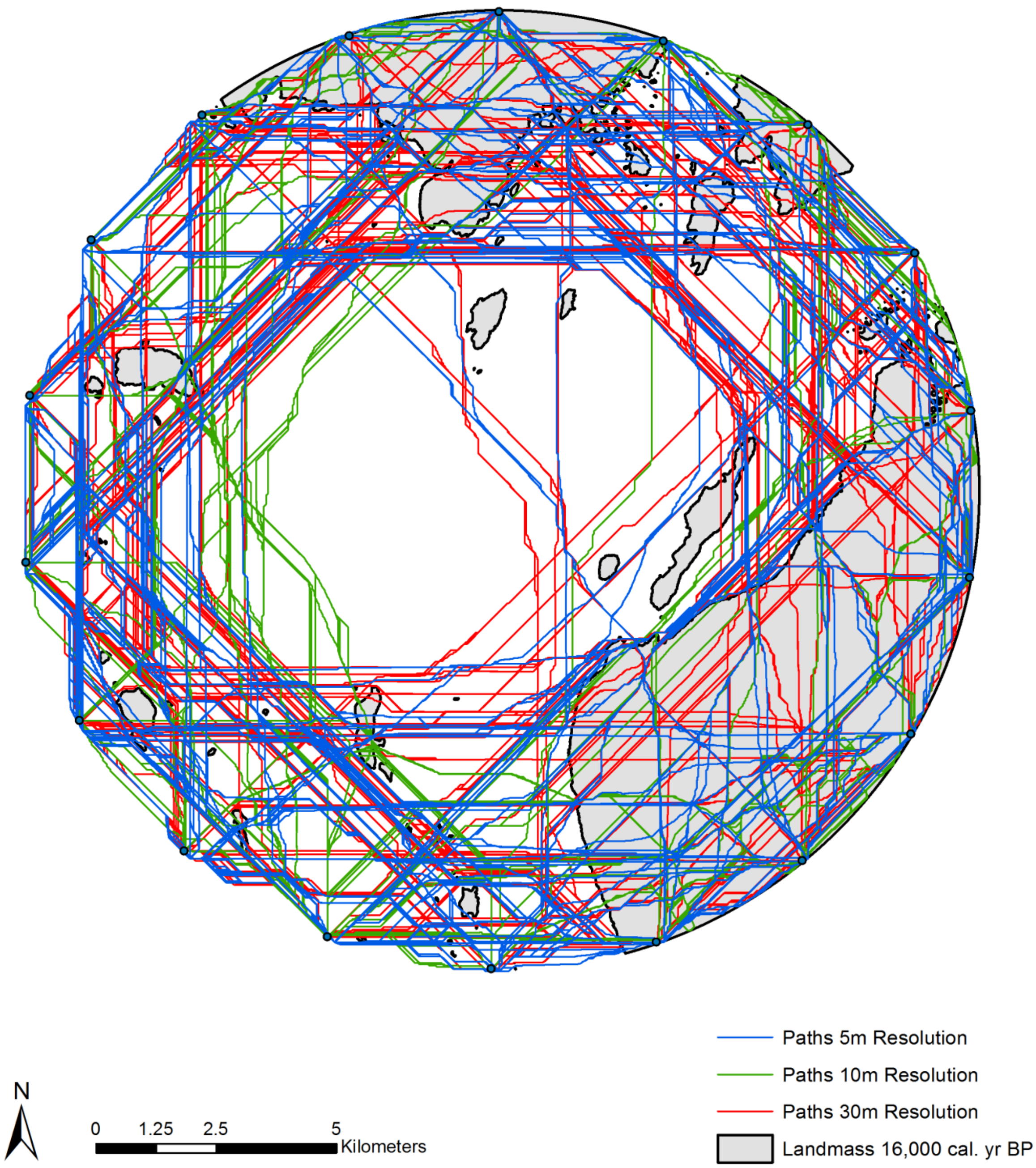


Figure 6.1 Prince Rupert Harbour Least Cost Paths 13,000 cal. yr BP

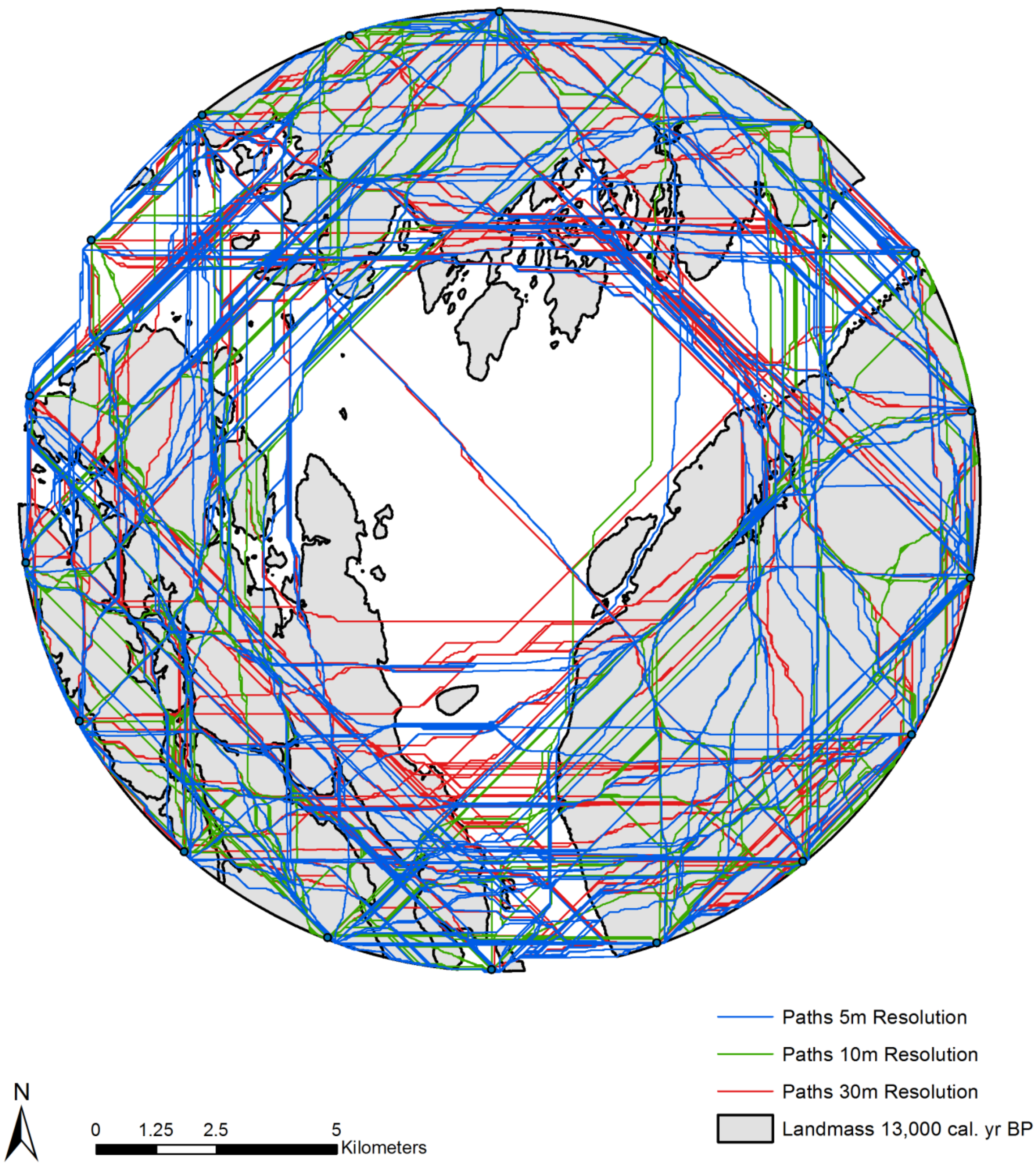
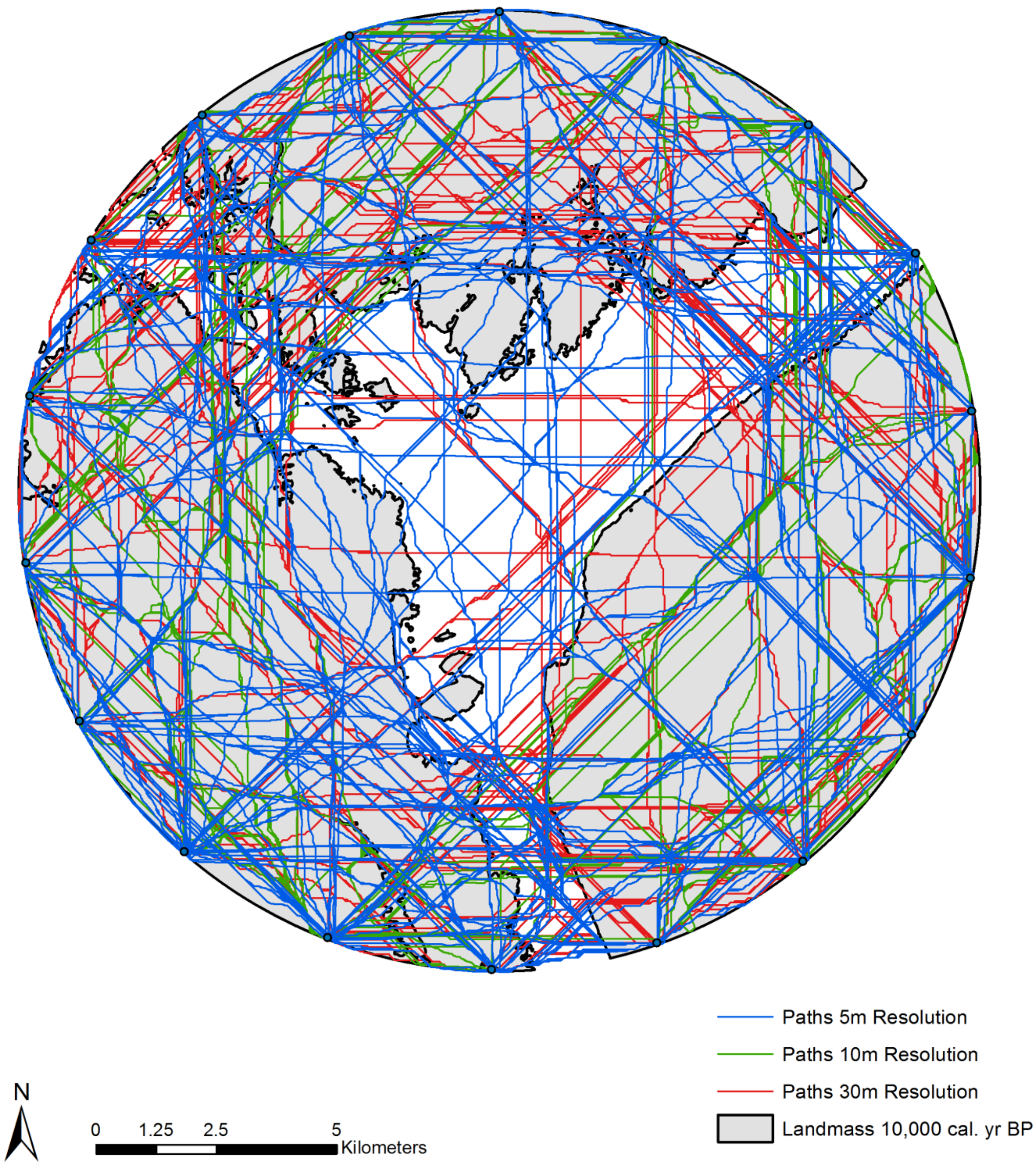


Figure 6.2 Prince Rupert Harbour Least Cost Paths 10,000 cal. yr BP



The calculation of least cost paths at the 30 m resolution, only one small portion of the larger analysis process, was a relatively quick process which could be completed in 45 minutes on a desktop computer. The 10 m resolution analysis took about 3 hours to run and the 5 m resolution analysis took a minimum of 6 hours to complete. These estimates include the time necessary to troubleshoot the inevitable errors that arise when running a complex geospatial workflow. Given the large difference in the amount of time necessary to calculate the paths at the different resolutions and the similarity of the 5 m and 30 m paths, I decided to run my analysis at the 30 m resolution for all remaining study areas. I believe that at this resolution this technique can produce high quality results and still be accessible with the average computer. While I did make use of a significantly upgraded computer to run my analysis for the larger study areas I believe that these analyses could have been run on an average machine and be completed in under a week's worth of processing time (see Appendix G for computer specifications).

6.2 Prince Rupert Harbour

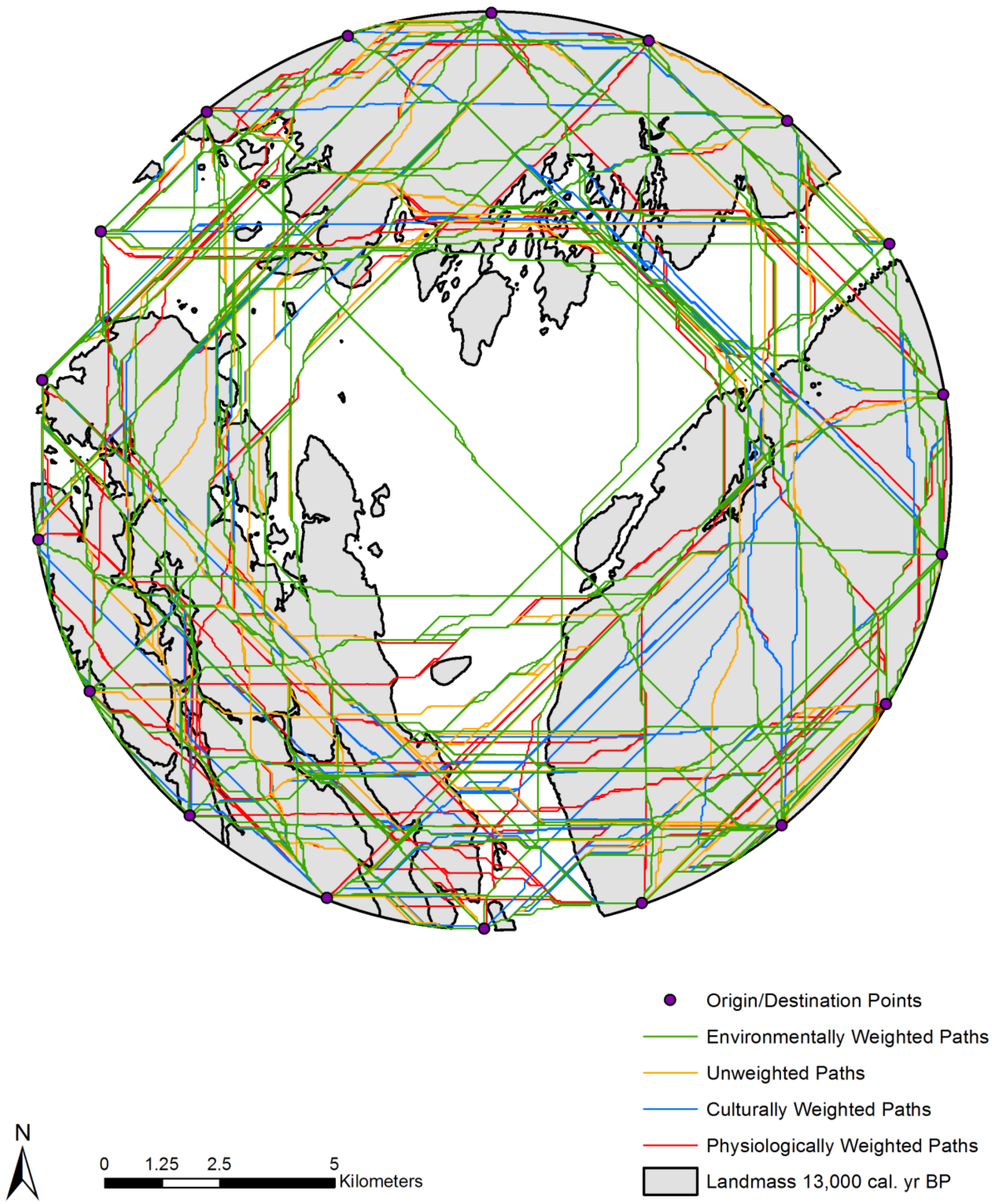
My discussion of the results that were produced from analyzing Prince Rupert Harbour will be limited to the results produced from the 30 m cell size input data to allow for comparison of results from different study areas (Table 6.1). At 10,000 cal. yr BP the physiological, cultural, and unweighted paths cluster around the periphery of the study area and largely travel over the landmasses and not through the interior harbour waters. The environmental paths travel through the middle of the study area and share little overlap with the other paths. In the northern and southern parts of the study area there is a high density of paths, creating areas that are hotspots of activity. The paths that follow the coastline most closely and have the least amount of terrestrial movement are those generated from the culturally and environmentally weighted friction surfaces. Analysis of the directional mean of the different sets of paths reveals that the cultural and physiological paths run east to west while the unweighted and environmental paths have a northwest to southeast orientation.

Table 6.1 Analysis Results Prince Rupert Harbour

Time Period (cal. yr BP)	Greatest Proximity to Coastline	Greatest Amount of Overland Travel	Clustering Pattern	Most Common Mean Direction
10,000	Cultural/ Environmental	Physiological/Cultural	Parallel to Perimeter	Southeast
13,000	Environmental	Cultural/Environmental/ Unweighted	Parallel to Perimeter	East
16,000	Cultural/ Environmental	Unweighted/ Physiological	Parallel to Perimeter	Northeast

The paths generated for the Harbour 3,000 years further back in time show many of the same patterns as those from the 10,000 cal. yr BP period. Here the paths still travel parallel to the study area perimeter but in this case they are not grouped as tightly to this boundary and run closer to the study area centroid. The environmental paths show the most variation moving through the study area's marine sections. Clustering takes place in the southeast and the southwestern portions of the study area. All the paths for this time period show greater tendencies to follow the coastline and to minimize overland travel. The environmental paths are the only ones that show strong patterns of following the coastline. There are significant differences in the directional trends of the paths from this time period. The cultural and unweighted paths travel in a northwestern direction while the environmental and physiological paths travel in a southwestern direction (Figure 6.3).

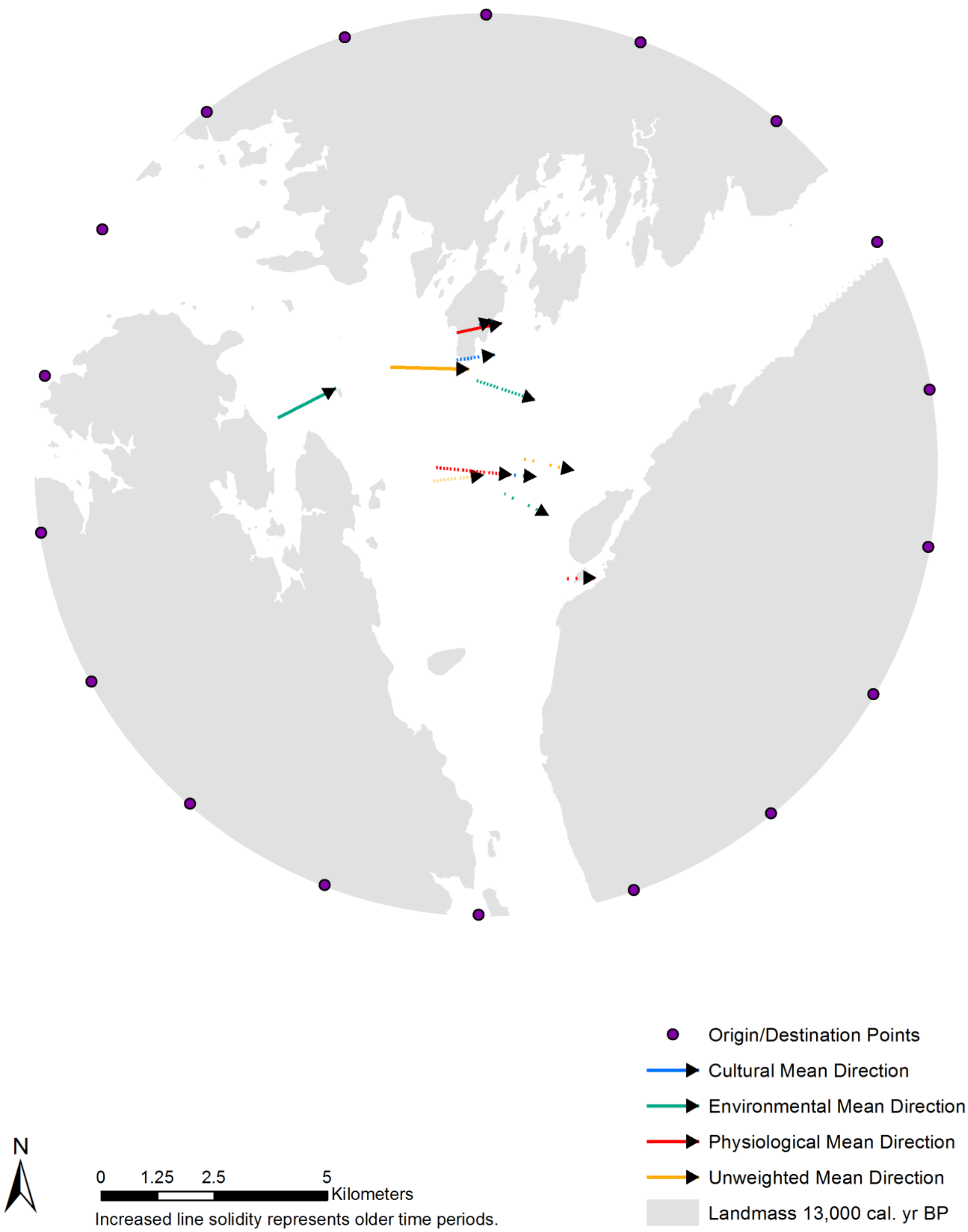
Figure 6.3 Perimeter Clustering Pattern – Prince Rupert Harbour 13,000 cal. yr BP



The paths from 16,000 cal. yr BP show slightly different trends than those from the previous two time periods. These paths minimize their movement through the central marine sections of the study area while increasing their amount of linear travel. Path placement is relatively equally distributed, with the notable exception of the environmental paths which have the greatest amount of movement through marine areas. The cultural and unweighted paths most closely follow the coastline while the physiological and cultural paths have the highest amount of overland travel. The physiological, cultural, and environmental paths all point to the northwest while the unweighted paths are oriented from west to east. The direction of travel for the cultural and physiological paths is nearly identical, which is striking given how different they are in their other attributes.

For Prince Rupert Harbour, the overarching trends are that paths travel from west to east with path direction gradually shifting northward as time progresses (Figure 6.4). Further back in time, paths become less tightly grouped along the study area perimeter and clustering decreases. A clear trend emerges as to which paths best mirror the coastline. Both the cultural and environmental paths performed the best in this regard in 2 out of 3 time periods. The physiologically weighted paths had the highest amount of overland travel in all three time periods followed closely by the unweighted and cultural paths. Overall, paths through this area are highly affected by the placement of origin and destination points along the study area perimeter.

Figure 6.4 Directional Mean Changes through Time – Prince Rupert Harbour 13,000 cal. yr BP



6.2.1 Stephens Island

Geographically Stephens Island is a very different landscape from that of Prince Rupert Harbour. These differences are caused because the Stephens Island study area is composed of a group of islands located on a geological hinge, which has resulted in minimized sea level change through time (McLaren 2008:iv). As a result, this study area exhibits different patterns in the least cost paths that traverse it (Table 6.2). For the conditions existing at 10,000 cal. yr BP, the paths travel through the landscape in a western clustered grid pattern where paths meet at right angles and are characterized by a high amount of linearity. Paths do not parallel the study area perimeter and instead pass freely through the study area interior. The amount of coastal proximity that paths from the different weighting scenarios display is very similar but the cultural and unweighted paths are closer to the shoreline in more locations. This is interesting given the fact that the environmental and the cultural paths are the ones that have the most overland travel across the island. The environmental, physiological, and unweighted paths all travel in an easterly direction while the cultural paths are oriented to the northeast.

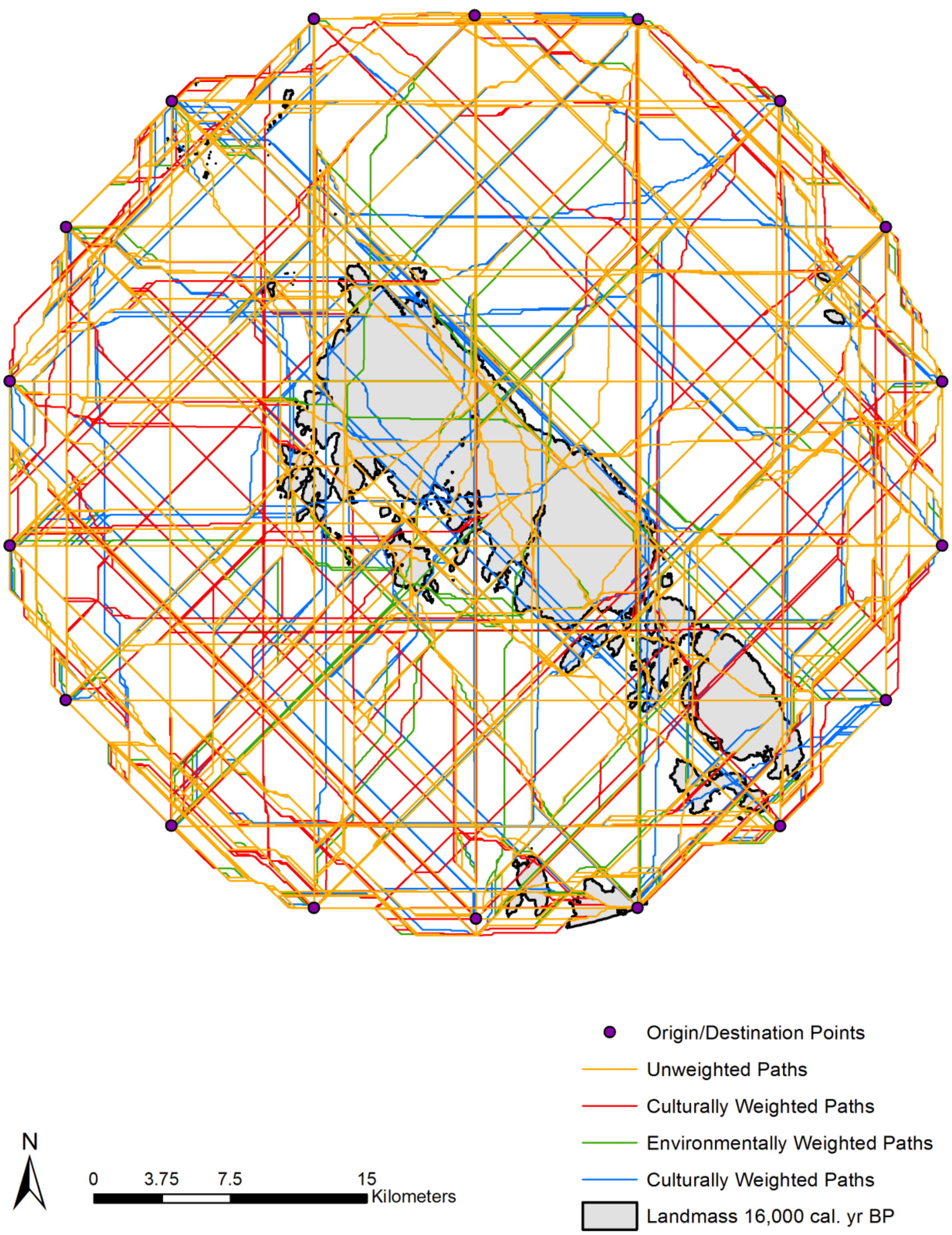
Table 6.2 Analysis Results Stephens Island

Time Period (cal. yr BP)	Greatest Proximity to Coastline	Greatest Amount of Overland Travel	Clustering Pattern	Most Common Mean Direction
10,000	Cultural/ Unweighted	Environmental/ Cultural	Clustered (Western) Grid	Northeast
13,000	Unweighted/ Physiological	Environmental/ Physiological	Clustered (Western) Grid	Northeast
16,000	Cultural/ Unweighted	Physiological/ Unweighted	Dispersed Grid	East

The clustered western grid pattern of paths is even more strongly displayed in the interior portions of the study areas at 13,000 cal. yr BP. These paths show a strong tendency to move along the perimeter of the study area with a greater density of paths in the southwest quadrant. The unweighted and the physiologically weighted paths most closely follow the coastline, moving through the passages and straights between islands. The physiological and cultural paths have the most overland travel segments, while the unweighted and environmental paths take circular routes around the island landmass. The paths produced from each of the different weighting scenarios all travel from the southwest to the northeast with the environmental paths move in a slightly more southward direction.

Due to falling sea levels through the LPEH, the landmass comprising Stephens Island gets larger and larger through time. At 16,000 cal. yr BP the landmass is composed of two large islands, producing subtle changes to the least cost paths through this landscape. Paths from this time period exhibit a dispersed grid pattern (Figure 6.5). Compared to the paths from 13,000 cal. yr BP, there are slight variations in the exact routes of the paths and there is a higher amount of overlap between the routes of paths produced from different weighting criteria. The clustering of paths on the western side of the island is not present during this time period and instead a dispersed gird pattern is present. The culturally weighted and unweighted least cost paths show the greatest tendency to follow the coastline, while the physiologically weighted and unweighted paths have the largest amount of overland travel. The directional mean of the culturally weighted paths is to the northeast. The physiologically weighted and unweighted paths run west to east and the environmental paths travel to the southeast. The breakup of Stephens Island into a chain of smaller islands has a minimal effect on the paths produced compared to the changes resulting from the switch to larger landmass seen between 10,000 and 13,000 cal. yr BP.

Figure 6.5 Dispersed Grid Pattern – Stephens Island 16,000 cal. yr BP



Overall, the least cost paths through Stephens Island are characterized by a grid-like pattern. Within this pattern is a high density of paths in the southern and western parts of the study area which is a trend which becomes more pronounced through time. In all three time periods the unweighted paths have the strongest tendency to follow the coastline. The paths created from the friction surfaces weighted to highlight the physiological and environmental cost of movement have the most overland travel in each time period. As sea levels dropped and Stephens Island solidified from an island chain into a larger landmass the variation in paths increased, however overarching patterns for this subarea remained largely unaffected.

6.2.2 Dundas Islands

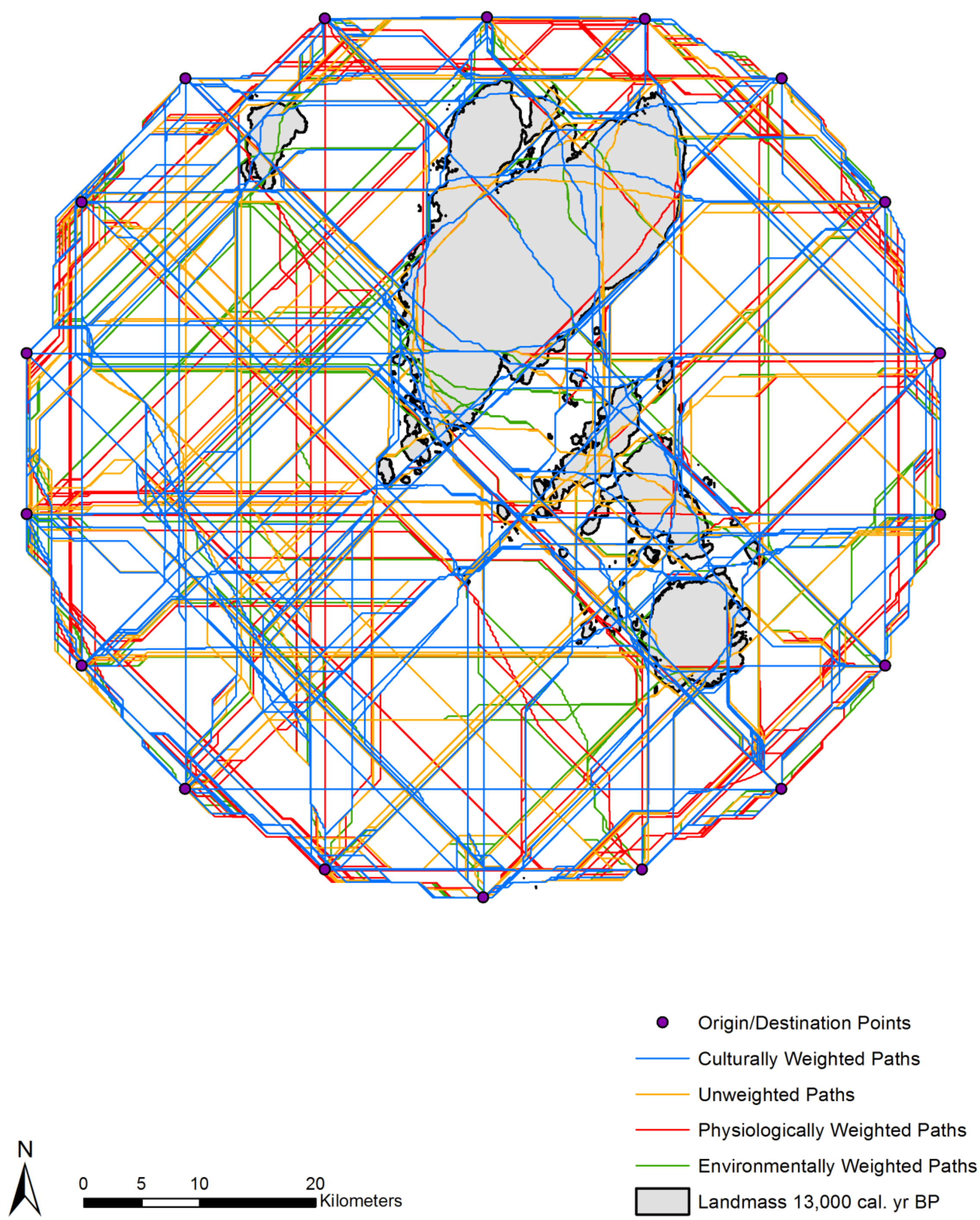
The Dundas Islands are geographically very similar to Stephens Island because they are located on the same geological hinge (McLaren 2008:iv). This study area is composed of four large islands surrounded by many smaller islands. Through time, the overall area of these landmasses does not change significantly and it was expected that the paths from different time periods would be very similar. At 10,000 cal. yr BP, paths calculated through this landscape show several interesting trends (Table 6.3). First, paths pass freely through all portions of the study area, both moving along the perimeter and through interior spaces. The density of routes on the western side of the island is much higher than the eastern side, with clusters both along the shoreline and in the offshore waters ~20 km from the western extent of the largest island. The paths that contained the greatest amount of overland travel were those created from the friction surfaces that emphasized the unweighted and environmental costs of movement. The paths that most closely follow the course of the coast were those created from the environmentally weighted and unweighted friction surfaces. The directional trends of the different paths are very interesting for this time period because the unweighted, physiologically, and environmentally weighted paths move in a northwesterly direction while the culturally weighted paths deviate from this pattern and point towards the southwest.

Table 6.3 Analysis Results Dundas Islands

Time Period (cal. yr BP)	Greatest Proximity to Coastline	Greatest Amount of Overland Travel	Clustering Pattern	Most Common Mean Direction
10,000	Environmental/ Unweighted	Environmental/ Unweighted	Clustered (Western) Grid	Northeast
13,000	Cultural/ Unweighted	Environmental/ Cultural	Clustered (Western) Grid	East
16,000	Cultural/ Unweighted	Physiological/ Environmental	Clustered (Western) Grid	Northeast

The sea level had risen 3 m by 13,000 cal. yr BP and paths calculated for this period show almost identical patterning while expressing less overlap and greater diversity in the routes they take through the landscape. Clustering still occurs on the western side of the islands but is spread out over a wider area, forming a regular grid-like pattern of paths. The passages between islands are very busy, serving as choke points for traffic across the study area (Figure 6.6). The environmentally and culturally weighted paths contain the greatest amount of travel through the terrestrial portions of the study area. The sets of paths that most closely follow the coastline are those calculated from the cultural and unweighted friction surfaces. All of the paths for this time period show a greater propensity for following the coastline than the previously discussed paths for this subarea. The directional trends of the different route are again very distinct for different sets of paths. The environmental and physiological paths move to the northeast, while the unweighted and cultural paths are positioned at an almost ninety degree angle moving towards the southeast.

Figure 6.6 Choke Points within a Clustered (Western) Pattern – Dundas Islands 13,000 cal. yr BP



The sea level change between 13,000 and 16,000 cal. yr BP is even less substantial than the change between the prior two time periods. During this 3,000 year block, the water level dropped approximately 2 m; however, the paths from this period are more similar to those from 10,000 cal. yr BP than they are to the ones from 13,000 cal. yr BP. The same overall trends exist in this data, however the paths are more stochastically clustered than they were 3,000 years earlier. The cultural and unweighted paths show the greatest tendency to follow the coast. The paths with the greatest amount of overland travel are those derived from the environmentally and physiologically weighted friction surfaces. Mean direction trends for the paths show them moving in three different directions. The cultural paths are oriented towards the southeast. The environmental and physiological paths point almost perfectly east and the unweighted paths' mean direction is to the northeast. There is more variation in these path orientations than those from 13,000 cal. yr BP, but the net difference in angle is not as severe.

The paths calculated for the Dundas Islands show significant similarity in the routes they take through this landscape at different chronological periods. However, the paths display surprising diversity in the exact placement of routes within these larger trends. All the time periods show path movement through the entire study area, with routes constrained neither to the interior or the periphery. There is also a strong tendency for paths to group in the western half of the study area. Regardless of chronologic setting, the unweighted paths had the strongest proximity to the coast followed closely by the cultural paths. The paths with the most terrestrial segments were the ones calculated from the environmentally weighted data. There was no clear runner-up in this category as all three other weighting criteria also showed extensive overland travel.

6.2.3 Haida Gwaii

Results from southern Haida Gwaii are different from the three areas previously discussed because this is the first study area in which sea levels dropped below their modern height during the last 16,000 radiocarbon years. At this location in earlier time periods the terrestrial areas are significantly larger than the marine areas. Surprisingly, this did not affect the results as strongly as I had anticipated (Table 6.4). At 10,000 cal. yr BP the sea level was higher than modern conditions and paths show a strong tendency to pass through all portions of the study area. There is a surprising amount of clustering on the landmass itself and in the waters directly to the east. A few segments of the study area's eastern perimeter have a lower density of paths than other portions of the study area boundary. This is a trend that is only observed here and in the Alexander Archipelago. The paths that best match the shoreline are those created from the cultural and physiological weighting scenarios. The greatest degree of overland travel can be witnessed in the environmental and physiological paths. There is little variation in the linear mean of the different paths as they all point to the east, with the physiological and unweighted paths having a slightly more northerly orientation.

Table 6.4 Analysis Results Haida Gwaii

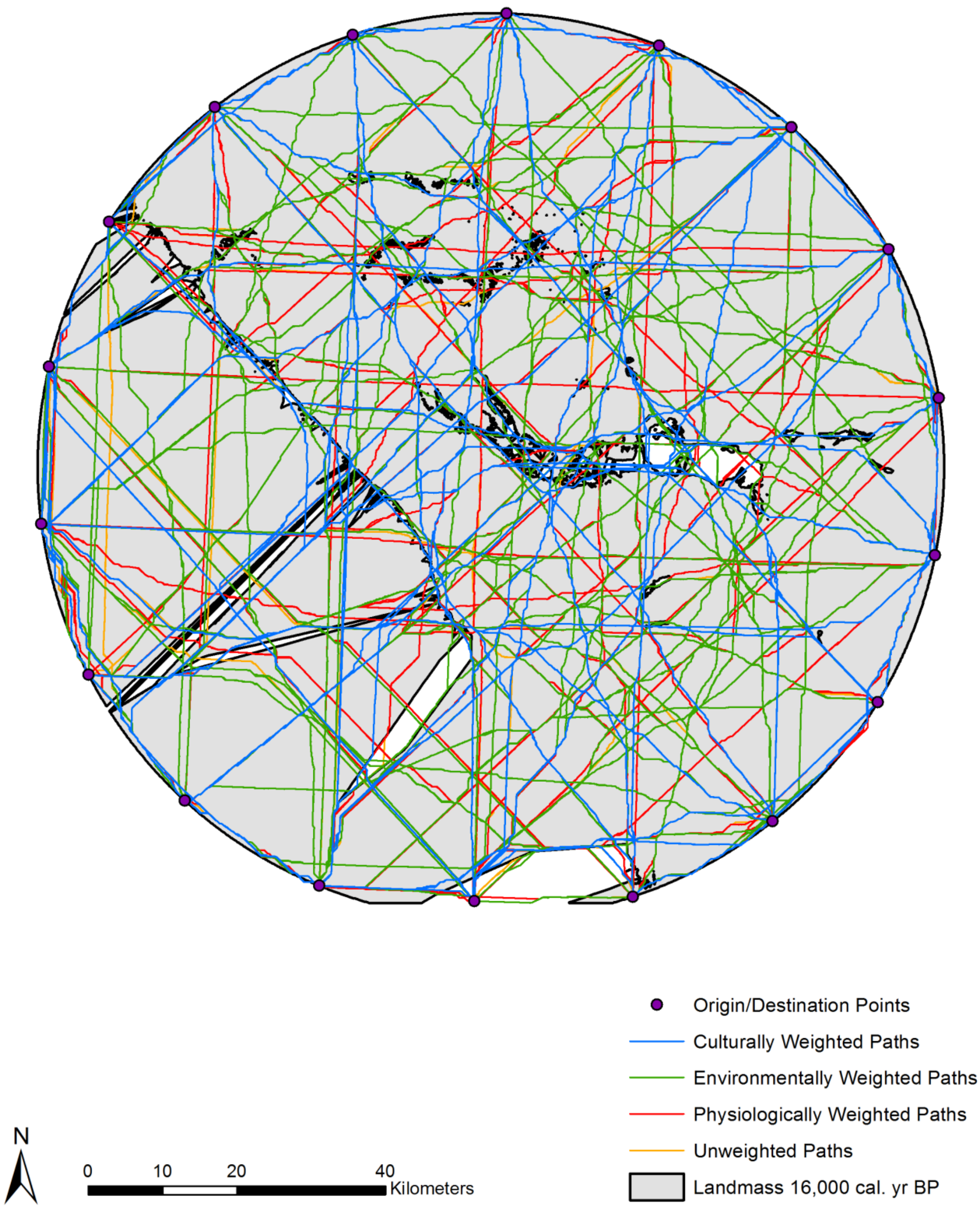
Time Period (cal. yr BP)	Greatest Proximity to Coastline	Greatest Amount of Overland Travel	Clustering Pattern	Most Common Mean Direction
10,000	Cultural/ Physiological	Environmental/Physiological	Clustered (Eastern) Grid	Northeast
13,000	Cultural/ Physiological	Environmental/Cultural	Dispersed Grid	East
16,000	Cultural	Physiological/ Environmental/Unweighted	Clustered (Interior) Grid	East

Haida Gwaii was characterized by significant sea level change from 10,000 to 13,000 cal. yr BP, with shorelines rising on average .05 m per year (Shugar *et al.* 2014:6). The landscape at 13,000 cal. yr BP was very different than the one presented in the previous analysis, since at this time over half the study area is now composed of dry land. Paths from this time period manifest themselves in a grid pattern throughout the study area. There is a very strong linearity to paths from all weighting scenarios and there are several hot-spots that have a spoke-and-wheel form within the large path network. The cultural and environmental paths show the greatest amount of overland travel and have relatively few segments that pass through ocean areas. The paths calculated for this time period show a higher degree of uniqueness than is seen in the other subareas. The cultural and environmental paths have the most overland travel while the computation of path directional mean shows that all of the paths have the same geographic orientation moving from the southwest to the northeast. When crossing the relatively rough topography of the landmass, in contrast to the geographically flat sea, the paths become increasingly affected by slope and aspect and other variables carry less weight in shaping the course of paths. This together with the increased area of the landmass present at this time appears to homogenize directional tendencies.

Sea levels remained fairly stable between 13,000 and 16,000 yr BP. At this point in time, the vast majority of the study area is drained and most travel would have been terrestrial. The paths present a grid pattern covering the entire study area and are characterized by a very strong amount of overlap. In comparison to earlier time periods, a weak tendency to move along the study area perimeter is present (Figure 6.7). For this landscape the culturally weighted paths show a much stronger tendency for moving along the coastline than the physiological, unweighted, and environmental paths. These latter three paths also express the greatest amount of overland travel. The physiological paths move towards the southeast while the other three sets of paths show a strong northeastern directional orientation. As seen with the paths from 13,000 cal. yr BP, there is little variation in these results by weighting scenario.

In summary, the amount of land present in the Haida Gwaii study area through time significantly affects the shape of the paths that are produced. Increased landmass results in decreased variation and greater regularity. Later in time paths have more defined clustering and more closely pass along the perimeter of the study area overall. The culturally and physiologically weighted paths are the most likely to travel along the coast. The cultural paths were the leader in this category in all three time periods with the physiological paths closely following the coast in two youngest chronologic windows. Looking at the amount of overland travel in a set of paths becomes significantly less important as sea levels drop and inundated areas are exposed. The datasets derived from environmental movement costs are very likely to travel through dry locations. Directionally we see that, moving back in time, paths shift from a northeast orientation to a directly eastward one. The variation in the direction of paths within time periods decreases further back in time and data becomes homogenized in the deep past.

Figure 6.7 Clustered (Interior) Pattern – Haida Gwaii 16,000 cal. yr BP



6.2.4 Alexander Archipelago

The geography of the Alexander Archipelago is very similar to that of Prince Rupert Harbour except this study area is an order of magnitude larger. It was therefore expected that the least cost paths moving through these two areas would have very similar patterns and trends. The results from this area in all time periods more closely matched those seen in Haida Gwaii or the Dundas Islands (Table 6.5) than Prince Rupert Harbour. The paths crossing through this landscape at 10,000 cal. yr BP in the Archipelago show erratic patterning on the eastern side of the study area and a regular grid formation on the western side. There are several points off the western coast of the landmasses showing an unusual amount of path clustering and overlap. Paths at this point in time are more prevalent and densely placed in the interior sections of the study area. There are segments of the perimeter on the northern side of the study area with decreased path density. The paths that best follow the course of the coastline are those that were derived from the data that was weighted to highlight cultural and environmental movement costs. Overland travel is least prevalent in the paths calculated from the culturally weighted and unweighted friction surfaces. In the Archipelago there is little variation between the directional means for the different movement cost-weighting scenarios. The environmental, physiological, and unweighted paths all travel to the east while the cultural paths are oriented in a slightly more northerly direction.

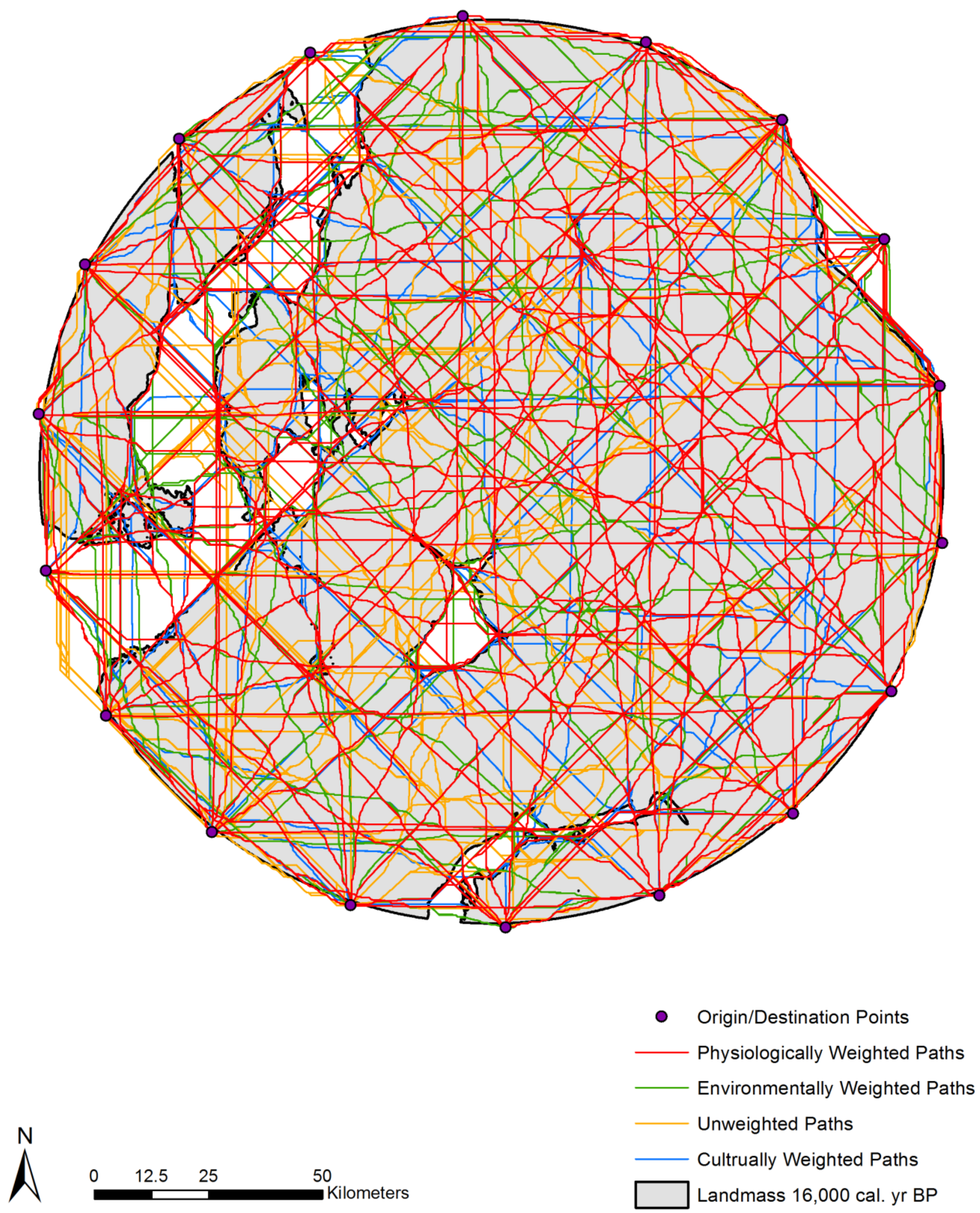
Table 6.5 Analysis Results Alexander Archipelago

Time Period (cal. yr BP)	Greatest Proximity to Coastline	Greatest Amount of Overland Travel	Clustering Pattern	Most Common Mean Direction
10,000	Environmental/ Cultural	Environmental/ Physiological	Clustered (Western) Grid	East
13,000	Cultural/ Unweighted	Environmental/ Physiological	Clustered (Interior) Grid	Northeast
16,000	Physiological/ Environmental	Environmental/ Physiological	Dispersed Grid	Northeast

At 13,000 cal. yr BP the majority of the Alexander Archipelago study area is composed of terrestrial areas, leading to similarities between paths in this study area and Haida Gwaii. Paths show a weak tendency to pass through the exterior portions of the study area. The earlier observed western gird and eastern irregular patterns are also observed here; however, the pattern has become more random. Paths are equally likely to travel overland or through marine environments despite the reduction in ocean areas. No clearly discernable hotspots emerge from this data. The environmental and unweighted least cost paths follow the coastline to a greater degree than the paths created from the other two weighting scenarios. The cultural and unweighted paths contain the least amount of overland travel. The different sets of paths show a surprising amount of variation in their directional means given the terrestrial nature of this landscape. The physiological and cultural paths on average travel to the northeast while the environmental paths travel directly to the east and the unweighted paths move in a southeasterly direction.

The rise of sea levels between 13,000 and 16,000 cal. yr BP results in minor changes to the landscape of the Alexander Archipelago, which is still dominated by a very large landmass (Figure 6.8). The most striking aspect of the paths from this time period is that they become more erratically placed with near-equal density over the entire study area. The tendency for paths to avoid segments of the perimeter is not present at this time and in many ways this collection of paths looks more like those from the smaller study areas to the south. Out of all the project results this set of paths has the least discernable patterns and trends, suggesting that it would benefit from a statistically rigorous examination. With that in mind the same overland travel patterns are weakly present at this time, as was seen earlier. The environmentally and physiologically weighted paths have the most overland movement. The physiological and environmental paths have the highest degree of co-occurrence with the perimeter of landmasses. Given the results from previous time slices, I had not anticipated that the physiological paths would so closely match the coastline. Two different directional orientations are expressed by the paths from 16,000 cal. yr BP. The environmental, cultural, and unweighted paths travel to the northeast, while the physiologically weighted paths travel on average directly to the east.

Figure 6.8 Study Area with a Large Landmass – Alexander Archipelago 16,000 cal. yr BP



Looking at the Alexander Archipelago throughout the LPEH, several things become apparent about this least cost analysis. As time progresses, the organization moves from randomness to increasing order. Paths move from a layout with no discernable clustering to a grid like placement running horizontally and vertically across the study area. In younger time periods, there is less of a tendency for paths to travel along the perimeter of the study area and routes tend to congregate in interior areas. This is the only study area in this modeling scenario in which for all three time periods the same sets of paths expressed the most overland travel. The environmentally and physiologically weighted paths pass through a significantly greater amount of terrestrial cells than the culturally or unweighted paths. In all three time periods, the environmental paths had a strong propensity for matching the contour of the coastline and no other study area showed a similar pattern through time. Directional path trends matched those seen in other study areas, with routes moving from west to east with a high degree of spatiotemporal consistency between weighting scenarios.

6.3 Very High Overland Travel Movement Cost

The analysis of the results produced from the modeling scenario where overland travel was made very costly was conducted in the same manner as the previous analyses, with the exception that the amount of overland travel was not considered. The purpose of this set of models was to see how results changed when the possibility of portaging a boat and other overland means of travel were eliminated. These modeling scenarios were only run for the three smallest study areas, because these locations were never inundated by ocean waters and are computationally easy to process.

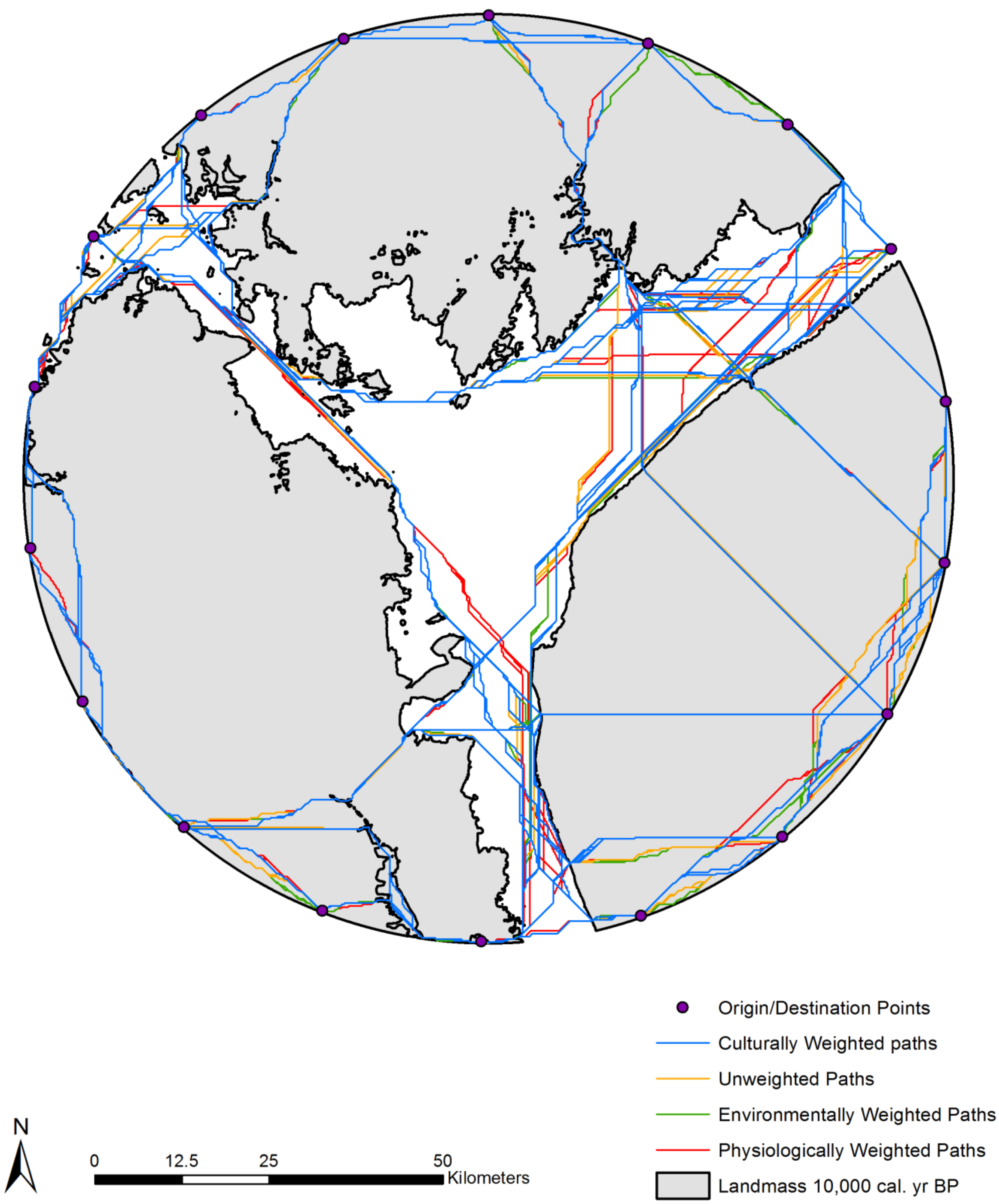
6.3.1 Prince Rupert Harbour

For Prince Rupert Harbour at 10,000 cal. yr BP, movement paths are constrained to the interior portions of the study areas due to the relatively low sea levels present at this time (Figure 6.9). These paths move directly across terrestrial obstacles from origin points to the coast making use of lakes and other aquatic landscape elements. Once at the coast, routes hug the eastern shoreline and avoid traveling through the middle of the Harbour. The organization of the paths can be best described as fitting the clustered interior grid pattern with hotspots of activity in the south, northwest, and northeast (Table 6.6). The physiological and unweighted paths travel to the south and the cultural and environmental paths are oriented towards the southeast. The routes derived from the culturally weighted data show a stronger tendency to follow the coastline.

Table 6.6 Analysis Results Prince Rupert Harbour – Very High Overland Movement Cost

Time Period (cal. yr BP)	Greatest Proximity to Coastline	Clustering Pattern	Most Common Mean Direction
10,000	Cultural	Clustered (Interior) Grid	South/Southeast
13,000	Physiological/ Environmental	Dispersed Grid	Northeast
16,000	Cultural	Clustered (Southwest) Grid	East

Figure 6.9 Clustered (Interior) Paths – Prince Rupert Harbour 10,000 cal. yr BP



At 13,000 cal. yr BP the orientation of routes shifts and a dispersed grid pattern emerges with hotspots occurring in the same locations as observed in more recent times. During this chronological window, there is a strong tendency for all paths to pass closely to the shoreline with the physiological and environmental routes having the greatest overall proximity. The routes created from all four weighting criteria have nearly identical orientations pointing to the northeast. Overall there is a high degree of similarity between the different paths.

Finally, at 16,000 cal. yr BP, the sea levels were significantly higher than they were at later times and much more of the study area is composed of marine environments. The result of this is that routes form a grid pattern that is clustered in the southwestern quadrant of the study area, with a slight tendency for paths to parallel the perimeter of the study area. The culturally weighted paths show a very strong alignment with the perimeter of landmasses and these paths point to the southeast, whereas the physiological, environmental, and unweighted paths are all oriented towards the east or northeast.

The Prince Rupert Harbour least cost paths through time show a pattern of becoming more diverse, especially in later time periods when sea levels were higher. The cultural paths show the greatest tendency to move close to the shoreline in both early and late periods. Paths do not conform to one pattern, which may be caused by the relatively large changes to sea levels between time periods. However, unlike in the scenarios freely allowing overland travel there is not a strong tendency for paths to mirror the study area perimeter. Paths most frequently point towards the east; however, they take on a more southerly orientation in later periods. Overall, this area is characterized by fairly radical change, with few consistent trends through the entirety of the LPEH.

6.3.2 Stephens Island

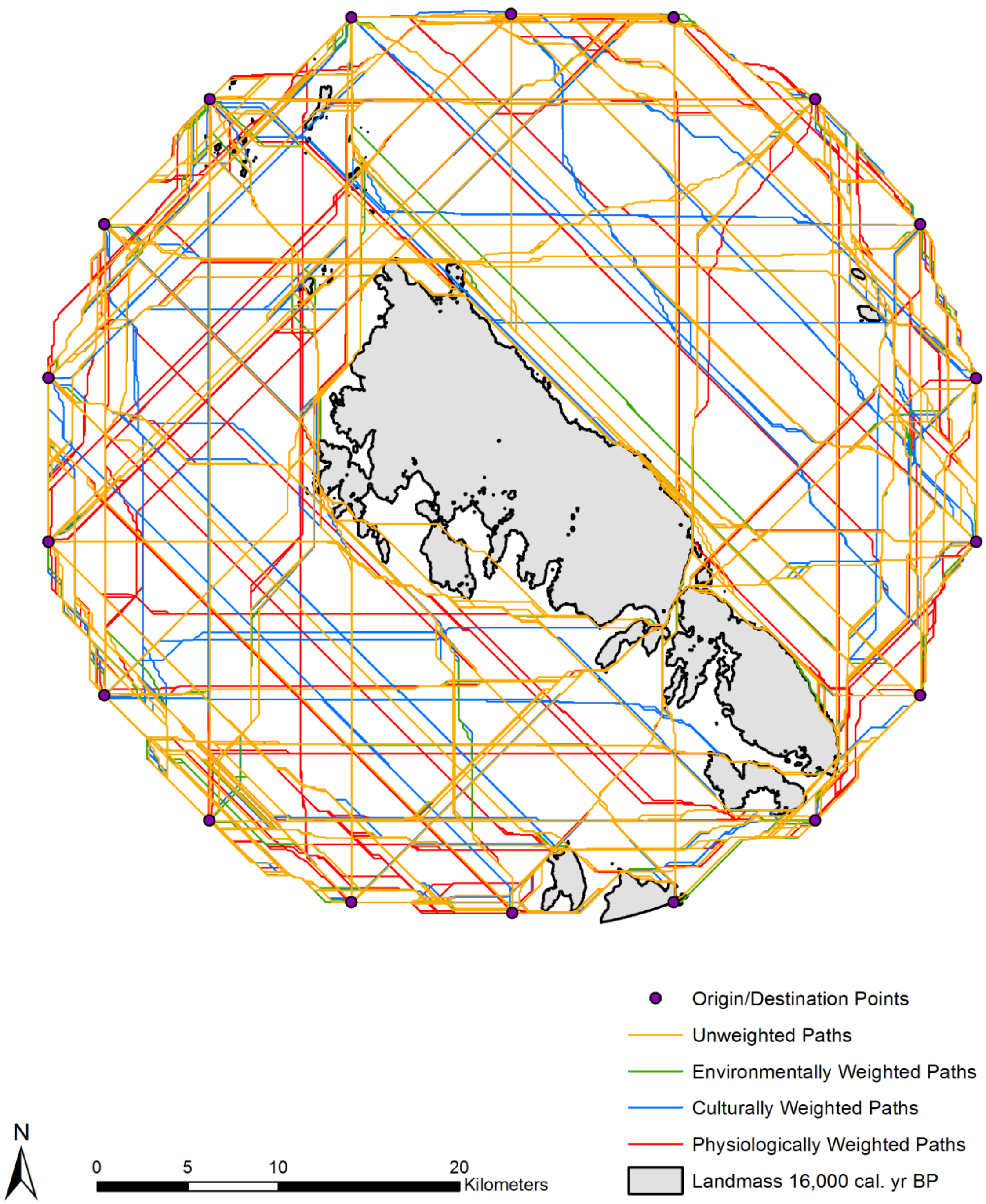
The trends displayed by routes around Stephens Island at 10,000 and 13,000 cal. yr BP are nearly identical and are characterized by a dispersed gird pattern with a near uniform distribution of paths through the study area (Table 6.7). There is a very slight concentration of activity in the southwest quadrant. For both these time periods, the environmental and cultural paths show the greatest amount of proximity to the coast. The only difference in the attributes of paths from these two time periods is that the routes from 13,000 cal. yr BP have a slightly southeasterly orientation whereas those from 10,000 cal. yr BP move in a more northerly direction.

Table 6.7 Analysis Results Stephens Island – Very High Overland Movement Cost

Time Period (cal. yr BP)	Greatest Proximity to Coastline	Clustering Pattern	Most Common Mean Direction
10,000	Cultural/ Environmental	Dispersed Grid	East
13,000	Cultural/ Environmental	Dispersed Grid	East
16,000	Unweighted	Dispersed Grid	Northeast

At the beginning of the LPEH the 16,000 cal. yr BP paths also form a dispersed grid pattern and the unweighted least cost paths most closely follow the coastline. The mean direction of all of the paths is to the northeast. An interesting feature of these routes is that they almost completely avoid moving through the bays which form on the western side of the main landmass (Figure 6.10). This is surprising, as this area would appear at first glance to be very desirable to travel through due to its high sinuosity and sheltered coastline.

Figure 6.10 Unweighted Paths – Stephens Island 16,000 cal. yr BP



In the past, Stephens Island looked very similar to the way it does today due to minimal sea level change. The result of this is relatively minor changes in least cost paths between different time periods. Through the LPEH the environmental and cultural paths clearly best mirror the coastline and all paths fit the dispersed grid pattern. The only significant variation in paths is in their directional mean, which switches from an easterly orientation in the deep past to a slightly northerly direction at the transition to the Holocene. Overall Stephens Islands is characterized by a lack of path route diversity which simplifies the process of deducing the activity of past humans in this landscape.

6.3.3 The Dundas Islands

The Dundas Islands represent a singular occurrence in my modeling of maritime migration through the Northwest Coast. For this landscape, regardless of time period, the defining characteristics of the least cost paths remain the same (Table 6.8). Results from all three chronological periods have identical clustering patterns, path coastline proximity's, and average directional means (Figure 6.11). The environmental and unweighted paths always pass in very close proximity to the coastline. Additionally paths are always arranged in a southern clustered grid pattern. Within this larger orientation, the paths show a remarkable amount of similarity, even in contrast to the paths from Stephens Island. This area also demonstrates the choke point phenomena seen in other modeling scenarios, which suggests that these locations would have a high probability of past human activity. Lastly, paths are oriented towards the northeast, shifting very slightly towards the south at 16,000 cal. yr BP. From this set of data it becomes abundantly clear that minimized sea level change, combined with prohibitively high overland travel costs, results in greater continuity and homogenization of paths through time.

Figure 6.11 Path Homogeneity – The Dundas Islands 13,000 cal. yr BP

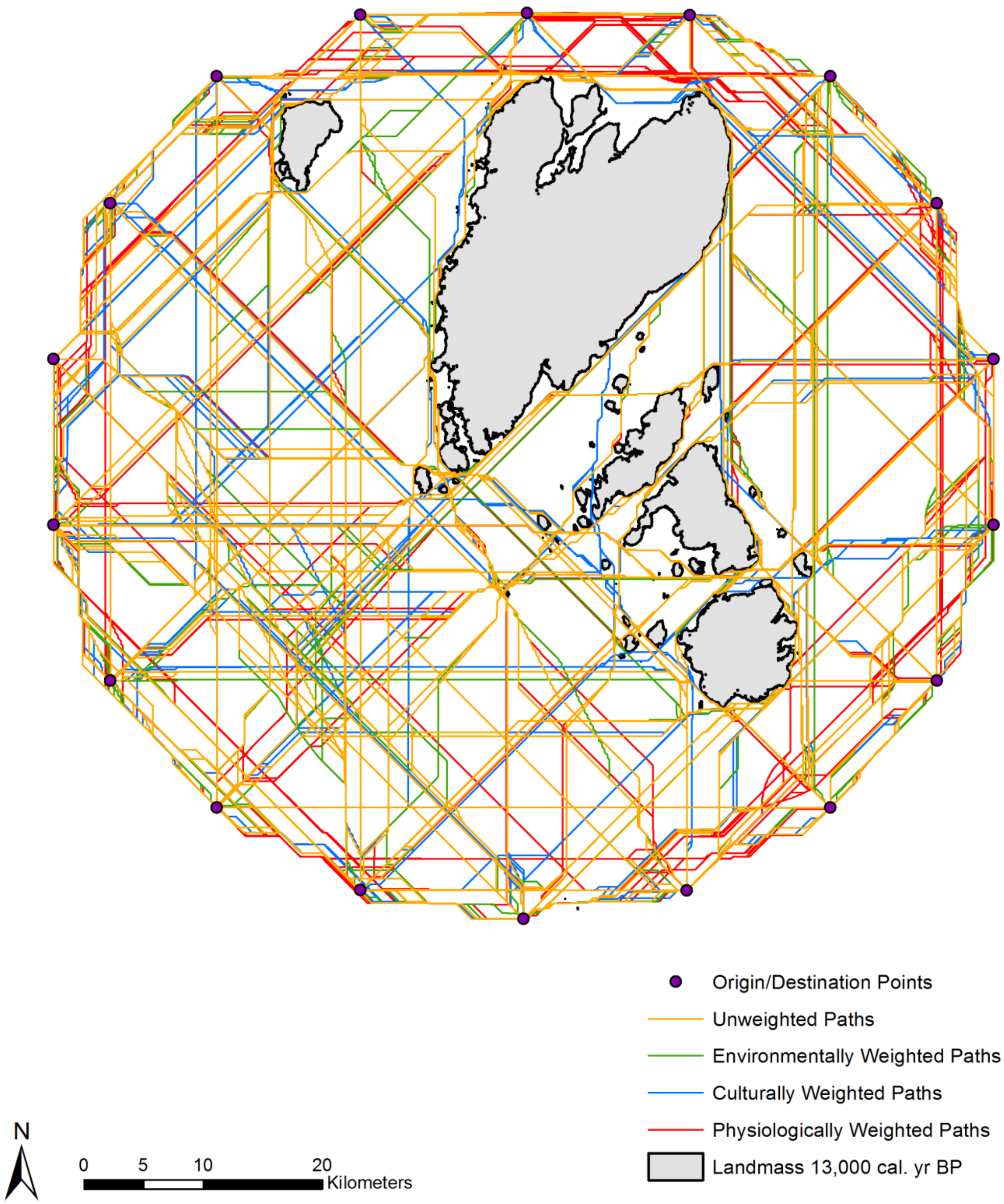


Table 6.8. Analysis Results Dundas Islands – Very High Overland Movement Cost

Time Period (cal. yr BP)	Greatest Proximity to Coastline	Clustering Pattern	Most Common Mean Direction
10,000	Environmental/ Unweighted	Clustered (Southwest) Grid	Northeast
13,000	Environmental/ Unweighted	Clustered (Southwest) Grid	Northeast
16,000	Environmental/ Unweighted	Clustered (Southwest) Grid	Northeast

6.4 Locations with High Probabilities of Containing Paleoamerican Sites

The main purpose of this thesis was to analyze the applicability of least cost analysis to studying LPEH maritime travel, which I consider to be separate but related to the process of creating actual predictions of site locations. Both of these processes involve the principles of site prospection but they are not one and the same thing. One looks at possible patterns of movement while the other uses those patterns to determine stopping points during migration events. However using the results that were previously reported in this chapter I was able to create basic predictions of where undiscovered Paleoamerican sites might be located in each of my study areas (Appendixes G and H).

Site location predictions were made by passing the culturally weighted least cost paths through the Line Density tool (ESRI 2015d). The culturally weighted paths, as discussed in detail in the next chapter, provide the best recreations of Paleoamerican marine travel routes and yield the information most useful for site prospection. To determine high probability site locations the Line Density tool was used (ESRI 2015d). This script calculates the weighted density of linear features in the neighborhood of each cell in a raster dataset. A circle is drawn around each cell and the portion of a given line feature that falls in that circle is multiplied by the cells population field. This total is then summed and divided by the circles area. In my analysis the number of least cost paths passing through a cell provides the population field value for each line. All other input values were set to the tools default parameters. The result of this operation is that areas that would have been the most traveled through in my models are identified and the cells with highest likelihood of containing undiscovered Paleoamerican sites are modeled.

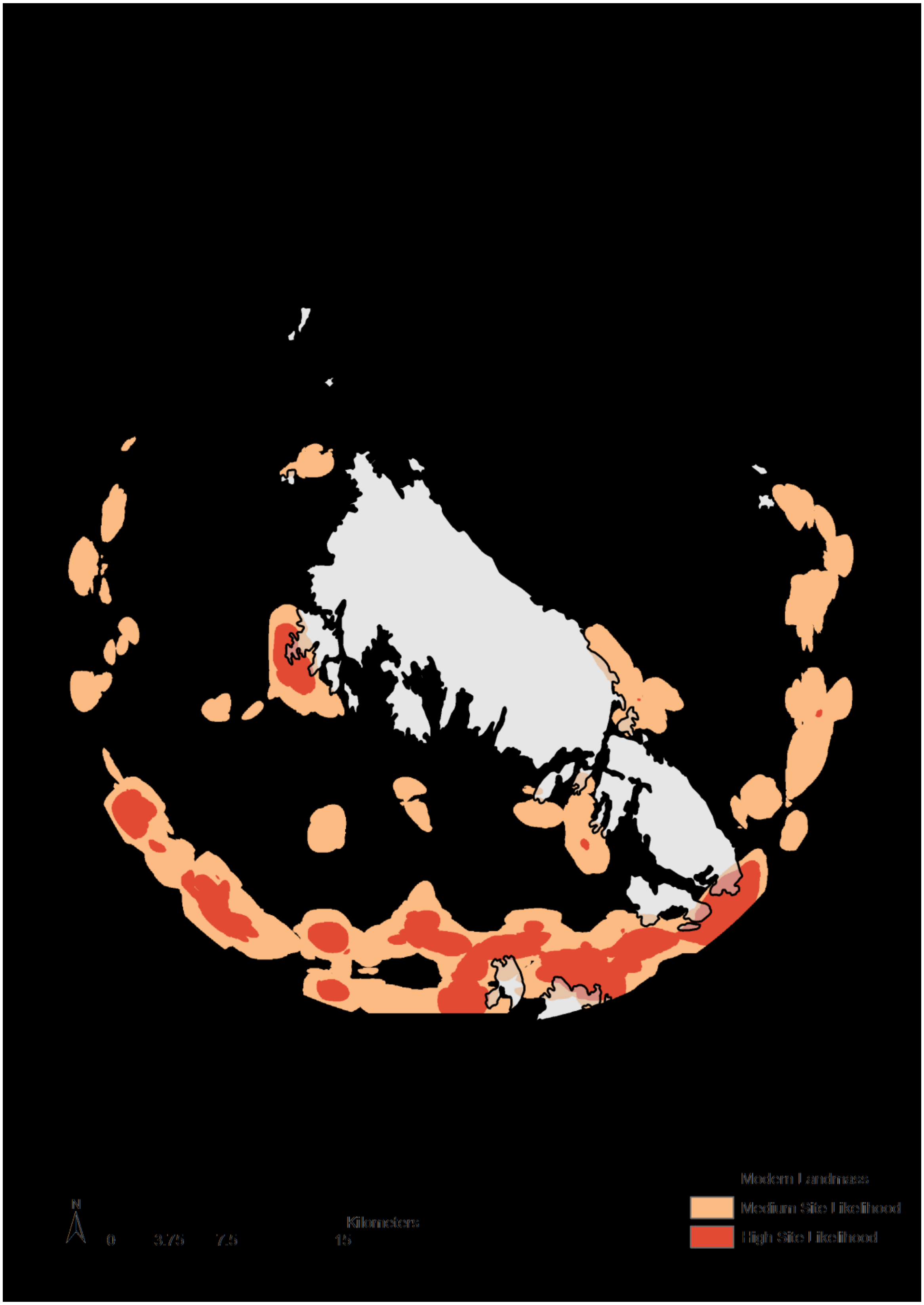
Looking at the results that were generated from the modeling scenarios that allow overland movement several trends emerge across space and time (Figure 6.12). The first of these is that high probability site locations fall in the vicinity of coastlines, usual falling on the western side of landmasses. Additionally these results mostly identify possible site locations as being located in the southern portions of study areas with line density immediately decreasing along northern axes and more gradually fading to the east and west along study area perimeters. Lastly high probability site locations display a strong gird patterns and in most study areas these match the patterns observed from the least cost path route clustering patterns. If a study area displays dispersed or clustered patterning then it is likely that this trend will also display in the linear density maps.

Figure 6.12 Site Prospection Trends – Stephens Island 13,000 cal. yr BP

The areas that were identified as most probably containing sites in the modeling scenarios that made overland travel prohibitively difficult produced different results. These datasets unsurprisingly selected far fewer terrestrial areas as having a high chance of Paleoamerican sites. An interesting aspect of this data is that clear linear corridors of high probability cells appear in most study areas connecting high probability cell clusters in interior areas to the study area periphery. An unexpected result was that far fewer cells located immediately offshore were high probability site locations (Figure 6.13). The majority of possible locations are located in marine settings that are removed from landmasses, however like in the previously mentioned scenario when high probability site locations are near a landmass they present most strongly on the western side. Another result that is quite interesting is that these locations are arranged in a grid but that this pattern is weak in that there are few large linear contiguous high portability areas. The results are patchy with isolated clusters of predicted sites seemingly arraigned at random intervals.

In conclusion there are differences in the site locations that are identified as most likely containing Paleoamerican sites based on how overland travel is factored into the modeling scenario. Additionally there are identifiable general trends and patters to where high portability sire locations fall which generally match the patterns displayed in the least cost path analysis. Further discussion of exactly how these findings should be applied will be discussed in Chapter 7.

Figure 6.13 Site Prospection Trends High Overland Cost – Stephens Island 13,000 cal. yr BP



6.4 Summary

Preliminary tests of this project's methodology on the Prince Rupert Harbour study area determined that it was possible to run this analysis at cell sizes as small as 5 m; however, the results at this resolution were very similar to results produced at the larger 30 m cell size. The computational requirements of running calculations at this coarser resolution were significantly less, decreasing the amount of time needed to run the analysis. Even at the 30 m cell size it was necessary to use a powerful desktop computer to complete this analysis in a timely manner. As such, it was determined that the 30 m resolution provided the appropriate balance of computational requirements and result accuracy. An added benefit of using a larger cell size for this methodology is that it also enables this technique to be conducted on most desktop computers.

Overarching trends in the results of this analysis can be viewed both in terms of comparison between study areas and between time periods. I will first discuss the patterns that emerge by looking at the results of the analysis scenarios that allowed overland travel, beginning with the prevalent patterns emerging out of each of the five study areas as a whole (Table 6.9). Several distinct trends emerge when the results are viewed this way. The cultural movement cost-weighting scenario produced paths with the greatest proximity to the coastline, regardless of study area. The environmental movement cost scenario created the paths that have the greatest amount of overland travel. Additionally, environmentally weighted datasets also frequently showed the greatest amount of travel through marine environments; however, these routes often cut directly across water bodies, meaning they were unsuitable for recreating past movement events. The spatial patterning displayed by paths was grid-like for every study area except for

Prince Rupert Harbour, an area in which paths tended to run parallel to the study area perimeter. Paths in grid patterns were either evenly distributed or clustered on the western/interior portions of the study area. Average path orientation for study areas was to the northeast. However, variation by as much as 45 degrees in either direction was present in some study areas.

Different trends emerge when subareas are examined by specific time period (Table 6.10). For 10,000 cal. yr BP, the cultural least cost paths showed the greatest proximity to the coastline. At this time the environmentally derived paths had the greatest amount of overland travel. Also, paths from the time period frequently take a grid formation with clusters of activity in their western halves. Lastly, the most common path orientation was to the northeast. At 13,000 cal. yr BP, the cultural and unweighted paths most closely mirror shoreline movement. The culturally weighted paths have the greatest amount of overland travel and the most common path pattern is a clustered grid with a west to east movement orientation. Lastly, at 16,000 cal. yr BP, the route of culturally derived paths is in closest proximity to landmasses. The physiological paths have the most segments that pass through terrestrial cells. As seen at 13,000 cal. yr BP, a dispersed grid pattern is the most likely to occur at this time and paths predominantly move from the southwest to the northeast, and there are distinct differences between different study areas and time periods, each of which have their own distinct signature of attributes.

Table 6.9. Results Summary by Location

Variable	Prince Rupert Harbour	Stephens Island	Dundas Island	Haida Gwaii	Alexander Archipelago
Greatest Proximity to Coastline	Environmental	Unweighted/ Cultural	Unweighted	Cultural	Environmental/ Cultural
Greatest Amount of Overland Travel	Physiological	Cultural/ Physiological	Environmental	Environmental	Environmental/ Physiological
Clustering Pattern	Parallel to Perimeter	Clustered (Western) Grid	Clustered (Western) Grid	Clustered Grid	Clustered Grid
Most Common Mean Direction	East	Northeast	Northeast	East	Northeast

Table 6.10 Results Summary by Time Period

Variable	10,000 cal. yr BP	13,000 cal. yr BP	16,000 cal. yr BP
Greatest Proximity to Coastline	Cultural	Cultural/Unweighted	Cultural
Greatest Amount of Overland Travel	Environmental	Cultural	Physiological
Clustering Pattern	Clustered (Western) Grid	Clustered Grid	Dispersed Grid
Most Common Mean Direction	Northeast	East	Northeast

The results from the modeling scenarios that minimized overland travel produced similar results to the models that allowed overland travel. It should be noted that only three study areas were used here, not the full five, and the amount of overland travel for each set of paths was not considered. Looking at patterns across study areas, it becomes apparent that the paths derived from the culturally weighted movement cost scenarios most closely followed the coastline (Table 6.11). Additionally, gird patterns that clustered in interior or southwestern areas were the most prevalent. Paths traveled in an eastern orientation with a slight tendency to tack to the northeast. Overall, these three areas displayed very similar trends and patterns, which may be caused by their close geographic proximity and analogous sea level histories.

Table 6.11 Results Summary by Location – Very High Overland Movement Cost Model

Variable	Prince Rupert Harbour	Stephens Island	Dundas Island
Greatest Proximity to Coastline	Cultural	Environmental	Environmental/Cultural
Clustering Pattern	Clustered (Various) Grid	Dispersed Grid	Clustered (Southwest) Grid
Most Common Mean Direction	East	East	Northeast

When we examine the results of these same models by looking at the patterns that emerge for different time periods for all the study area locations, slight variations occur (Table 6.12). The environmental paths show the greatest proximity to the shoreline. Again here we see the prevalence of southwest clustered grid path patterns. Lastly, the most common directional mean is to the northeast. Based on these results, eliminating the possibility of overland travel from the modeling scenario creates greater uniformity in paths with lower amounts of variation between time periods and locations.

Table 6.12 Results Summary by Time Period – Very High Overland Movement Cost Model

Variable	10,000 cal. yr BP	13,000 cal. yr BP	16,000 cal. yr BP
Greatest Proximity to Coastline	Cultural/ Environmental	Environmental	Unweighted
Clustering Pattern	Clustered (Various) Grid	Dispersed Grid	Clustered (Southwest) Grid
Most Common Mean Direction	East	Northeast	Northeast

When both sets of the models are compared, it becomes obvious that while the actual routes that the least cost paths takes varies significantly, the overall patterns and trends of the paths remain very similar (Table 6.13). The cultural paths are the most likely to pass in close proximity to edges of landmasses. Path mean direction is also almost always to the east or northeast with the previously mentioned exception of Prince Rupert Harbour. The only significant variation between the two modeling scenarios arises when comparing path distribution patterns. Allowing overland travel creates a variety of pattern types with an emphasis on distributed paths. Restricting overland travel results in clustered grids with hotspots of activity frequently occurring in the south and west. All in all, the two different approaches are remarkably similar and warrant further discussion.

Table 6.13 Comparison of Most Common Results by Modeling Scenario

Variable	By Location – Overland Travel Allowed	By Location – Overland Travel Disallowed	By Time Period – Overland Travel Allowed	By Time Period – Overland Travel Disallowed
Greatest Coastline Proximity	Cultural	Cultural	Cultural	Environmental
Clustering Pattern	Various Grids	Clustered Grids	Dispersed Grids	Clustered (Southwest) Grid
Most Common Mean Direction	Northeast	East	East/Northeast	Northeast

Here I show that a spectrum of results was produced from running this analysis under different conditions. These findings display distinct trends and patterns that can be meaningfully generalized by study area and time period to provide insightful information about the peopling of the New World. They also demonstrate the validity of the application of least cost path analysis to maritime movement events in the deep past. What exactly these results mean in the context of my research questions will be discussed in depth in the next chapter.

Chapter 7: Discussion and Conclusion

7.0 Introduction

The results of my research have important ramifications for both the application of least cost path analysis for site prospection in coastal environments and our knowledge of Paleoamerican peoples. When viewed through the theoretical framework of landscape migration and in the context of the LPEH, my work provides important insight into how to best look for traces of the first humans to arrive in the New World. My thesis also successfully addresses the research questions that I proposed at the beginning of this project. The overarching goal of my work was to determine whether least cost analysis can be applied to maritime migrations by Paleoamerican peoples on the Pacific Northwest Coast. Can a technique most frequently used in relatively recent terrestrial settings be applied to boat-based travel by peoples in the deep North American past?

Within the umbrella of my larger research topic are several smaller questions which address specific aspects of my research. First, what data resolution is most appropriate for conducting least cost analysis? Where does the proper balance between result accuracy and computational efficiency lie? The second question that I pose is how do different movement logics, represented through weighting scenarios emphasizing different types of movement cost, affect the path routes that are modeled? The Northwest Coast is a temporal landscape that has been characterized by rapid and dynamic change throughout the last 16,000 years. This change necessitates the analysis and comparison of results from different chronological periods. My study looked at what we can learn about past human activity in five distinct locations on the Northwest Coast individually and in comparison to each other. Marine transportation does not have to be strictly limited to travel across water. Boats can be portaged by foot considerable distances and whether this type of transportation is allowed in a modeling scenario influences the results that are produced.

This chapter begins by addressing each of my research questions by connecting them to the method, theory, and results of this project. Next, I discuss of the limitations of my work and suggestions for future directions this project could take. Lastly, this chapter will be concluded with a summary of what my research means for both the application of least cost analysis to archaeology and for the overarching issue of Northwest Coast site prospection.

7.1 Spatial Data Resolution

The Northwest Coast is an extremely large area including over 2,000 km of coastline (Ames and Maschner 1999:17). The result of working within such a large geographic extent is that the datasets which represent different phenomena occurring in this area can be very large and subsequently slow to compute (Wheatley and Gillings 2012:47). Reducing the amount of time necessary to run a process requires either using more powerful equipment or simplifying the data. The process of simplifying data almost always results in a degradation of accuracy while the software and hardware to run more powerful computations are often financially unavailable. In order to determine what the appropriate analysis resolution for my work was, I conducted a series of trials producing least cost paths for the Prince Rupert Harbour from input data at a variety of resolutions.

I found that changes in the accuracy of the data used produced significant variation in the exact placement of path routes, but did not significantly change the overarching trends between results calculated from the highest and lowest accuracy data. Paths computed at the 30 m resolution were very similar to those created from 5 m data. A smaller spatial resolution should more accurately capture the actions and decision making process of past human groups and using data with a small cell size would have allowed for modeling on a human scale, providing the most accurate results. However, this was not a computationally feasible option, nor were there adequate sources of high resolution data for all study areas. I determined that a 30 m cell size allowed results to be computed using a desktop computer while maintaining a high level of result accuracy and precision. While exact path locations may not be correctly predicted, the most important attributes of the data are still determined and can be used to answer my research questions.

7.2 Movement Cost-Weighting Scenarios and Movement Logic

The process of trying to figure out how past peoples would have navigated through a landscape is based on our ability to determine how different aspects of their physical and cultural world would have affected their decision making process (Surface-Evans and White 2012:6). In order to examine how different movement logics affected path placement, I created three different movement cost-weighting scenarios, in addition to the unweighted data, which emphasized the environmental, physiological, and cultural cost of movement. These different scenarios allow for a processual-plus approach to thinking about the costs of moving through a landscape by removing purely environmental or physiological considerations of movement cost (Llobera 2001:1005). Here a variety of different measurable phenomena from different facets of the human experience were considered. By comparing all of my results across geographic and chronological boundaries, I discovered that the culturally weighted friction surfaces show the most potential for recreating past movement events based on their low amount of overland travel and tendency to move along the coastline. These paths closely follow the coastline and minimize their overland travel in relationship to results from other weighting scenarios. Directionally, all of the models produce a similar result, which is surprising because I assumed the main direction of travel would be from north to south, as was observed by Anderson and Gillam (2000), not the west to east pattern that is present in my findings. I believe that this west to east movement pattern reflects a tendency of Paleoamericans to move when possible from the open Pacific Ocean into protected environments because these areas have lower movement costs, more kelp, and are more suitable places to establish waypoints. These lateral movements would be a small part of larger north to south migrations.

The suitability of the culturally weighted data is unsurprising when we consider the limitational landscape knowledge that would have been accessible to Paleoamericans about the New World. The biogeographical approach to migration assumes that people would have lived in places that they deemed suitable based on cultural values, and this logic is reflected in the high suitability of the culturally derived results (Rockman 2003:15-17). Cultural-based units of knowledge about the landscape, such as an understanding of how to live in kelp-based ecosystems, would have been readily available, whereas locational and social transferable information about the New World would not have been accessible in the earliest time periods (Erlandson *et al.* 2007:171; Rockman 2003:4). If scouting activities or return migrations were a significant source of information for these peoples, I would except that either the physiologically or environmentally based paths would be better at modeling maritime movement (Anthony 1990:92). The paths generated from my analysis support the theoretical framework that I created to explain Paleoamerican migration and reinforce the applicability of maritime least cost analysis for prospection.

7.3 Chronological Resolution in a Dynamic Landscape

Over the last 16,000 radiocarbon years, the Northwest Coast has been a dynamic landscape in which sea levels have dramatically changed (Shugar *et al.* 2014:1). Modeling this landscape at a fine temporal resolution creates the most accurate picture of how this temporality has affected the movement of people through the Northwest Coast over time. However, here again computational resources limit the size of the analysis that can be conducted. Running my study at 3,000 radiocarbon year intervals provided a nuanced look at how least cost paths change through time without requiring supercomputing. These windows allowed for distinct chronological trends to emerge and demonstrated the necessity of incorporating temporality into this analysis.

The use of multiple chronological windows allowed for a simultaneously dynamic, social, quantifiable, and temporal approach to migration. Discrete information suitable for GIS analysis was gathered for each point in time and analyzed, producing individual datasets that by themselves are of limited value, because humans are not static entities frozen in time. Once placed along a temporal continuum, however, these datasets provide rich insight into how migration routes change through time in response to environmental and cultural events. I propose that Paleoamerican peoples would have viewed the physical world as an ideational and conceptual landscape, based on their cultural familiarity with the ecosystem of the Northwest Coast (Ashmore and Knapp 1999:12; Erlandson *et al.* 2007:162). The increasing proximity of environmental paths to landmasses and the targeted clustering of paths in specific portions of study areas as time progressed suggest that the type of landscape knowledge shifted through time away from the ideational and conceptual. How people moved through the landscape became increasingly based on locational and social knowledge as they become familiar with the physical geography of the Northwest Coast. Looking at these trends illustrates how the transformation of this landscape from a place devoid of humans to a populated continent may have unfolded. Additionally, these changes in landscape knowledge may be connected to the fact that North

America was becoming deglaciated and the coastal environment was shifting from a scattering of isolated refugia to an open ecologically viable landscape (Dixon 2013:63). The very nature of migration itself may have been changing from the leapfrog method, which is especially suited for a LPEH environment, to a Wave of Advance or String of Pearls approach that is more feasible in a warmer world (Anthony 1990:902-904; Gillam and Anderson 2000:58). Such inferred changes in migration and movement would not have been apparent without results from multiple chronological points and demonstrate the need to conduct research on a temporal continuum when working on coastlines without consistent sea level histories.

7.4 Comparison of Different Northwest Coast Regions

Working at a variety of different methodological scales allowed for the comparison of results, representing a variety of locations ranging in size from a few hundred square kilometers to tens of thousands of square kilometers. This comparison revealed significant differences in the results that were produced from the two different types of physical landscapes I studied. The Dundas Archipelago and Stephens Island have similar results, while Haida Gwaii, Prince Rupert Harbour, and the Alexander Archipelago have similar patterns that are distinct from those seen in the other two study areas. Within each of these types of study area there is a high degree of result consistency.

The Dundas Islands and Stephens Island are small island chains where sea levels never fell below their current levels. In contrast, Haida Gwaii, the Alexander Archipelago, and Prince Rupert Harbour landmasses extend beyond the boundaries of the study area, meaning that they are not completely surrounded by water for the purpose of this analysis. For these locations, with the exception of Prince Rupert Harbour, sea levels significantly dropped before rising to their modern levels. The two sets of smaller islands which are completely surrounded by water show higher amounts of path clustering, a more northerly movement orientation, and greater unweighted path suitability. In these locations, there seems to be a slight trend for paths to cluster along the western side of landmasses and for decreased overland travel. Paths through study areas that include significant landmasses are characterized by less clustering, an eastern movement orientation, greater suitability of cultural paths, and increased overland travel. These two different types of geographies produce very different results that are controlled by sea level history, the locations of landmasses, and the percentage of the study areas composed of marine environments.

The different clustering trends observed at different study areas make sense within the framework of how transient explorer groups would have navigated the LPEH Northwest Coast (Beaton 1991:223). It is expected that these groups would move in small bands fluidly across diverse landscapes, making use of a wide variety of resource patches. The clustering of paths in different study areas suggests that the input factors in my analysis form groupings of low movement cost cells that Paleoamerican travelers may have been using in similar ways as resource patches. Early travelers could have glided from patch to patch, using them as waypoints in longer journeys. The clustering of routes in specific areas of very low movement cost is to be expected and is encouraging for the successful application of maritime least cost analysis to site prospection.

The general similarity in results between study areas of the same geography type also fits the transient explorer form of migration. Transient explorers would freely make use of landscapes that are noncontiguous and geographically distributed, such as the different study areas I looked at. Path mean direction in all study areas and most time periods is oriented to the east or northeast and, when combined with the similarity of path coast proximity and clustering patterns, suggests fluidity of movement. These path trends also support my conception of the structure and scale of Paleoamerican migration events.

7.5 High Overland Movement Cost Models

The differences in results produced from study areas with small island chains vs. large landmass geographies illustrate the importance of working with a hybrid definition of landscape that includes both dry terrestrial areas and ocean waters. Maritime least cost analysis results are highly influenced by whether they are computed for areas which are predominantly terrestrial landscapes bordering bodies of water or are mainly marine seascapes that include small landmasses. The combination of the traditional definitions of landscape and seascape provides the theoretical flexibility which is necessary for working with methodologies that allow for analysis of different types of geographic environments. Modeling scenarios that allow for overland movement are more suitable for study areas and chronological periods with greater amounts of dry land. In contrast, the models that made overland travel very costly are better suited for landscapes that are composed of island chains and in which sea levels have fallen through time. The logic behind each of these approaches reflects the fundamental differences between the forms of transportation being used. The former scenario is predicated largely on travel by walking with short maritime segments, while the latter assumes the majority of the distance that is traveled will be covered by boat with short overland segments.

The results produced for Prince Rupert Harbour, the Dundas Islands, and Stephens Island that made the possibility of overland movement very costly produced movement routes that closely fit the expected patterns for Paleoamerican travel. In these locations, culturally based limitational knowledge was important in path selection and routes are highly clustered. Path directional mean remains to the east and northeast. Overall, this modeling scenario is a better fit for predicting movement through mostly marine landscapes. The application of the high overland movement cost modeling scenario to Prince Rupert Harbour provides a glimpse of how the products of this technique would manifest if applied to Haida Gwaii and the Alexander Archipelago. Paths through the maritime segments of these areas would be more accurately predicted using the high overland movement cost model, but due to the inherent geographic characteristics of these areas, applying this approach during time periods where the landscape is drained is not appropriate. High overland cost maritime least cost path modeling should be considered to predict travel through these locations when the researcher is only interested in the maritime segments or there is a significant body of water present. The methodology that eliminates overland travel should be applied to landscapes where landmasses are mostly contained inside the analysis extent and have large marine areas. In areas where marine travel may have been one segment of a larger overland journey, modeling scenarios should be used in which overland travel is not prohibitively expensive.

7.6 Predictions of Possible Site Locations

The identification of new possible site locations in my study areas was a useful byproduct of my larger investigation of the application of least cost path analysis to Paleoamerican maritime travel during the LPEH. Calculating the line density of the paths created from the weighting scenario which best predict marine travel, the one that was culturally weighted, reveals that archaeologists trying to find sites connected to peopling events on the Northwest Coast should look at locations which fit a specific set of criteria.

Sites as predicted by my models are equally likely to be located in marine environments that are immediately offshore of large landmass or currently located in the open ocean space between smaller islands. Sites should also be prevalently located in the southern half of study areas with the density of sites decreasing dramatically moving northward. The falloff of line density is more gradual to the east and west but the amount of lines moving through these areas is still much smaller than in the southern portions of study areas. In the modeling scenarios that allow overland movement, possible sites locations tend to cluster together, meaning that once a positive identification is made of human activity immediately adjacent areas also have a high chance of containing items of material culture. This means that extensive testing may be necessary to initially find sites, but once one is discovered, others should be relatively easy to locate. This trend is not true of the scenario that prohibits overland travel. The line density results from these models show a more random distribution of high probability areas that frequently do not border one another. The implications of this are that less initial testing may be necessary to discover new sites but that testing will have to be ongoing in order to continue to find new site locations. Further ground truthing and statistical testing as discussed below will be necessary to shed light on how sites are actually patterned and the underlying assumptions about the amount of terrestrial movement in the migration being modeled influence which modeling scenario should be used.

A final interesting aspect of the position of high probability site locations is that these results show that the movement corridor routes that fit the patterns described in the previous paragraphs were traveled much more heavily than others. These areas almost always stretch from the interior of the study area to a point on the boundary. These patterns could be used to determine optimal points of entry into study areas, which could be used to target survey efforts. Also these corridors of high site probability cells should be the first investigated and further work should be done to see why the paths passing through these areas appear to be so much more heavily traveled than other nearby paths.

These site prospection results are preliminary and much further work is needed to fine-tune our ability to discover new sites based on least cost path modeling. In the next section I offer a detailed summary of the next steps that should be taken to create applications of the least cost paths analysis that could be used to better predict site locations.

7.7 Future Work

The results of my analysis create just as many questions as they attempt to answer. First among these new lines of inquiry is what would the results of an analysis that encompassed the entire Northwest Coast look like? There is significant practical value in running least cost analysis for specific small areas, especially given how local geography and sea level change influence path placement. An analysis using carefully placed boundaries which created a mostly marine environment in the study area would allow for the very high overland cost movement model to be applied to recreating LPEH migrations along the entire stretch of coast from Northern California to Southeast Alaska. Looking at movement on this scale has tremendous value because it allows for trends and patterns to become apparent that otherwise would be invisible. Running this analysis would most likely require supercomputing resources and new high-accuracy sea level curves for much of the coast. Once identified large-scale movement trends would allow for even greater accuracy in selecting specific areas for analysis by archaeologists. It might also provide insight into changes in Paleoamerican landscape knowledge over time.

A crucial step in the creation of any archaeological site prospection model is ground truthing activities where researchers test their predictions in the real world. The results that have been generated for my study area should be tested in this manner to see if the patterns and trends that are projected are actually displayed in the archaeological record. I would recommend testing both sets of site prospection results I created for the Dundas Islands, because this area has a history of previous archaeological research and is a good proxy for other areas of the Northwest Coast both environmentally and culturally. Unrestricted and very high overland movement cost analysis was conducted for this area, allowing for a comparison of these two techniques. Most importantly, ground truthing would allow for the different movement cost-weighting scenarios to be compared and a determination made of which one most accurately predicts the activity of mariners in the deep past. The ocean never inundated the Dundas Islands and underwater archaeology methods would not need to be employed to test model results. In terrestrial locations, excavations or shovel test pits could be used to look for the presence of human activity and materials for radiocarbon dating would need to be collected to verify the antiquity of any discovered sites. Lastly, time and resources allowing, looking at Haida Gwaii or the Alexander Archipelago would be useful given the very different sea level histories of these locations.

If traditional "boots on the ground" model accuracy assessment is not possible, there are also a variety of statistical tests that could be conducted to gain useful information about the accuracy of this methodology. Visual comparison was sufficient to answer the questions that I posed, but techniques such as regression analysis, geospatial statistics, and gain comparison can provide a more robust analysis. "Regression analysis allows you to model, examine, and explore spatial relationships and can help explain the factors behind observed spatial patterns" (ESRI 2013b:1). In the context of least cost paths and site prospection, regression tests would allow for the determination of the extent to which the different input variables used in my model are responsible for the absence or presence of past human activity. This would allow cost variables that are not related to Paleoamerican movement logic to be removed from the analysis and for the better assignment of variable influence in the creation of weighting scenarios.

Another statistical tool that would be very valuable is the computation of Kvamme's Gain. This is a statistical test that allows for the comparison of the overall predictability of different models (Kvamme 1988:325-328). This is a relatively simple calculation designed for testing archaeological predictive models in which the value of the gain equals the percentage of the total area covered by the model divided by the percentage of total sites within the model area. As the gain value approaches one the model has greater predictive value, and conversely as the gain approaches zero the model's predictiveness decreases. The value of this statistic is in comparing different models and would allow for the identification of the modeling scenarios and weighting criteria that are most useful. Kvamme (1988:330) specifically discusses the application of this technique to Paleoamerican contexts and stresses the need for adequate site sample sizes. Currently, as identified in the Canadian Archaeological Radiocarbon Database there are only 26 unique sites on the Northwest Coast that predate 8,000 cal. yr BP (Canadian Archaeological Radiocarbon Database 2015). This is a problem that must be circumvented prior to the application of gain statistics to maritime least cost path analysis. However, with a sufficient sample size of site locations, friction surfaces could be reclassified into low, middle, and high probability areas and Kvamme's Gain determined.

Lastly, the Getis-Ord General-G test, commonly referred to as hot spot analysis, could be conducted to mathematically determine areas where high and low movement costs cluster (ESRI 2013a). This is an inferential statistic, the results of which must be interpreted within the context of a null hypothesis. In this test, the null hypothesis is that there is no spatial clustering present in the data. A z-score and p-score are determined for the input data and used to accept or reject the null hypothesis as well as determine whether high values or low values are clustering. Friction surface values could be converted to vector data and then passed through this process to locate areas to be targeted for further analysis. This tool is not contingent on having a specific sample of site locations and side steps the previously discussed issues with the number of known old sites. Statistical tests offer a low-cost alternative to field testing that can provide many of the same types of information as ground truthing. However, these should not be seen as a perfect replacement for this process and should be used to complement them.

7.7.1 Structural Changes

My methodological and theoretical framework influences the results that were produced in this thesis and there are several changes that I would make to these structures if this work is repeated. The first set of changes I would make is theoretical. In my definition of landscape, I did not account for the presence of glaciers and ice sheets through time. Previous work with least cost analysis of Paleoamerican migration has demonstrated that including the location of ice sheets in analyses significantly alters results (Anderson and Gillam 2000:47). Oral-histories also provide evidence for the importance of ice in the recent past and it is fair to assume that ice would have been even more important in earlier periods when it was far more plentiful (Cruikshank 2005:5). A glacial-sea-land-scape would be a more appropriate conception of the physical environment for modeling Paleoamerican movement. Incorporating glacial features as very high movement cost areas in friction surfaces would significantly change what locations were viable for human travel. I would categorize the absence and presence of glaciers as an environmental variable for the purpose of calculating weighting scenarios and the inclusion of ice sheets in this analysis could potentially improve the poor predictive ability of the environmentally weighted modeling scenarios.

Another change I would make is to modify the placement of migration origin points. When placing starting locations it would also be useful to run scenarios in which origin points were only located on marine environments. This would fully eliminate the possibility of a terrestrial origin for migration events and would better recreate the path of purely maritime movement events, especially when combined with the very high overland movement cost analysis methodology.

Based on the results that I observed from my analysis I would reconsider the structure of Paleoamerican migrations that I used. In the future I would assume a general north to south movement event orientation punctuated with eastward moving forays into protected environments. These deviations from the overall direction of migrations could either represent attempts to travel through parts of the landscape with lower movement costs or efforts to establish waypoints along the journey. This stands in contrast to Anderson and Gillam's (2000) findings; however, the origin and destination point placement in their model forced a north to south movement orientation and their results may not actually reflect the reality of movement events. I think that all of these changes to the structure of migration events would lead to greater predictive capabilities for maritime least cost path models.

Methodologically, I would make several minor changes to my work. In determining the environmental costs of movement I would like to find a better method for estimating past stream locations on drowned landscapes. The technique for estimating stream location available in the software I used greatly overestimates the number of past streams and more accurate techniques may be available with more advanced hydrology modeling tools. This is a change that could make the environmental weighting scenario more accurate.

When determining the physiological cost of movement instead of calculating Euclidean distance from the origin points, I would determine movement cost as origination at landmasses moving outward towards origin points. The existing movement calculation technique works well for the small landscapes that I ran my proof of concept tests on. However, this approach is not as useful for large landscapes like Haida Gwaii and the Alexander Archipelago. Running distance calculations from landmasses would create a better approximation of the difficulty of reaching different locations. I would also like to include more detailed information on how ocean currents affected maritime travel in the past. Madonna Moss (2008) has demonstrated the importance of tidal seascape features in navigating the Northwest Coast by canoe and similar factors should be considered for Umiak travel.

The process of calculating the cultural costs of movement could also be refined. The process of locating straights and passages in my methodology could be improved by developing tools that can topologically identify the coastlines that bound these features. The current approach is clumsy and erroneously identifies some open ocean shorelines as being located in straits and passages.

Additionally, when combining movement cost variables to create different weighting scenarios, I would individually factor in all of the inputs that make up the near shore travel corridor instead of lumping them together. In the current weighting scenarios the results of strait/passage presence, shoreline visibility, and protected waters analyses are summed together to compose the Near Shore Corridor. In the future I would not combine these variables and would individually include them in the calculation of friction surfaces, because this would allow for more flexibility in how weighting values are assigned in different scenarios. Related to this is the fact that the results of a regression analysis could be used to more appropriately determine how much influence each variable should carry in each weight scenario. When classifying data I would make greater use of the Jenks method to determine cut-off points for cost values when ethnography, oral histories, or archaeology do not supply a reclassification value. Lastly, there are several places where human operator error can produce small differences in the models used for different study areas. I do not believe these differences significantly change the analysis results, but greater automation of workflows using Python or another scripting language would ensure that models are identical between iterations. By changing how I think about LPEH human migrations and how I calculate the cost of moving through marine landscapes, least cost analysis of Paleoamerican migrations on the Northwest Coast can be made to better predict events in the deep past.

7.8 Limitations of Maritime Least Cost Analysis

The application of least cost analysis to questions about past human movement through marine environments is a powerful technique for gaining information about past human activity when used in the appropriate context. An awareness of the limitations of this technique is essential for its successful application. Issues that should be considered include computational limitations, study area geography, ability of inputs to reflect movement logic, spatial resolution, and temporal resolution. The datasets that drive this type of analysis can be quite large, containing hundreds of millions of data points. The geographic size and resolution of the analysis that can be run are determined by the computing resources that are available. Project scope should be considered in terms of these requirements and reasonable objectives determined. This will prevent both time and money being wasted on analyses that are unfeasible.

As was established above, the type of geography for which least cost path analysis is being applied determines the best methodological approach. For areas where travel was mostly maritime, models that reduce overland travel are the most appropriate. In locations where marine travel may have been a small component of a longer journey, models with unrestricted overland travel produce better results. When working in dynamic environments, analyses should be conducted at a variety of chronological points. The exact interval of time periods is determined by the archaeological context and the amount of time available for running the analysis. Smaller temporal windows will result in a larger number of model iterations.

Additionally, spatial resolution must be considered when planning an analysis. A researcher must determine what the appropriate balance of accuracy and computational requirements are for the movement events they are trying to recreate. General trends and pattern can be interpreted from course data but site prospection and large scale analyses looking at small areas need to be more accurate.

Any type of predictive modeling applied to archaeology is limited by the researcher's knowledge of the cultural group for who past activity is being recreated. In the context of Paleoamerican peoples, there is significant lack of information, which while providing much of the impetus for this project, also limits the accuracy of the least cost paths that are produced. The results of a least cost analysis are only as good as a researcher's understanding of what environmental and cultural landscape factors were viewed as detrimental or desirable by the people who were migrating through these places. If an accurate picture of this movement logic cannot be created, the model usefulness will be severely decreased. The underlying factors that limit this methodology are the time and money that a researcher is willing to invest and their understanding of the people they are studying. Once both of these obstacles have been navigated, analysis can begin.

7.9 Conclusion

My thesis work has addressed the research questions that I proposed. I investigated five different areas that are home to a rich history of human activity dating back thousands of years and which have been extensively studied by archaeologists. Using the foundation that my predecessors established, I applied the idea of transient explorers using limitational biogeographical knowledge to move through a world equally constructed from terrestrial and marine environments to construct a theoretical framework from which to apply landscape and migration to Paleoamerican maritime events. This understanding of past human movement was manifested through the identification of variables that would have facilitated maritime travel. These were then projected onto recreated past landscapes to identify the paths of least resistance through different areas on the Northwest Coast.

This thesis has demonstrated that least cost analysis can be applied to modeling LPEH migration events into the New World through marine landscapes and predicting the possible locations of new sites. Different movement cost modeling scenarios produce a spectrum of results, some of which are much more suitable for site prospection than others. The spatial and temporal resolution of the analysis play a significant role in the quality of the results that are produced, as does the physical geography of the study area. The comparison of different study areas and time periods produced new information about the movement patterns of Paleoamericans in the deep past. Most notably, this comparison showed that culturally weighted movement cost scenarios produced the best results for site prospection and the prevalent direction of movement was along a west to east axis. The application of this technique is limited by some factors and further work is needed to refine this approach. However, the results that were generated provide significant original insight into the history of the Americas. Least cost analysis of maritime movement is a young field which has much to contribute to archaeology and that will drastically change the way site prospection is carried out in coastal Paleoamerican contexts.

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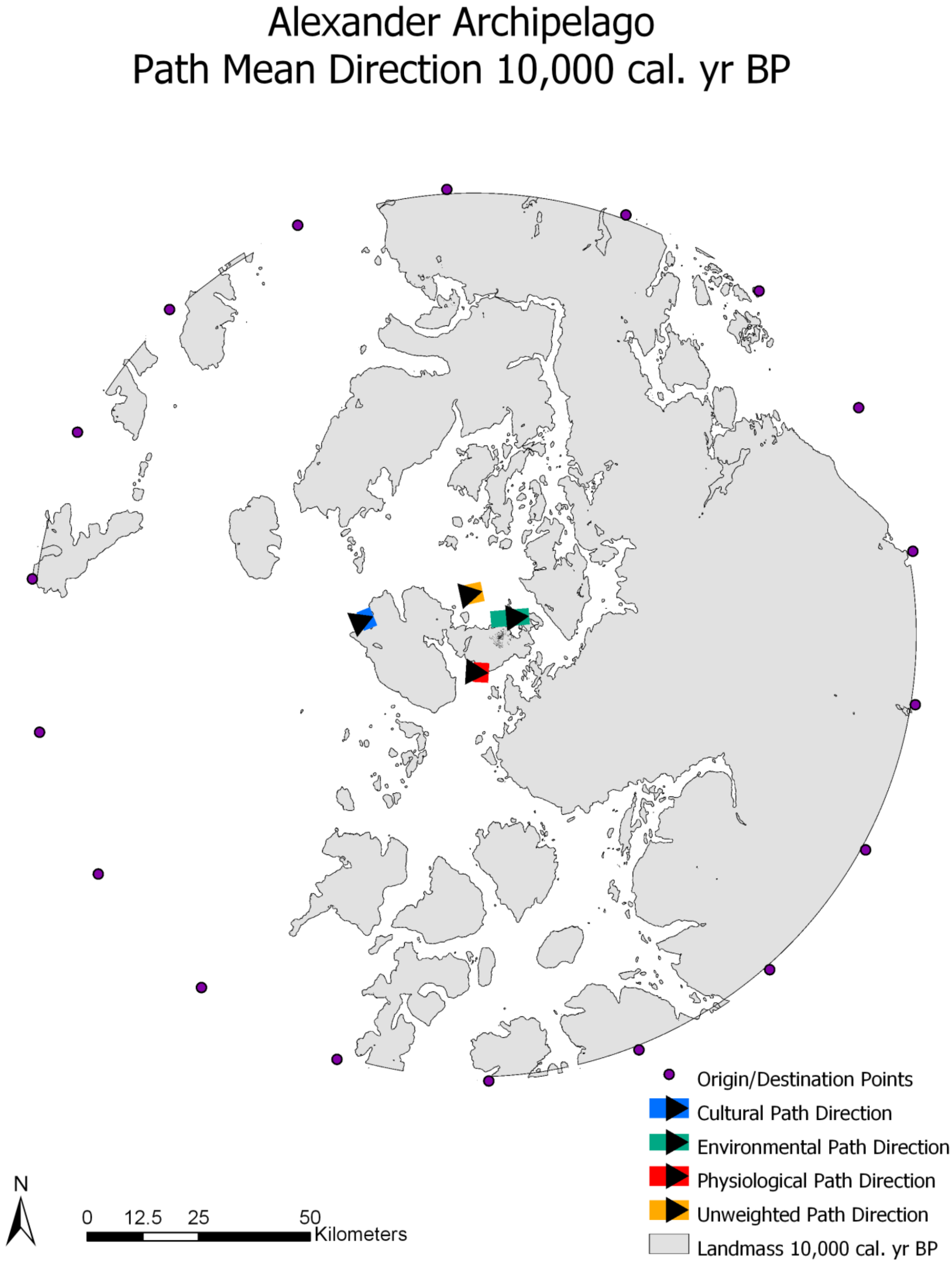
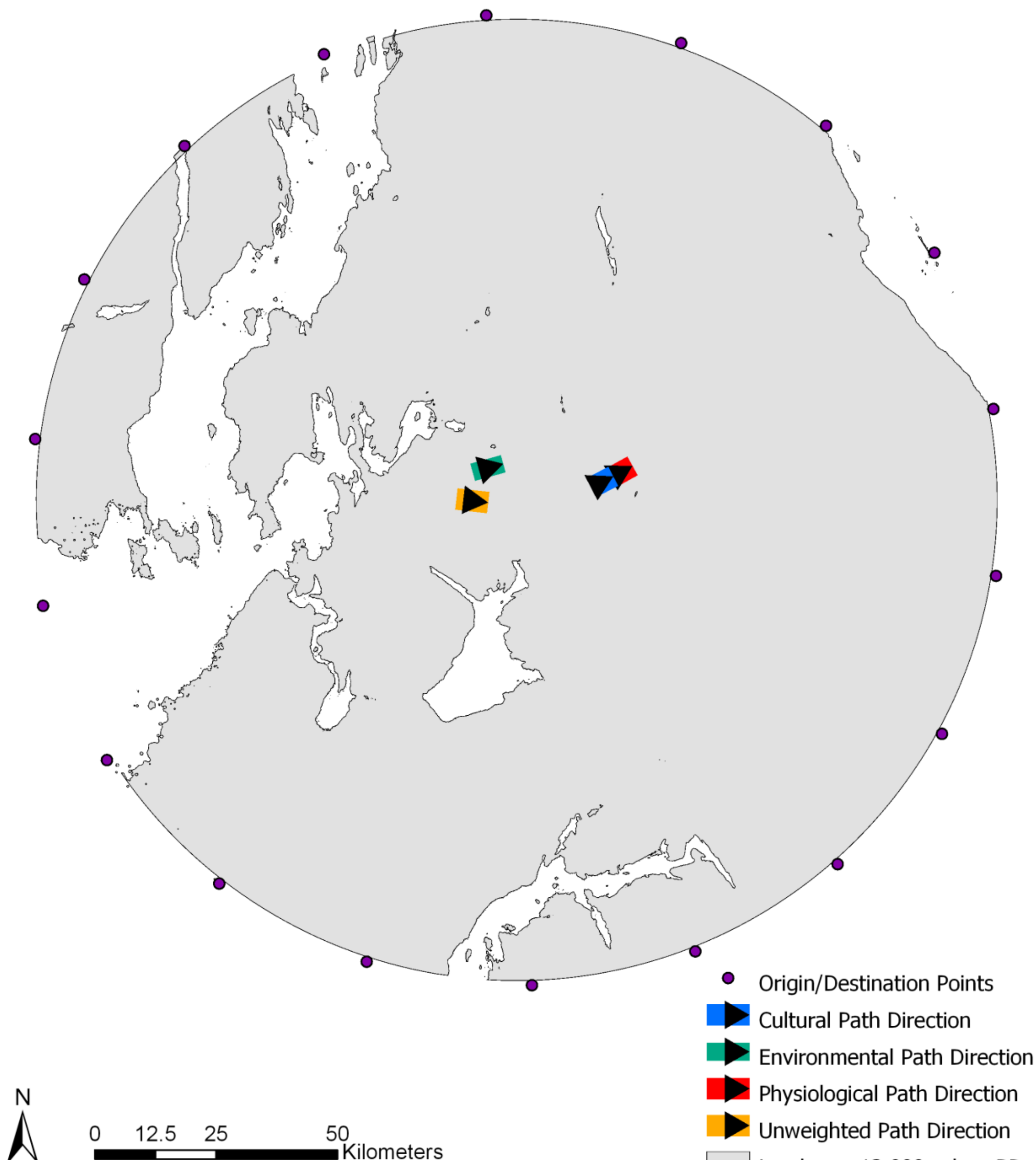
Appendix A: Path Mean Direction Results



Alexander Archipelago
Path Mean Direction 13,000 cal. yr BP



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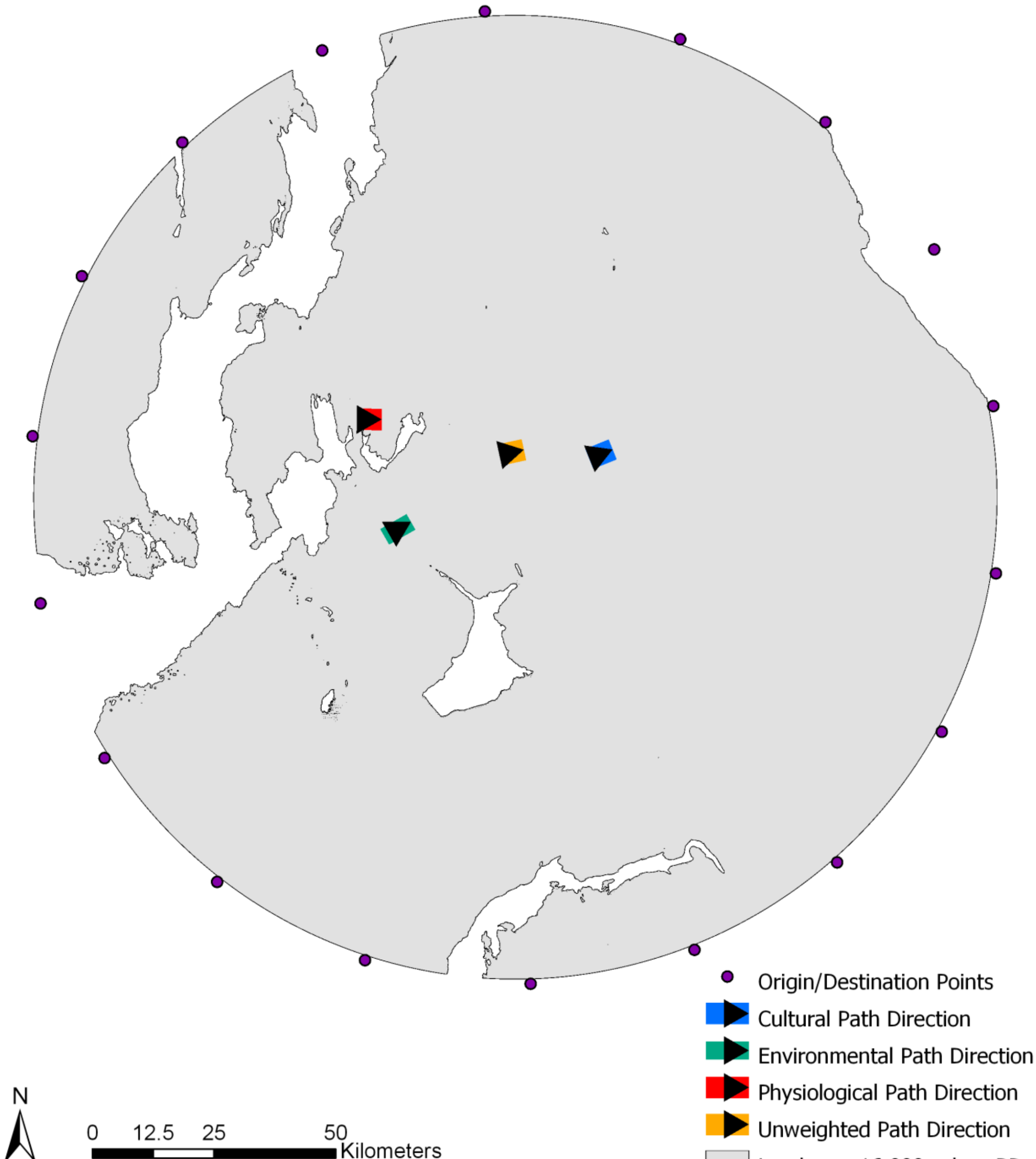
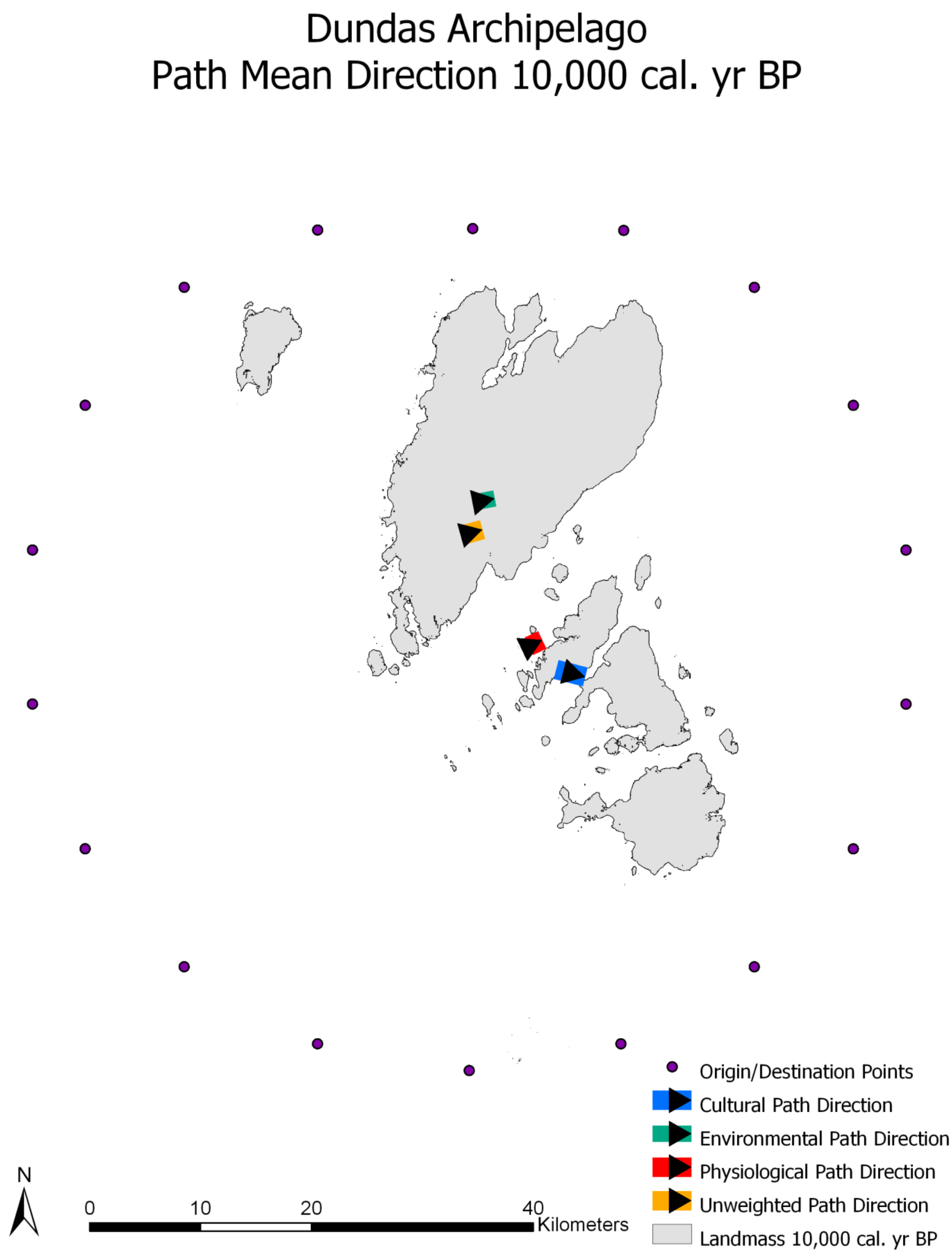
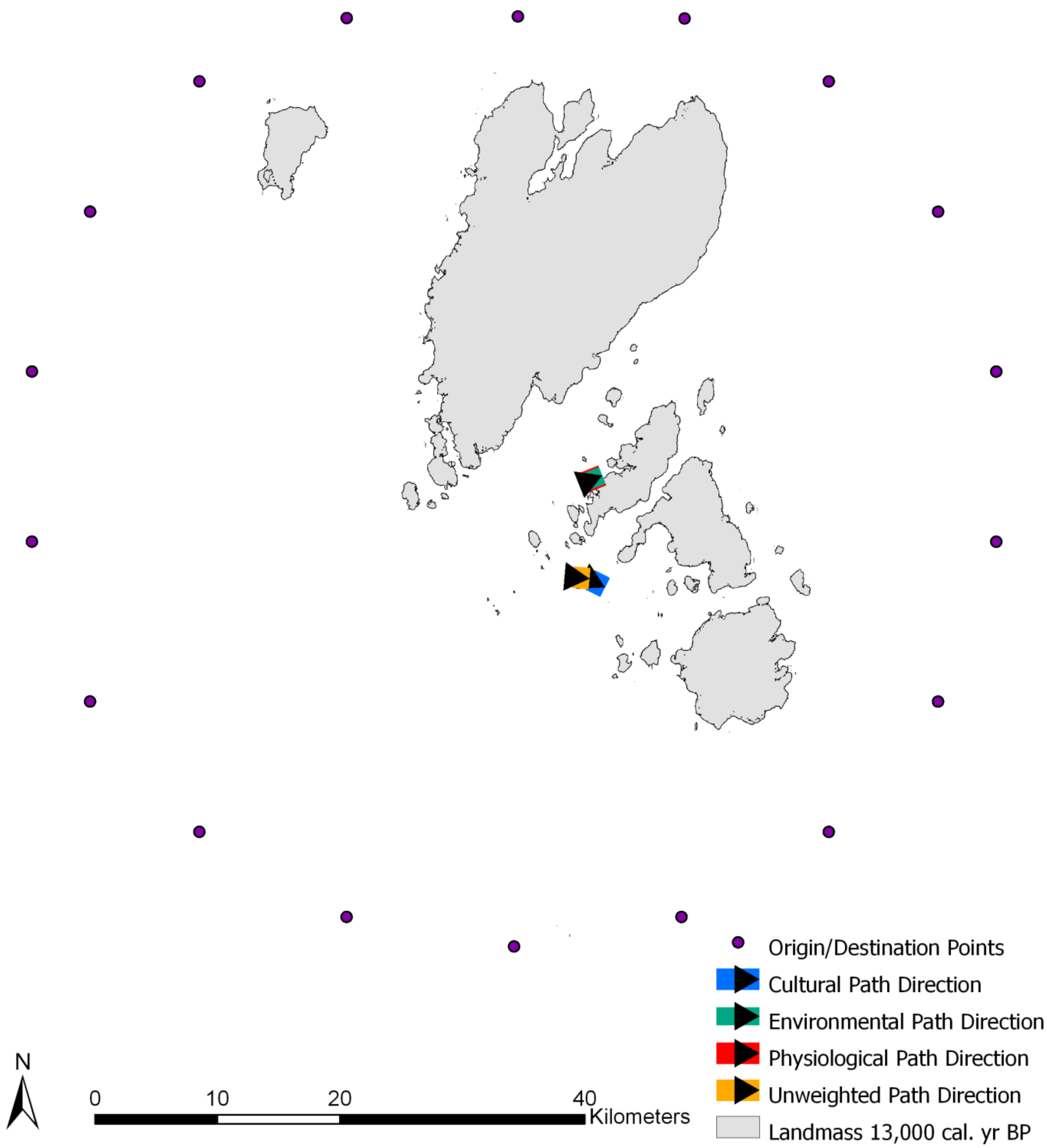
Path Mean Direction 16,000 cal. yr BP

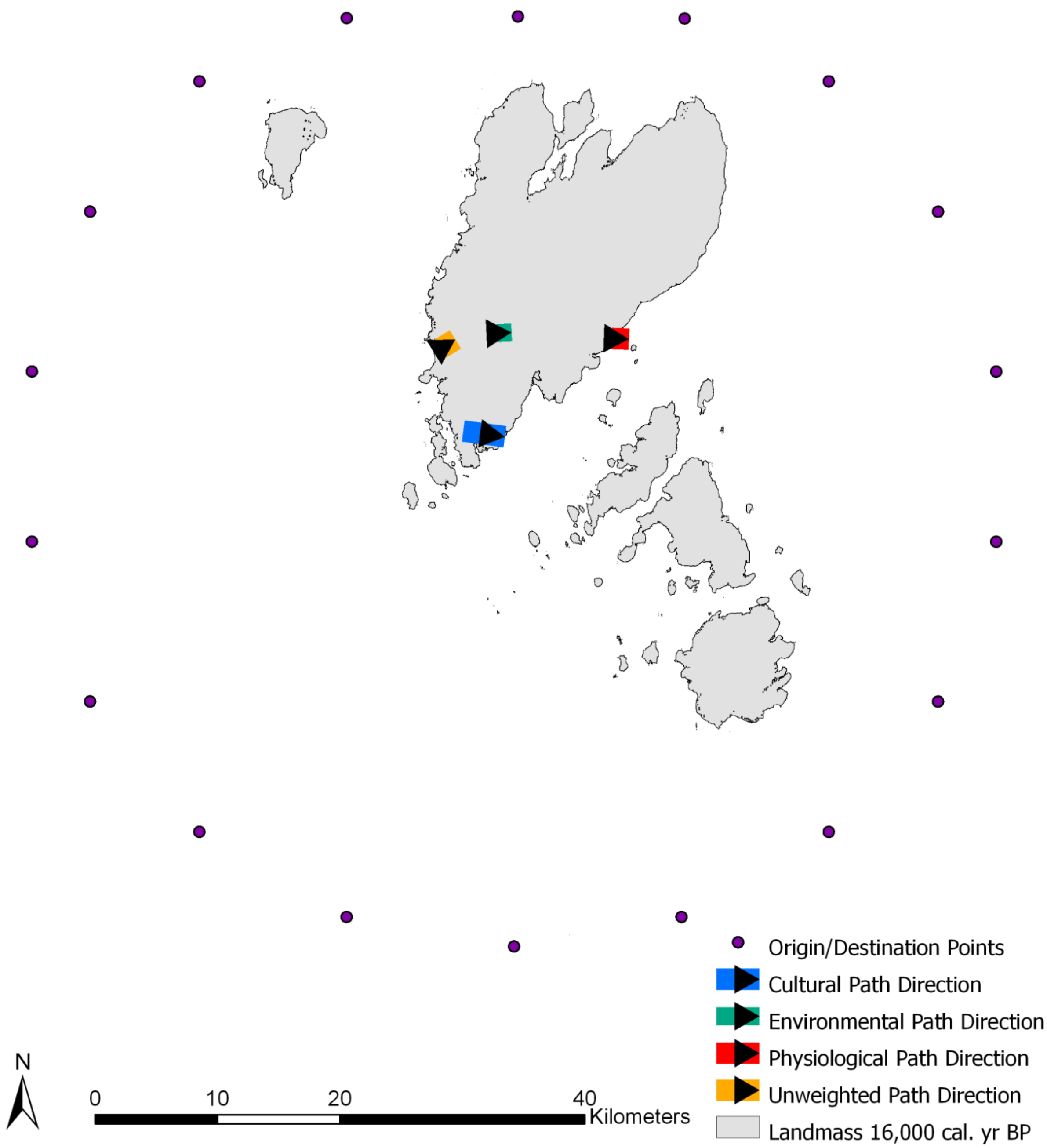



Dundas Archipelago
Path Mean Direction 10,000 cal. yr BP
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 10,000 cal. yr BP
N
0
10
20
40
Kilometers

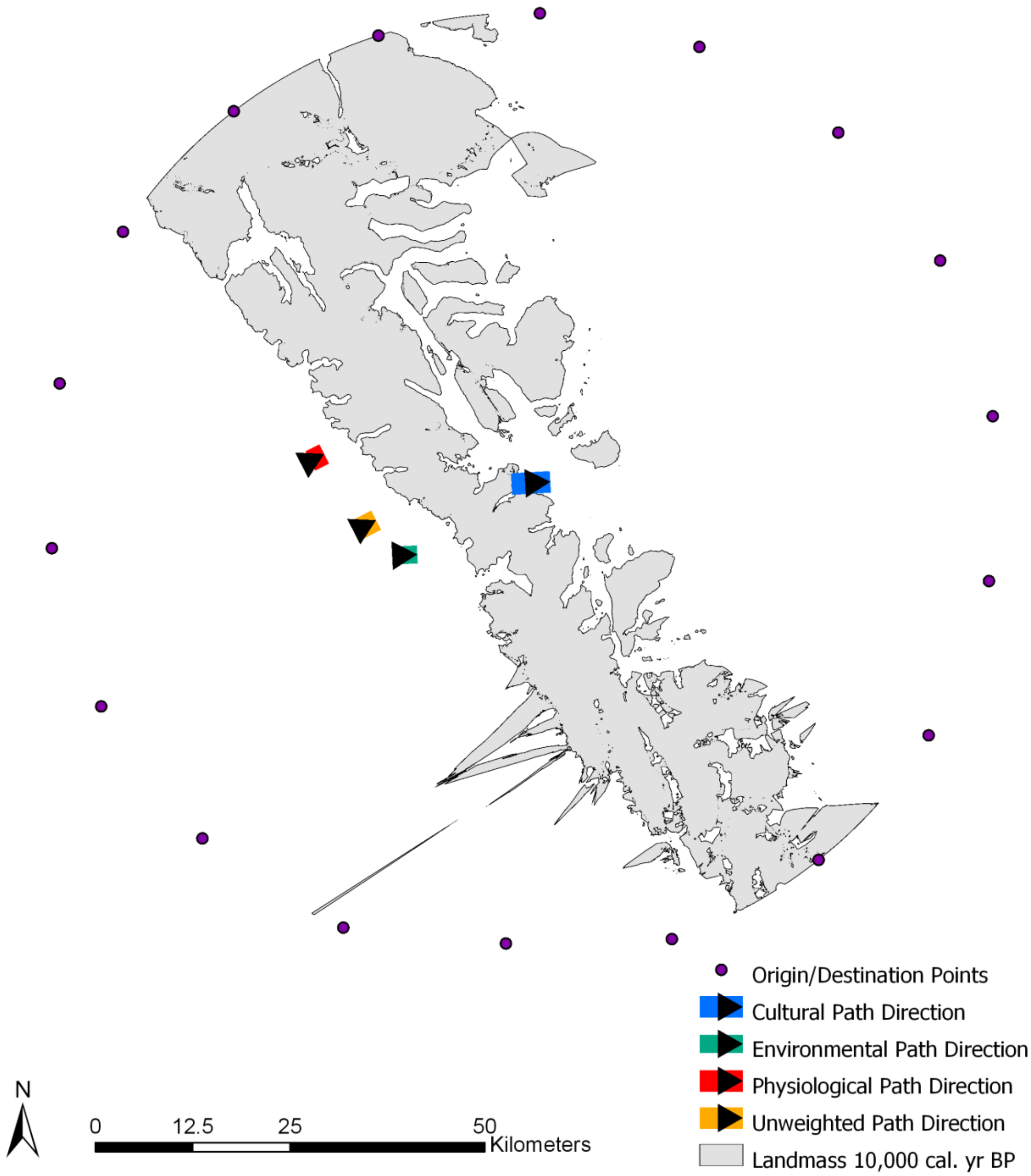
Dundas Archipelago
Path Mean Direction 13,000 cal. yr BP



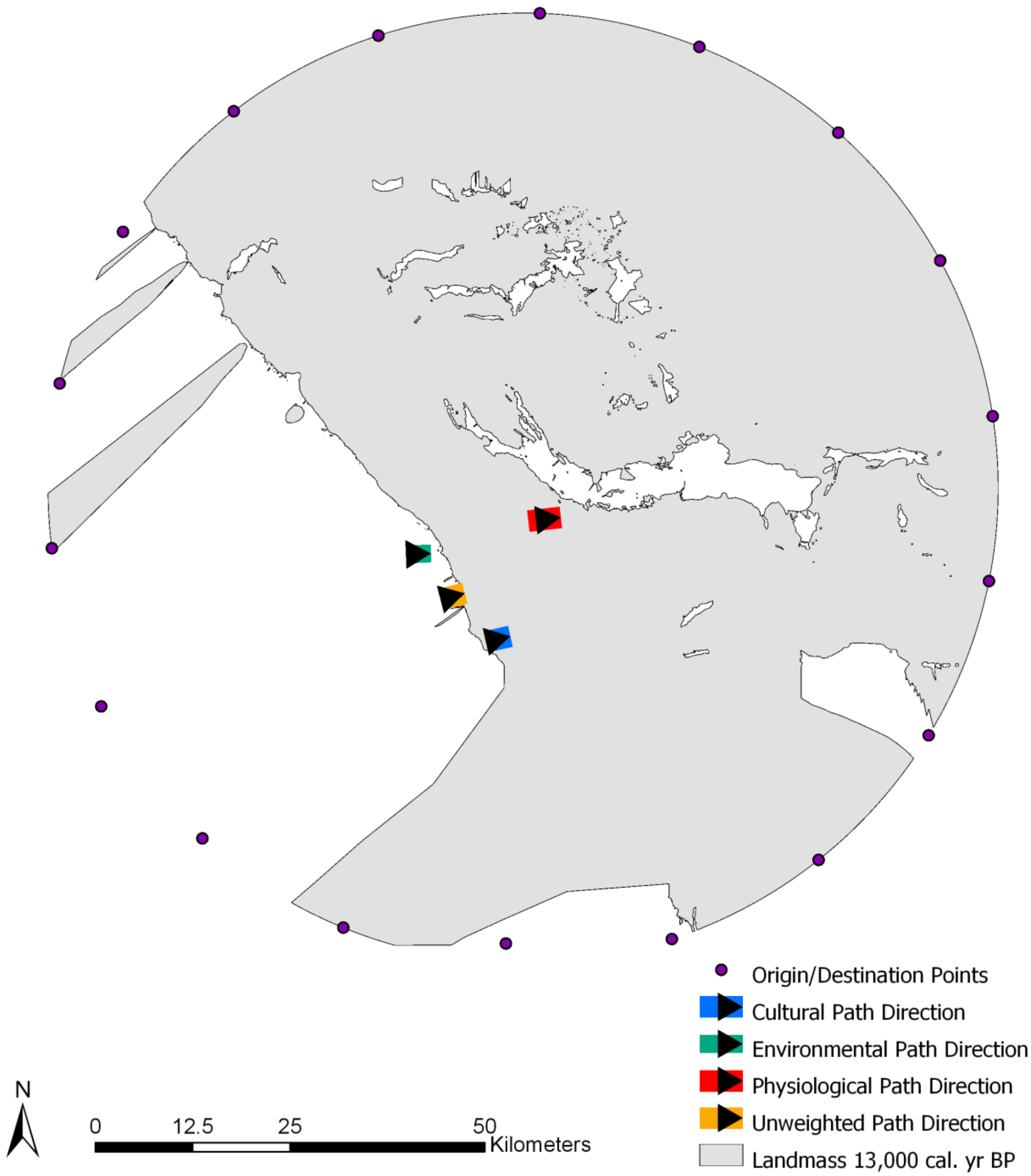
Dundas Archipelago
Path Mean Direction 16,000 cal. yr BP



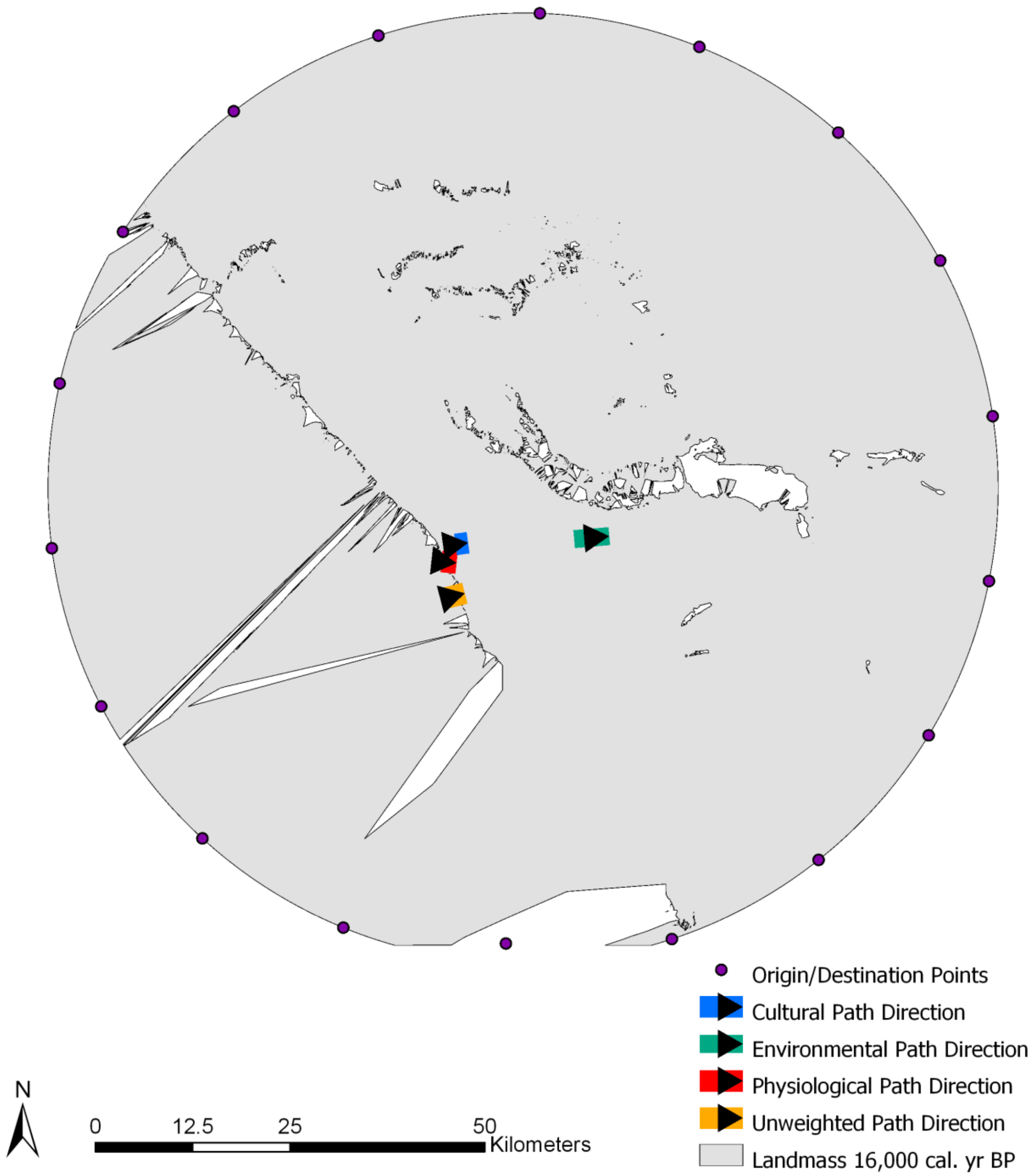
Haida Gwaii
Path Mean Direction 10,000 cal. yr BP



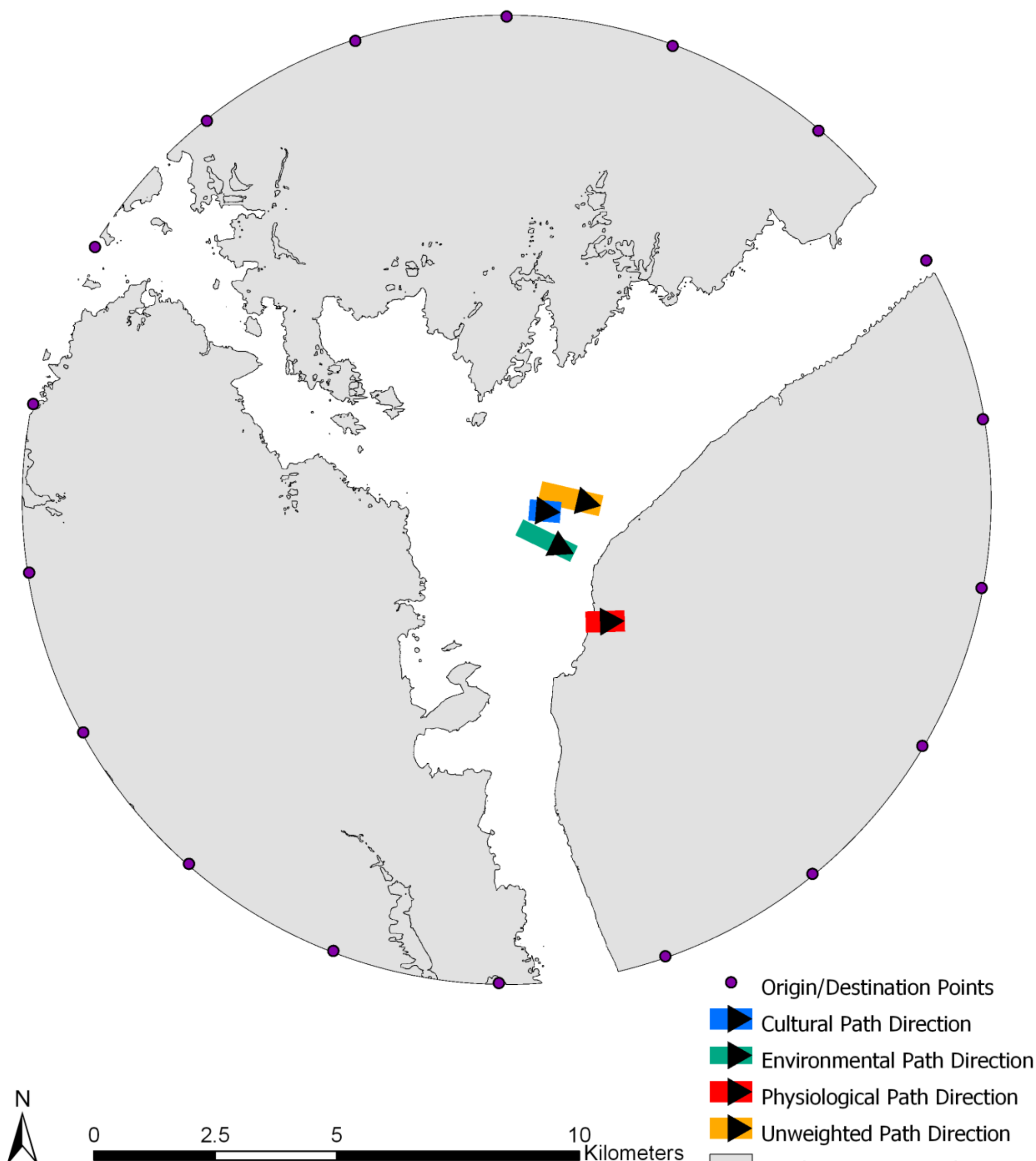
Haida Gwaii
Path Mean Direction 13,000 cal. yr BP

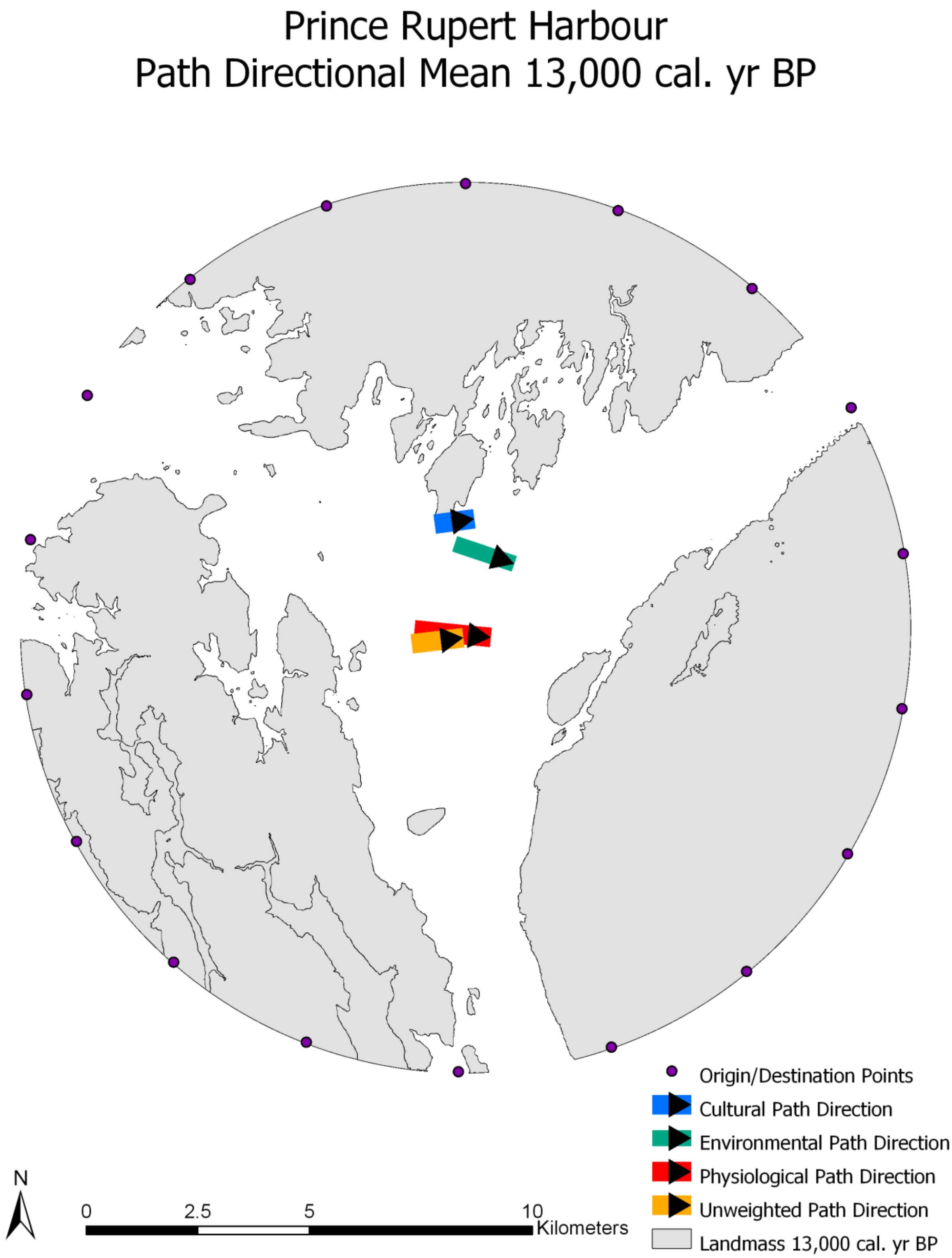


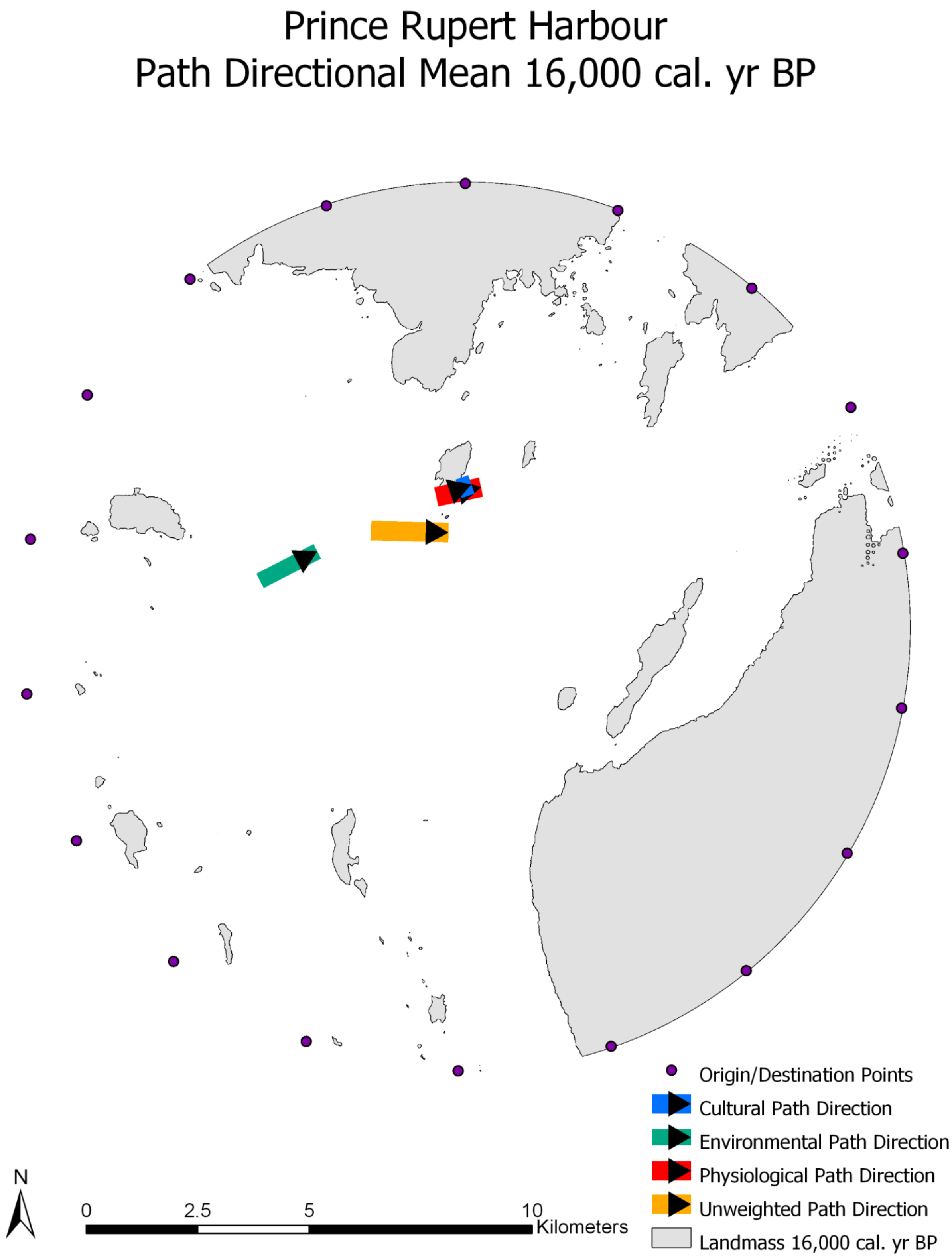
Haida Gwaii
Path Mean Direction 16,000 cal. yr BP



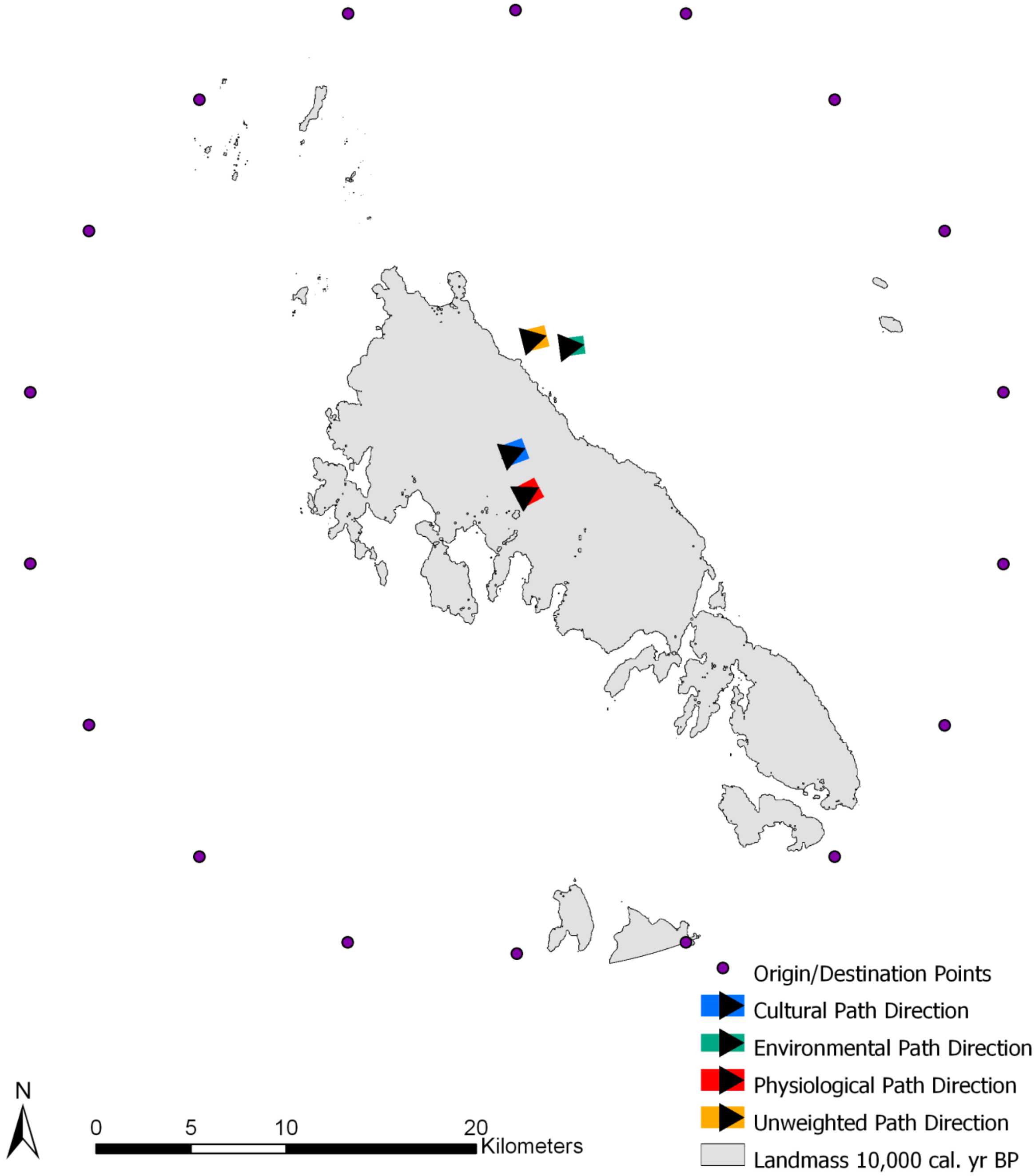
Prince Rupert Harbour
Path Directional Mean 10,000 cal. yr BP

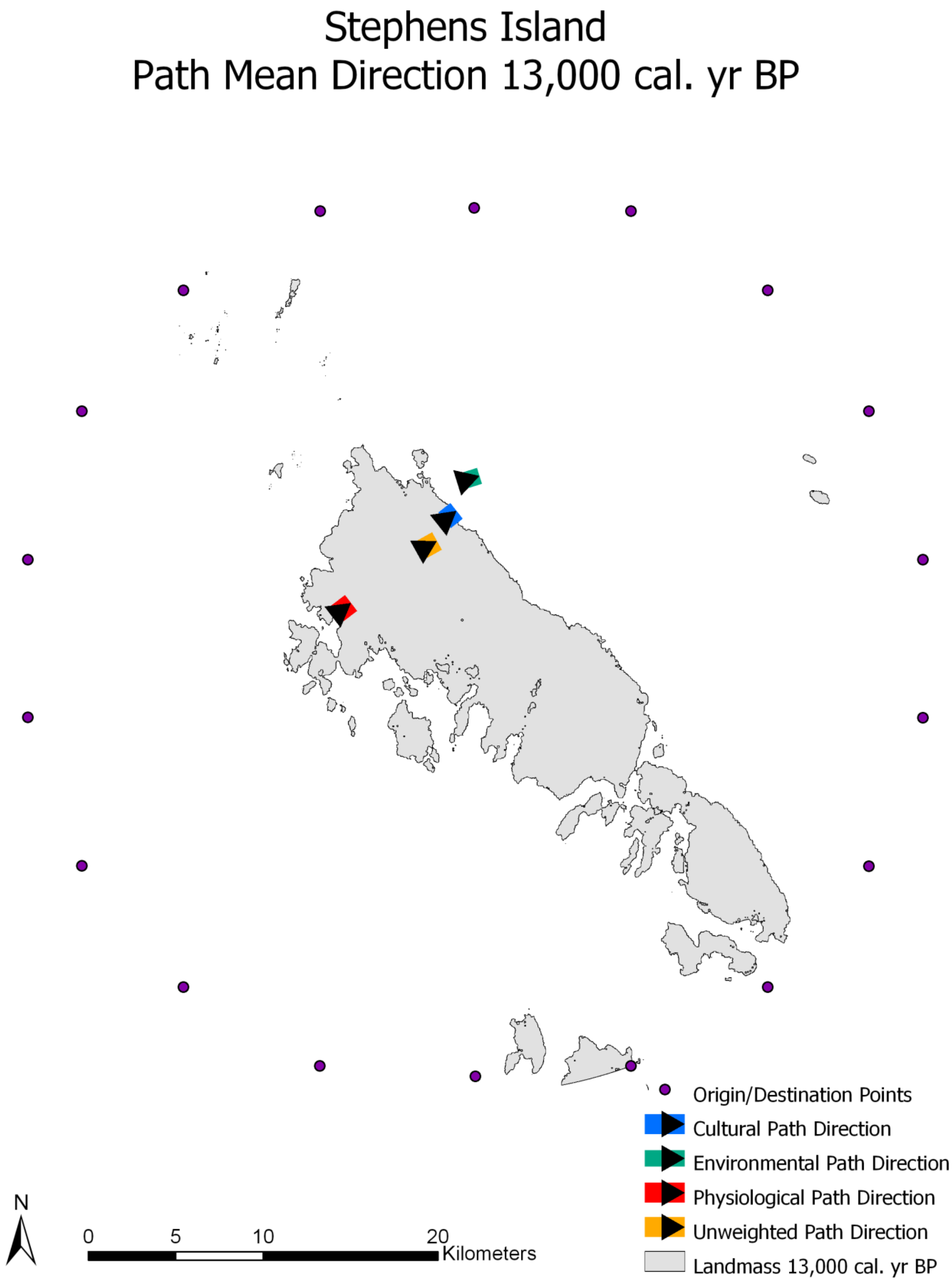



Prince Rupert Harbour
Path Directional Mean 13,000 cal. yr BP
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 13,000 cal. yr BP
N
0
2.5
5
10
Kilometers

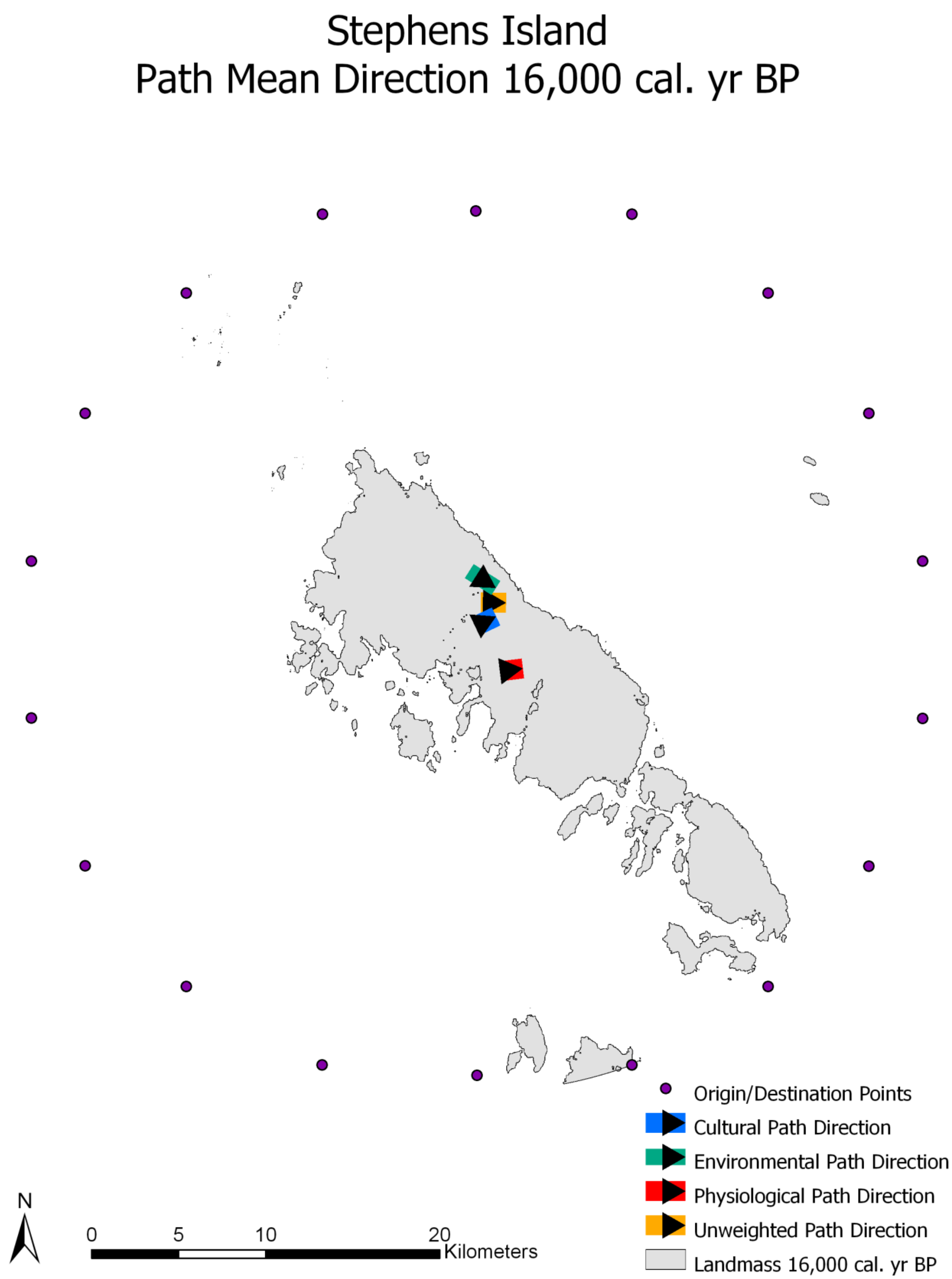

Prince Rupert Harbour
Path Directional Mean 16,000 cal. yr BP
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 16,000 cal. yr BP
N
0
2.5
5
10
Kilometers

Stephens Island
Path Mean Direction 10,000 cal. yr BP



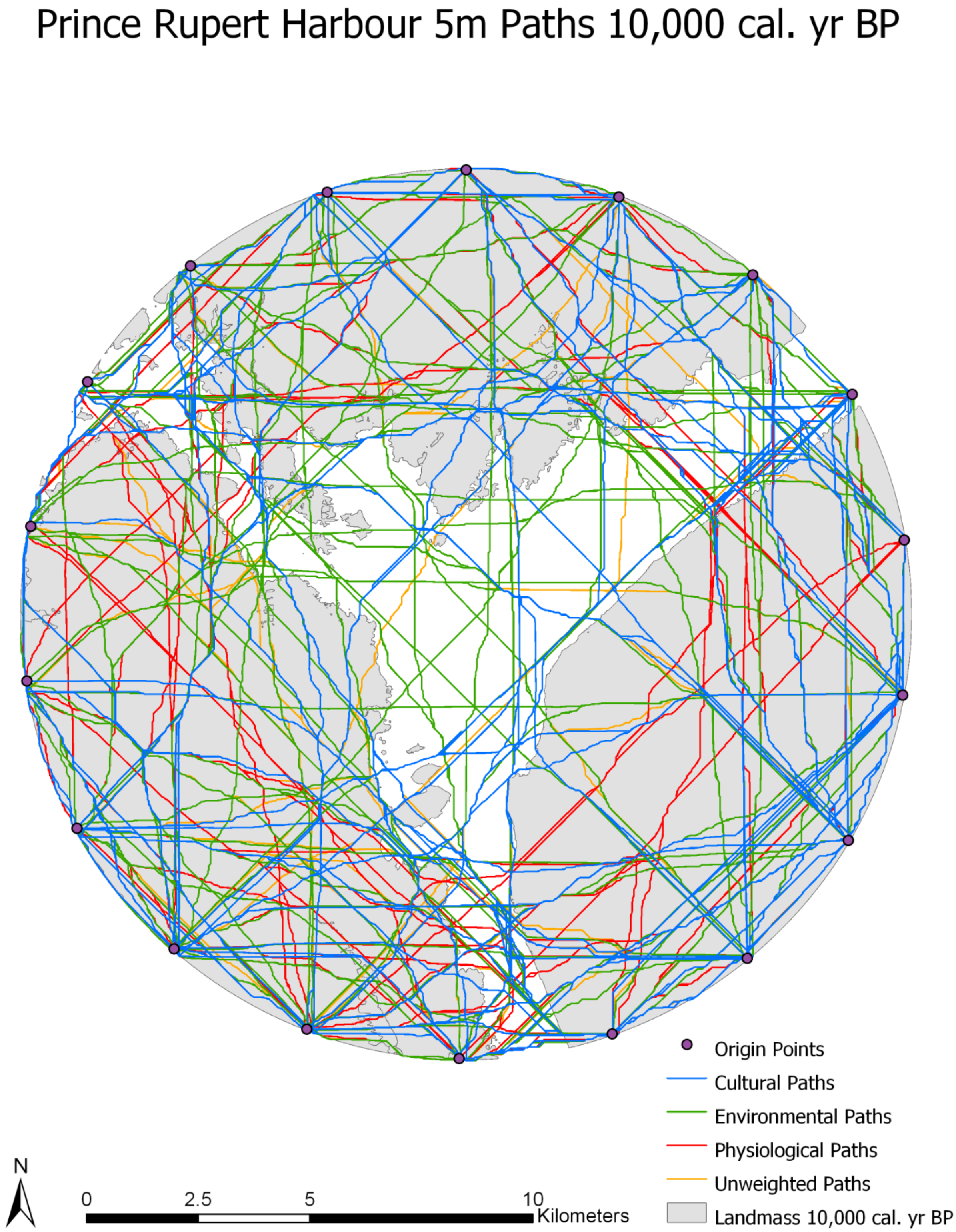


Stephens Island
Path Mean Direction 13,000 cal. yr BP
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 13,000 cal. yr BP
N
0
5
10
20
Kilometers

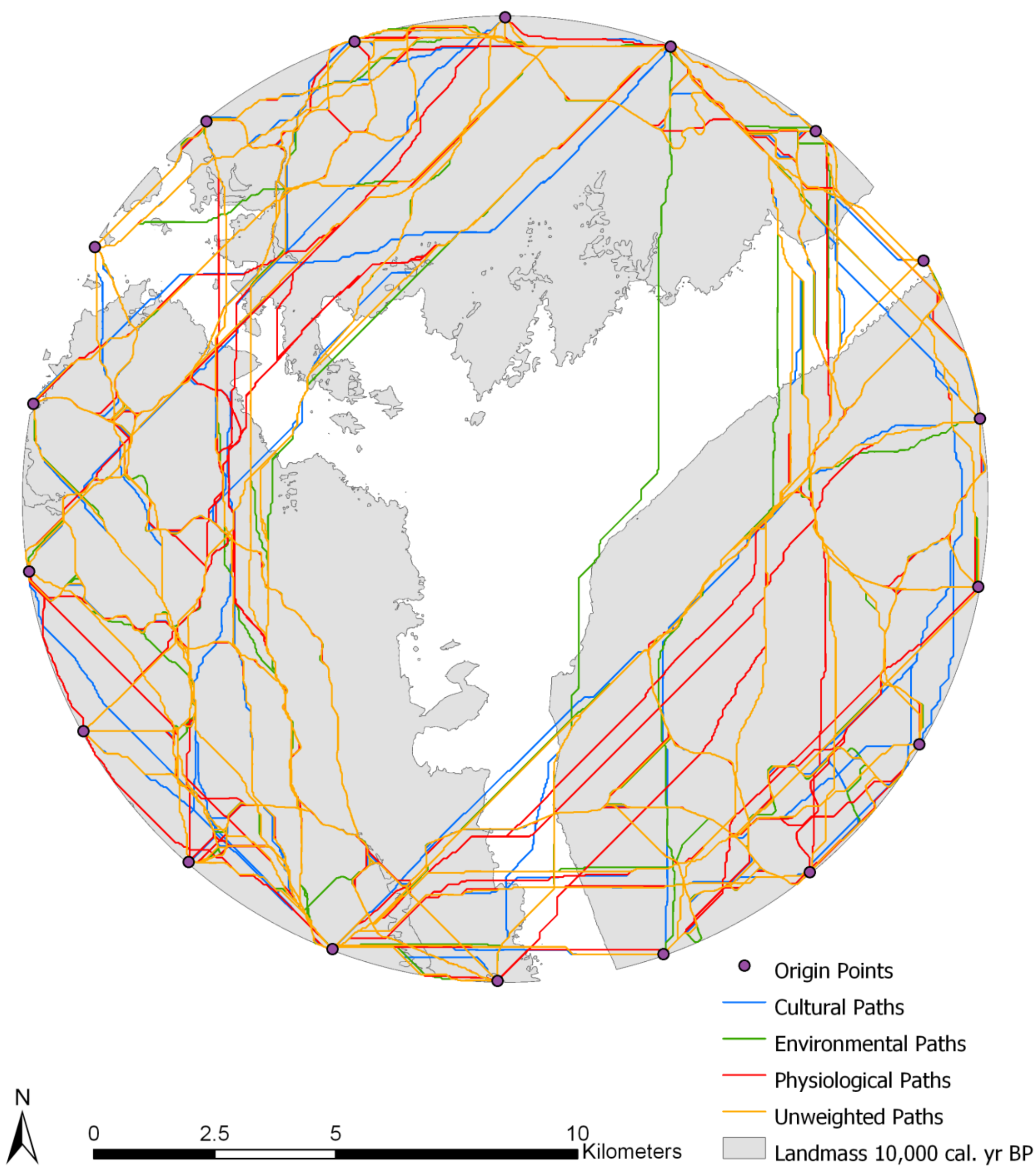


Stephens Island
Path Mean Direction 16,000 cal. yr BP
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 16,000 cal. yr BP
N
0
5
10
20
Kilometers

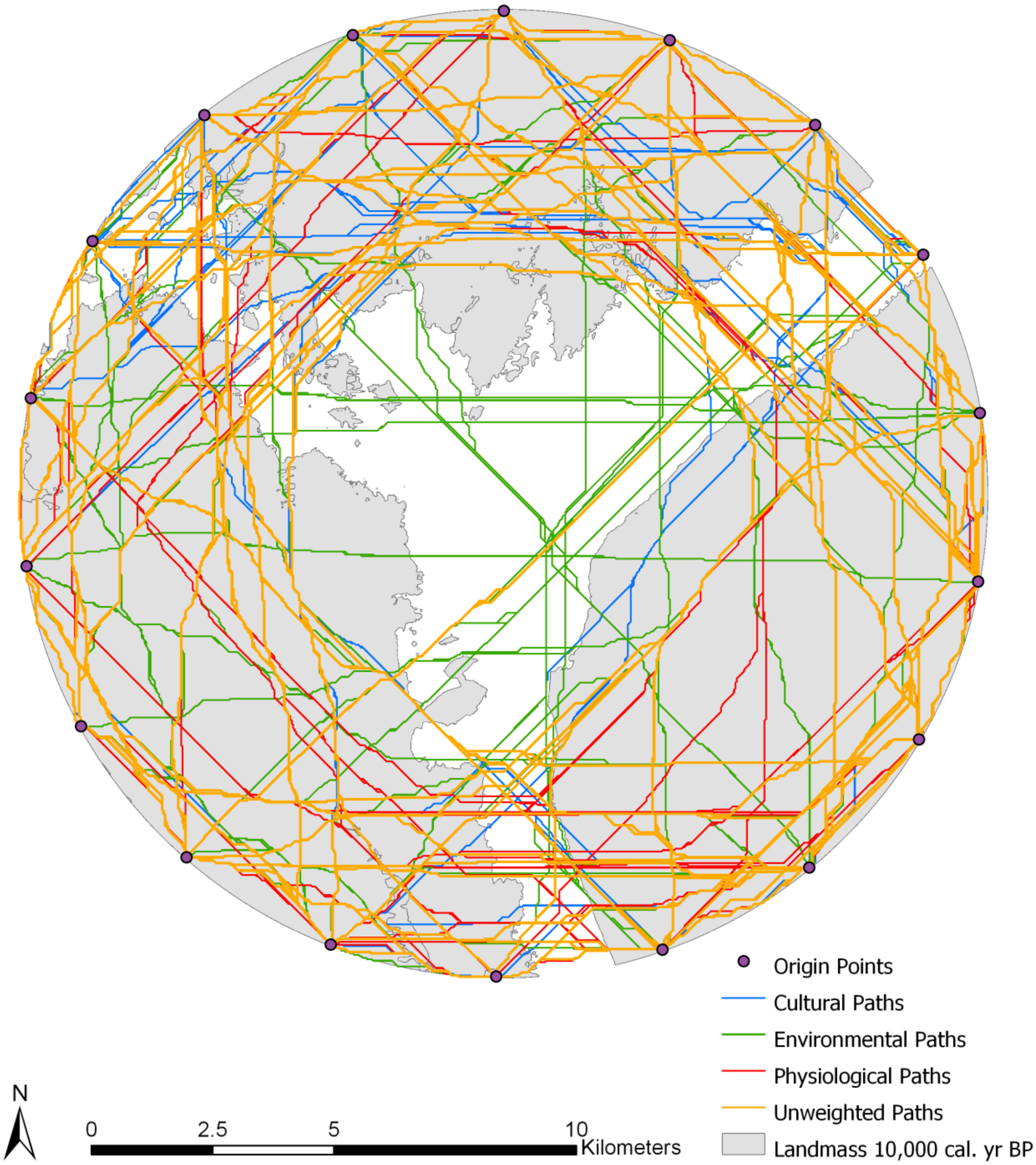
Appendix B: Data Resolution Comparison – Prince Rupert Harbour



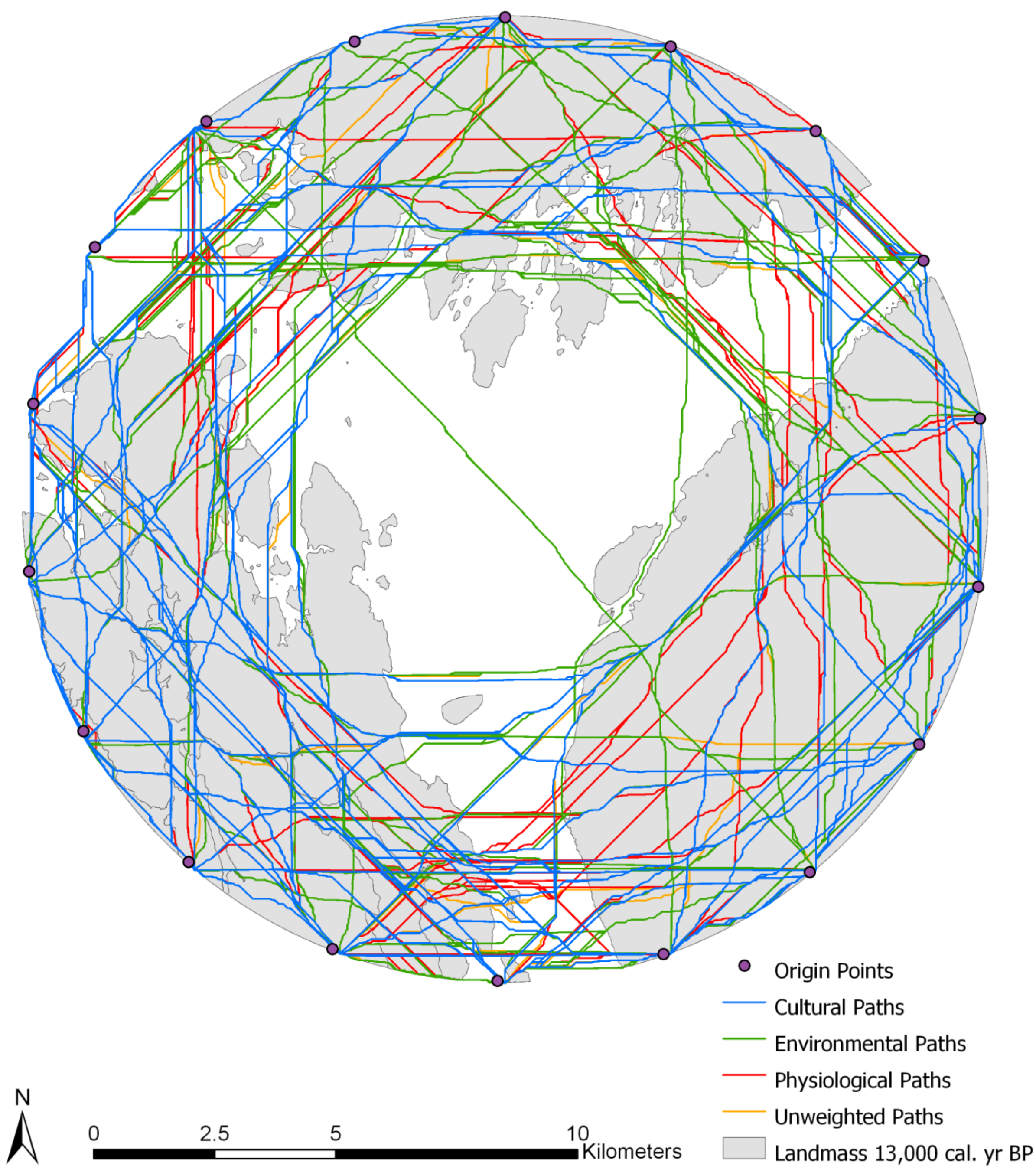
Prince Rupert Harbour 10m Paths 10,000 cal. yr BP



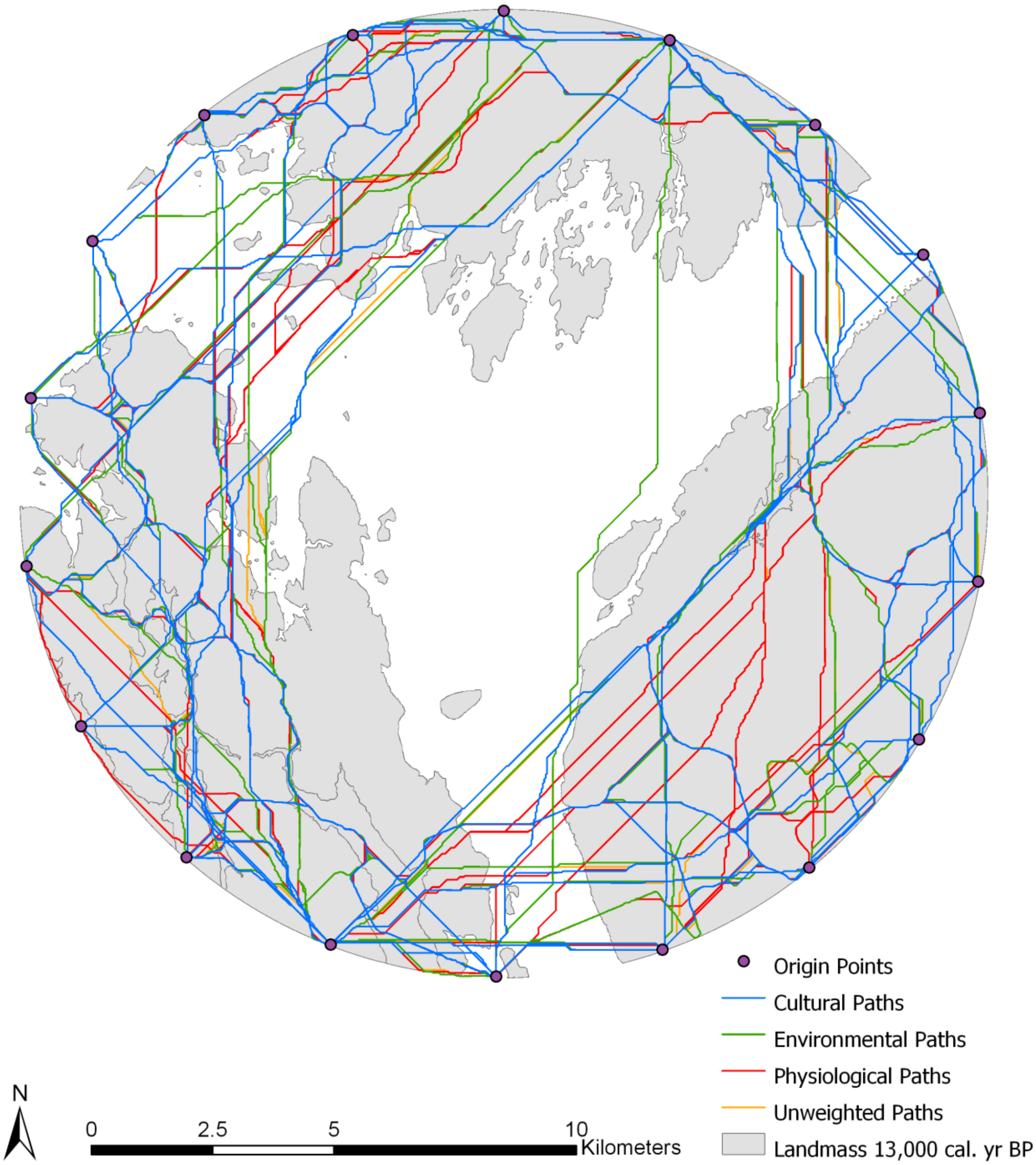
Prince Rupert Harbour 30m Paths 10,000 cal. yr BP



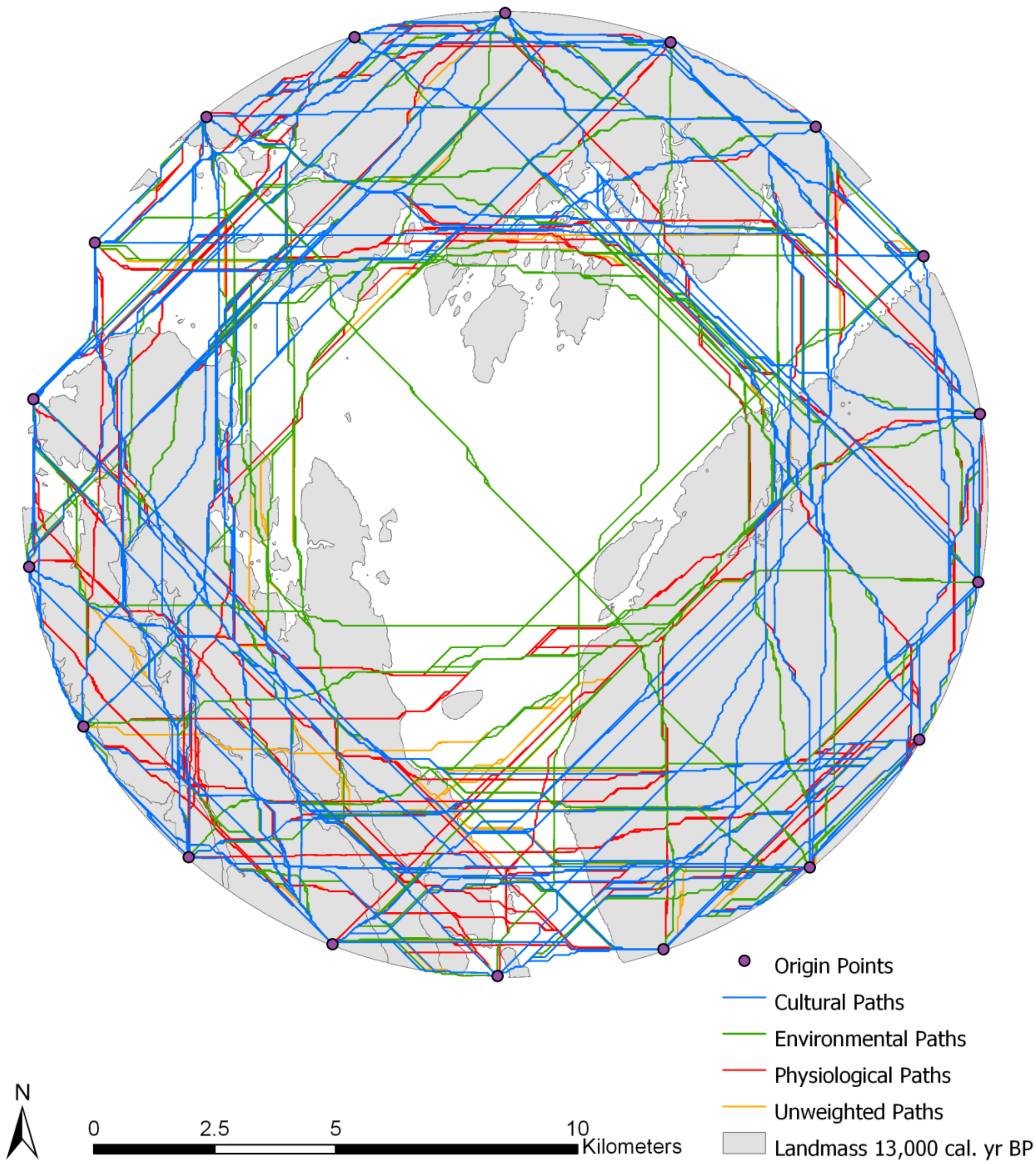
Prince Rupert Harbour 5m Paths 13,000 cal. yr BP



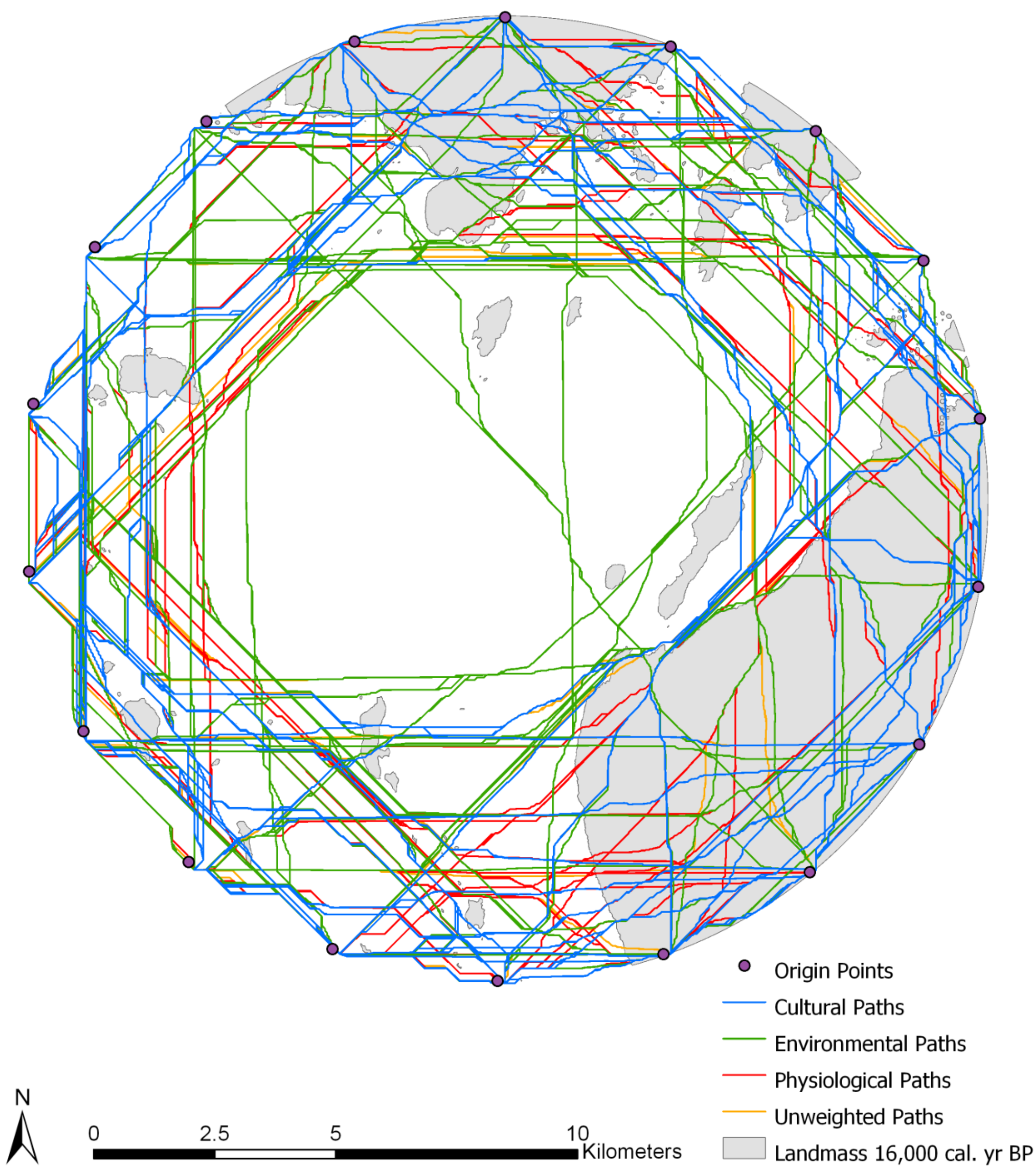
Prince Rupert Harbour 10m Paths 13,000 cal. yr BP

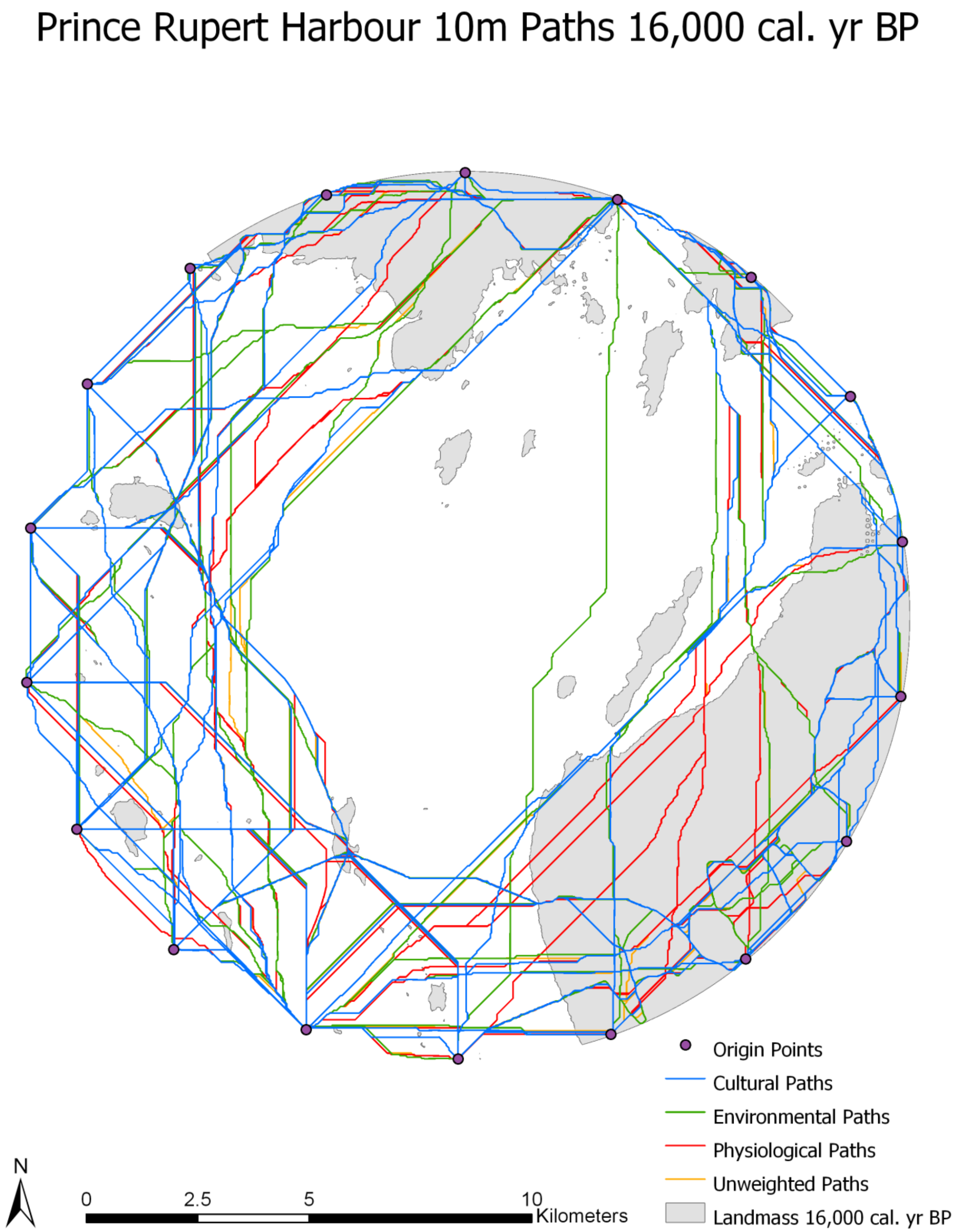


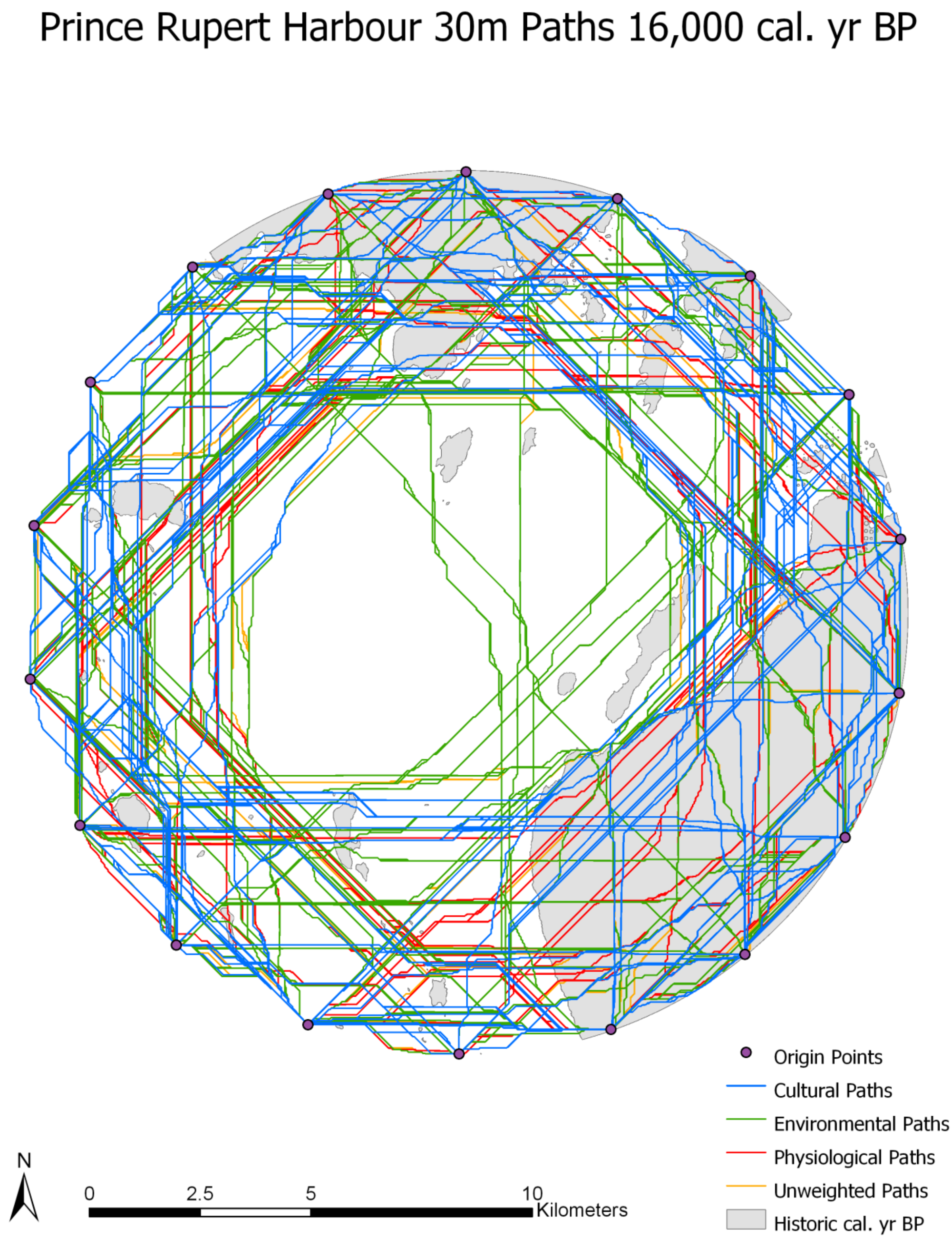
Prince Rupert Harbour 30m Paths 13,000 cal. yr BP



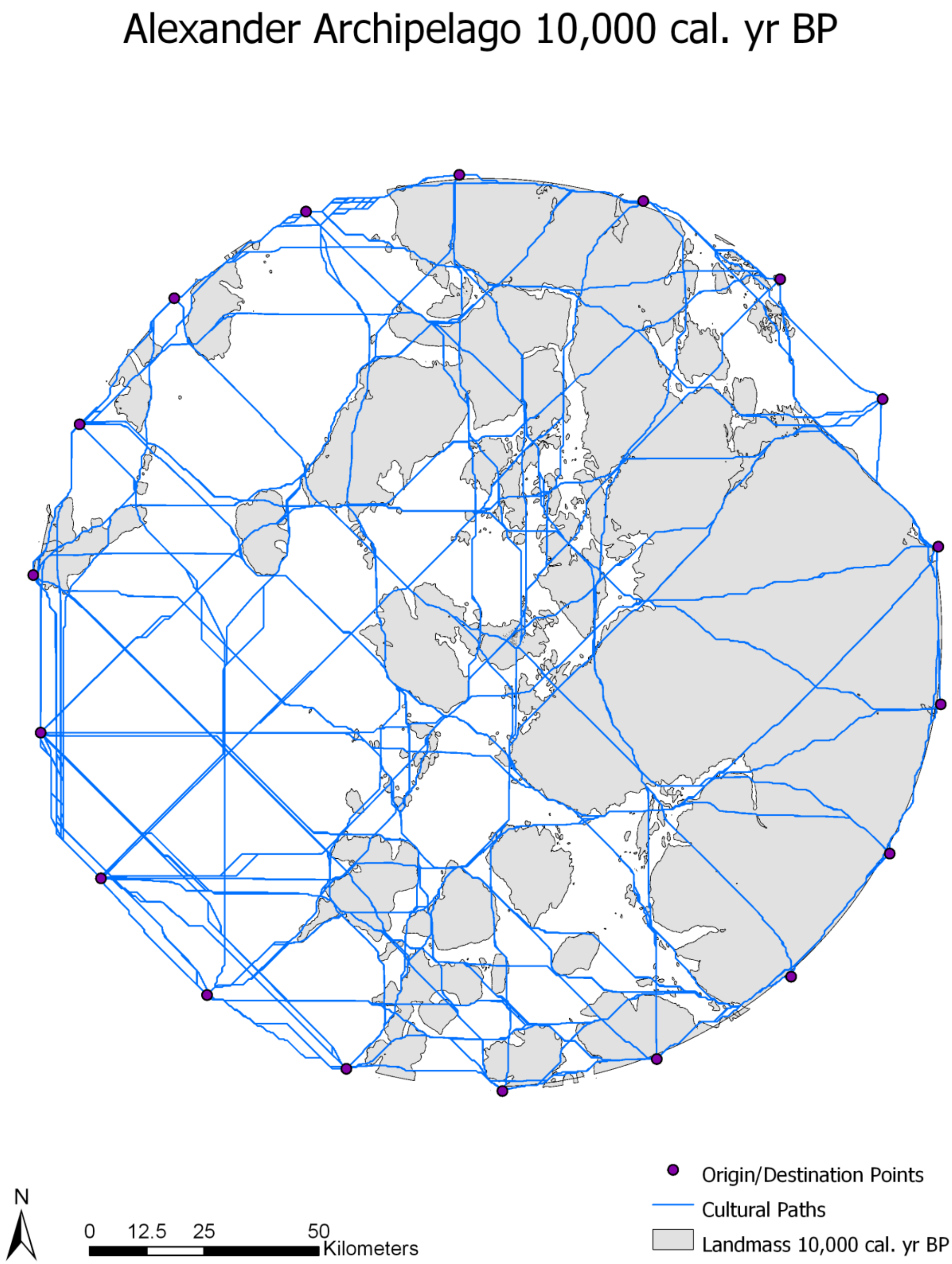
Prince Rupert Harbour 5m Paths 16,000 cal. yr BP



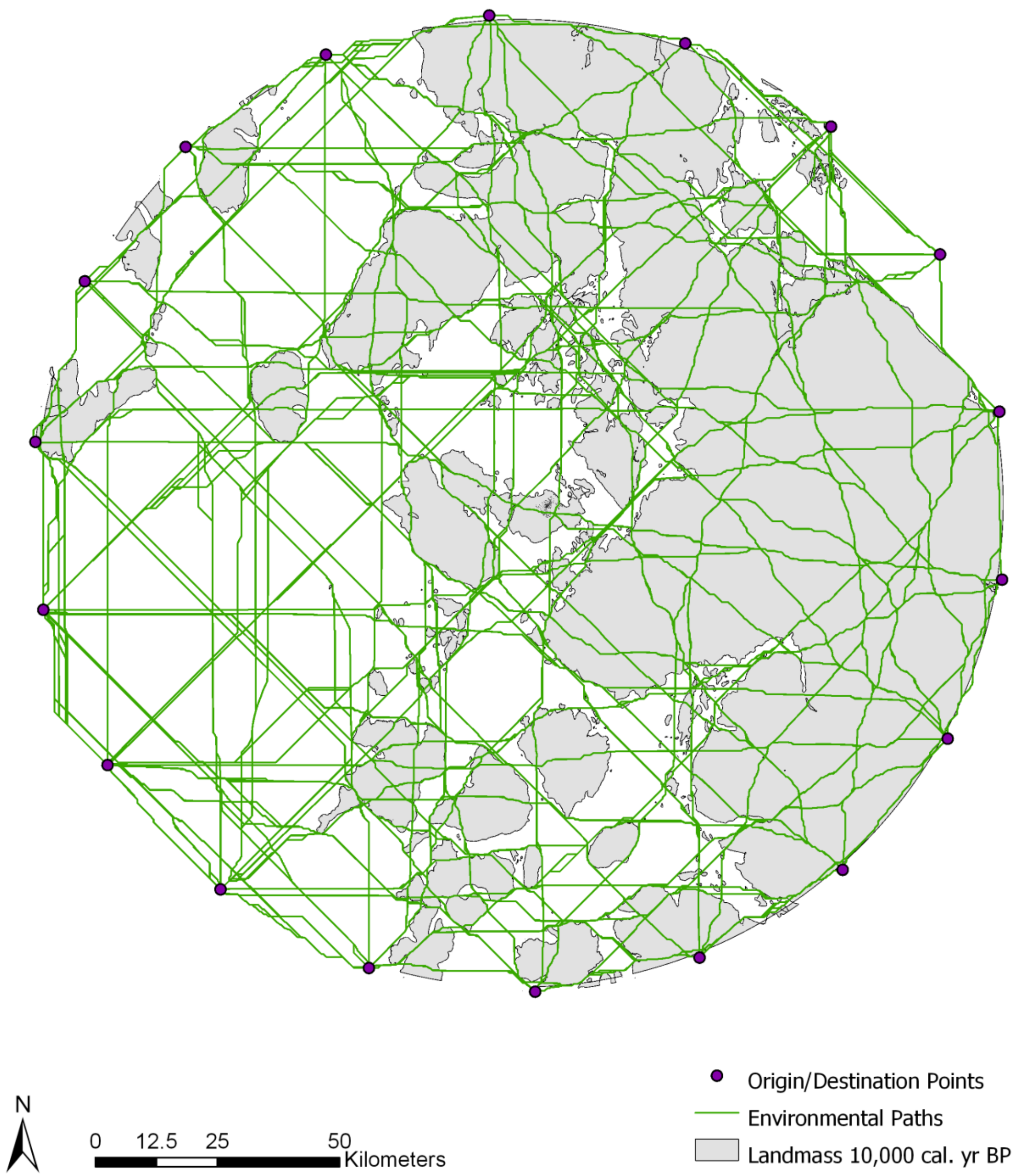

Prince Rupert Harbour 10m Paths 16,000 cal. yr BP
Origin Points
Cultural Paths
Environmental Paths
Physiological Paths
Unweighted Paths
Landmass 16,000 cal. yr BP
N
0
2.5
5
10
Kilometers


Prince Rupert Harbour 30m Paths 16,000 cal. yr BP
Origin Points
Cultural Paths
Environmental Paths
Physiological Paths
Unweighted Paths
Historic cal. yr BP
N
0
2.5
5
10
Kilometers

Appendix C: Paths by Study Area



Alexander Archipelago 10,000 cal. yr BP



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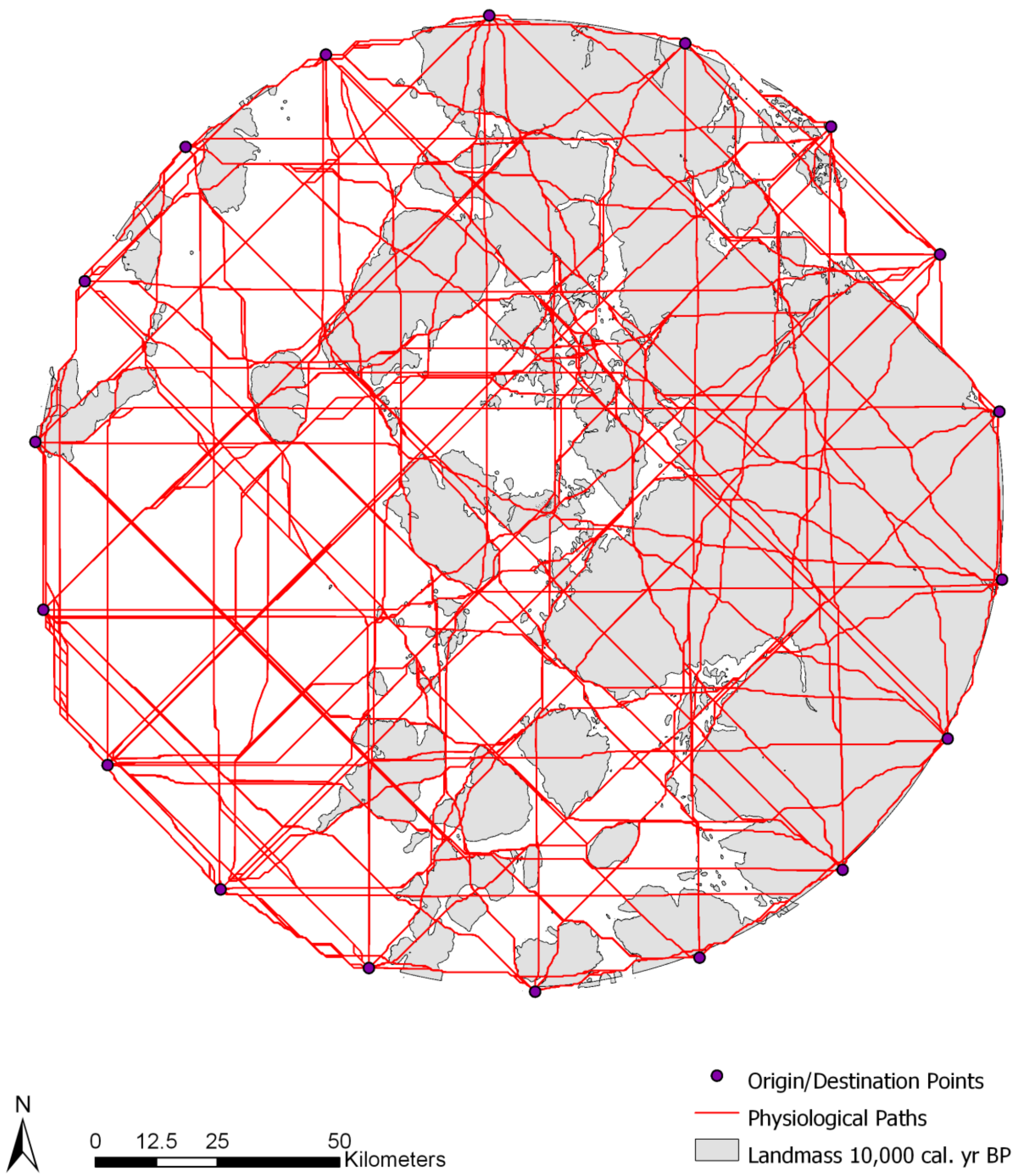
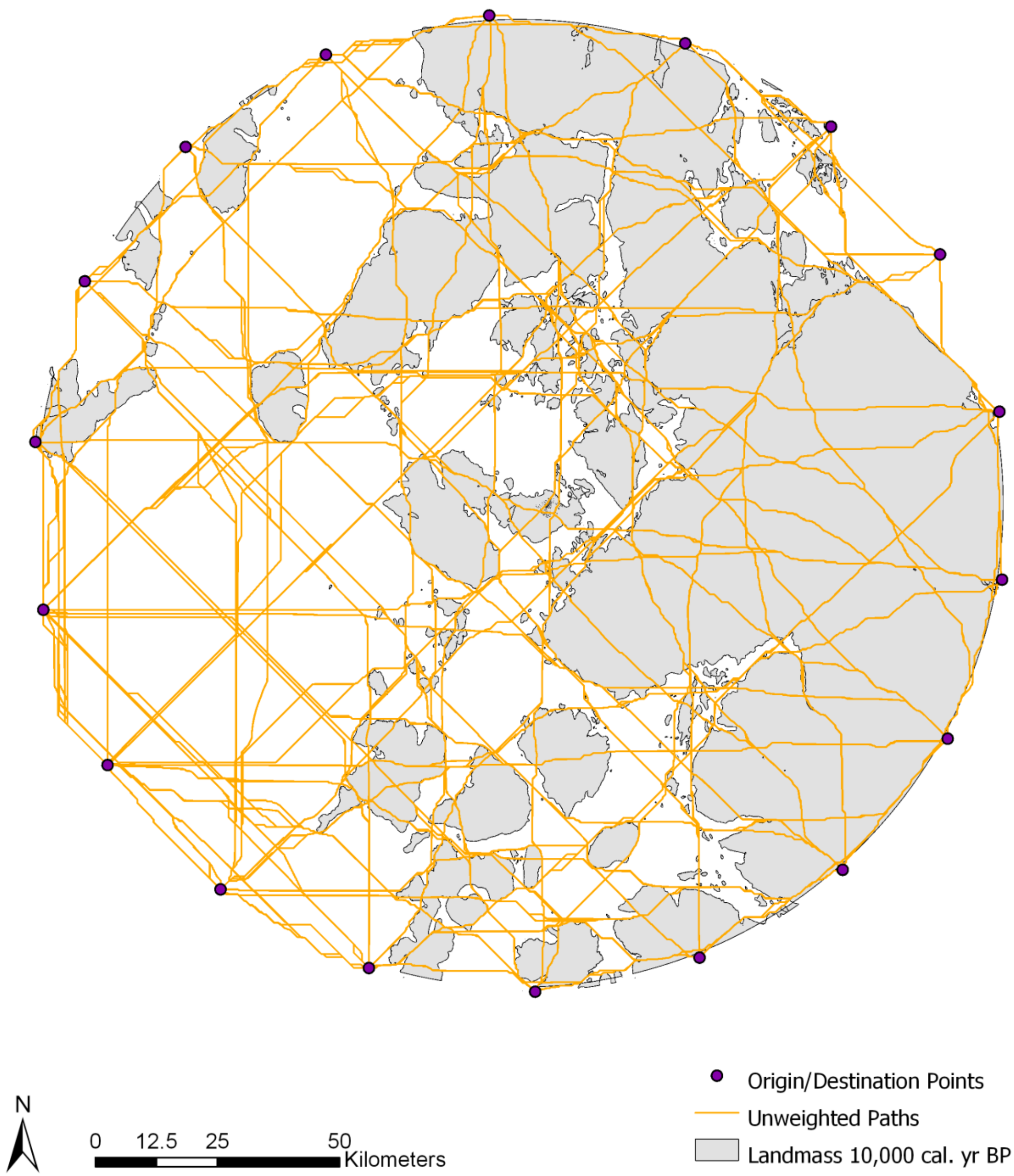
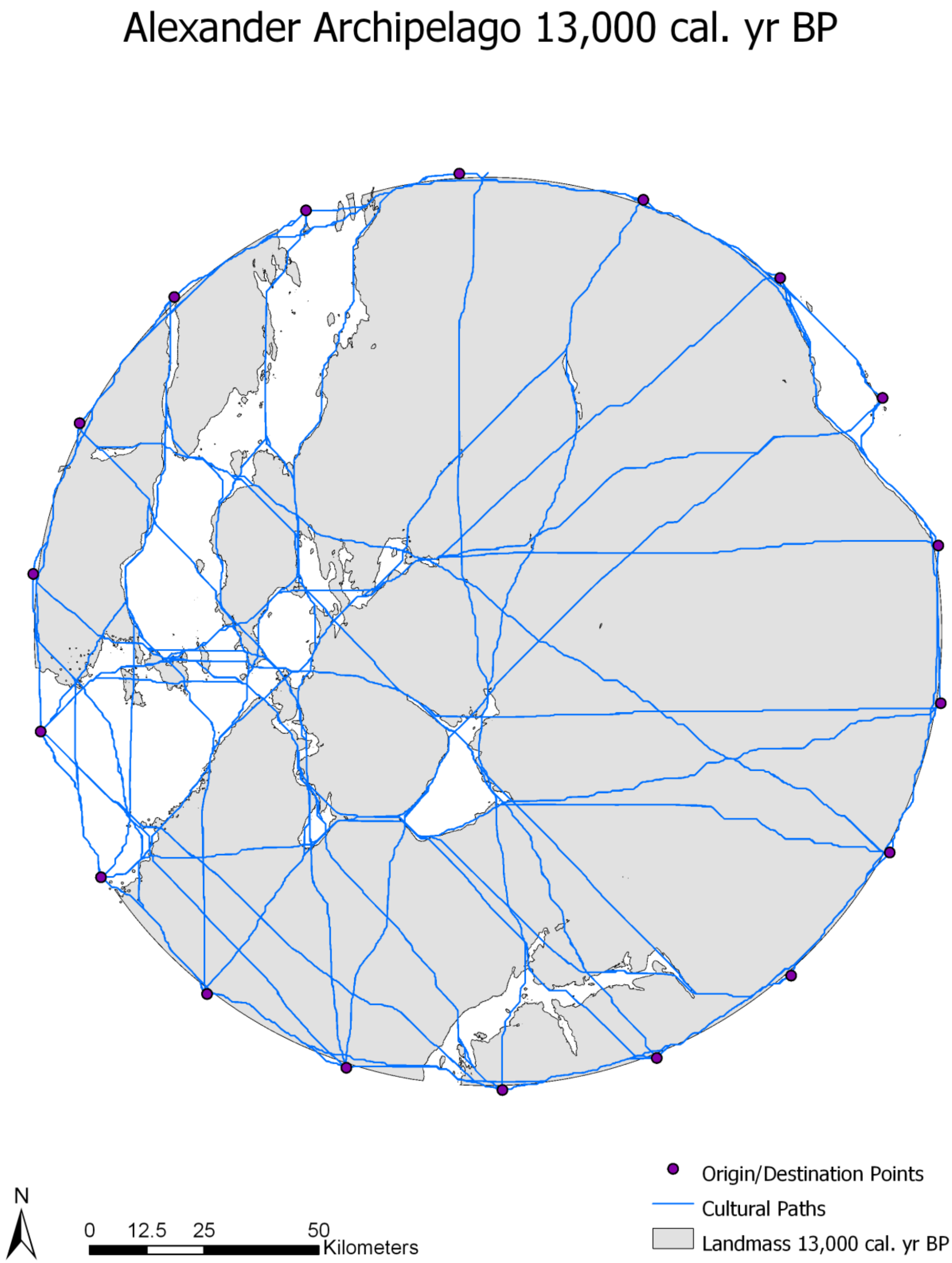
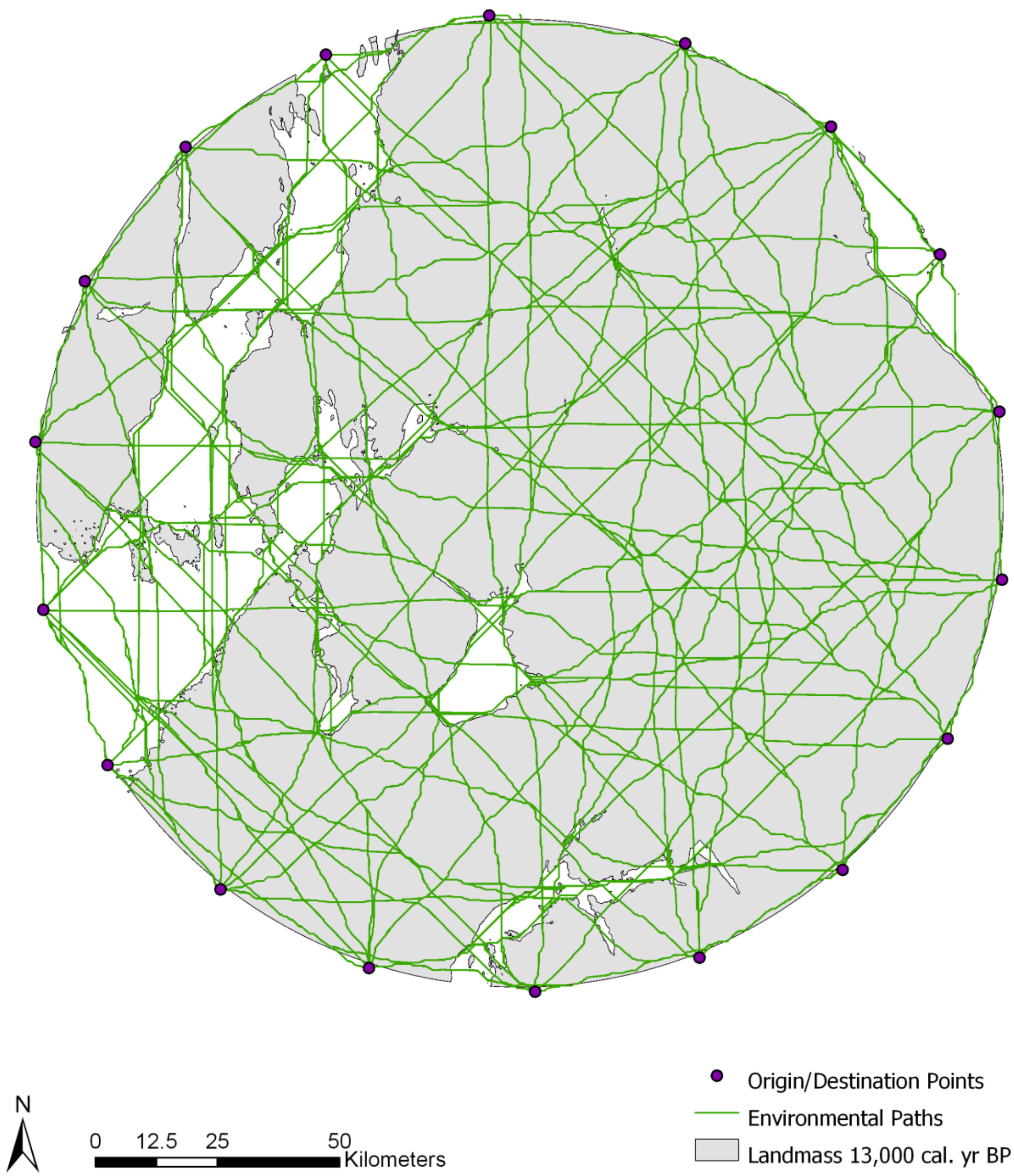


Alexander Archipelago 10,000 cal. yr BP

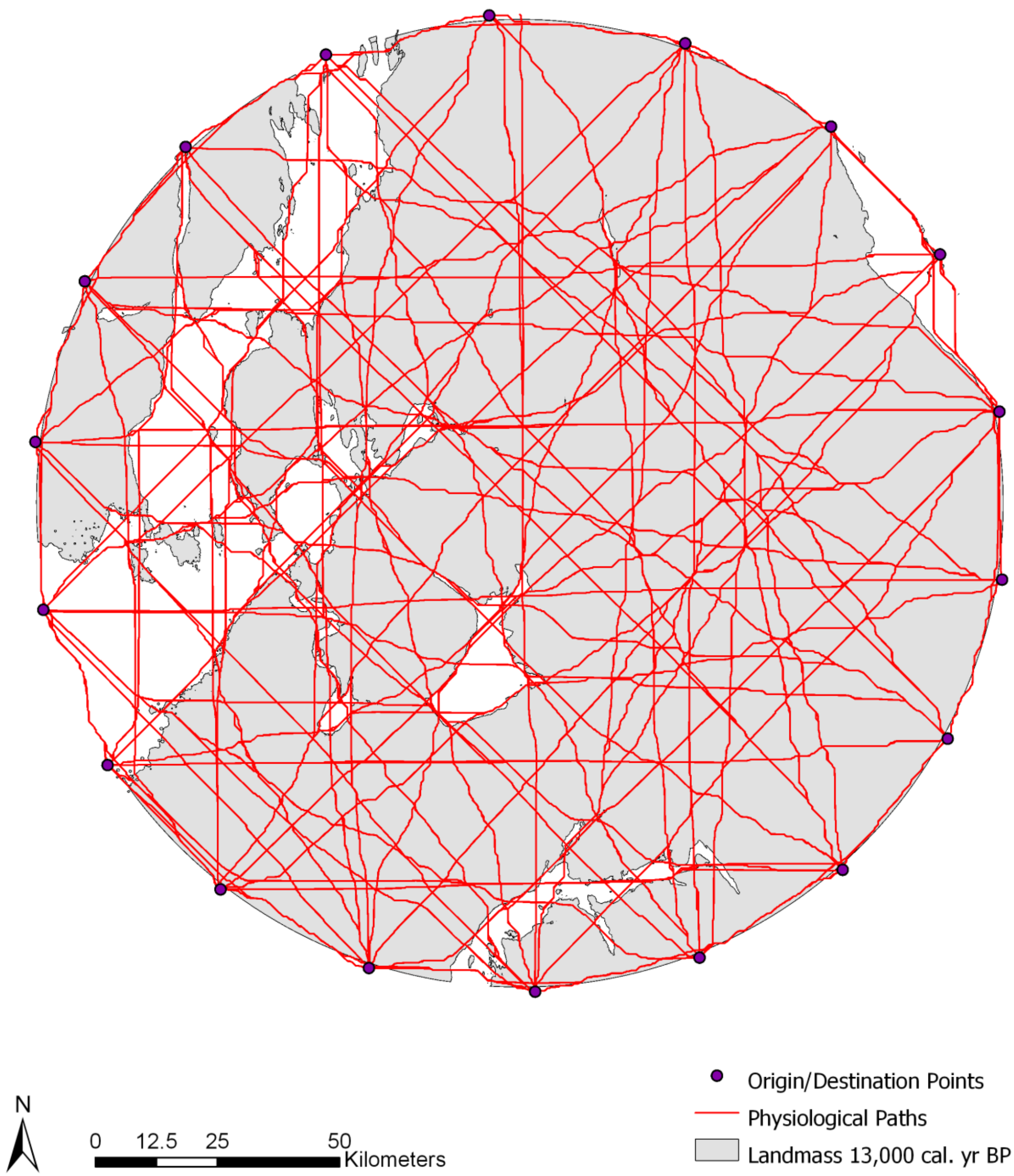



Alexander Archipelago 13,000 cal. yr BP
Origin/Destination Points
Cultural Paths
Landmass 13,000 cal. yr BP
N
0
12.5
25
50
Kilometers

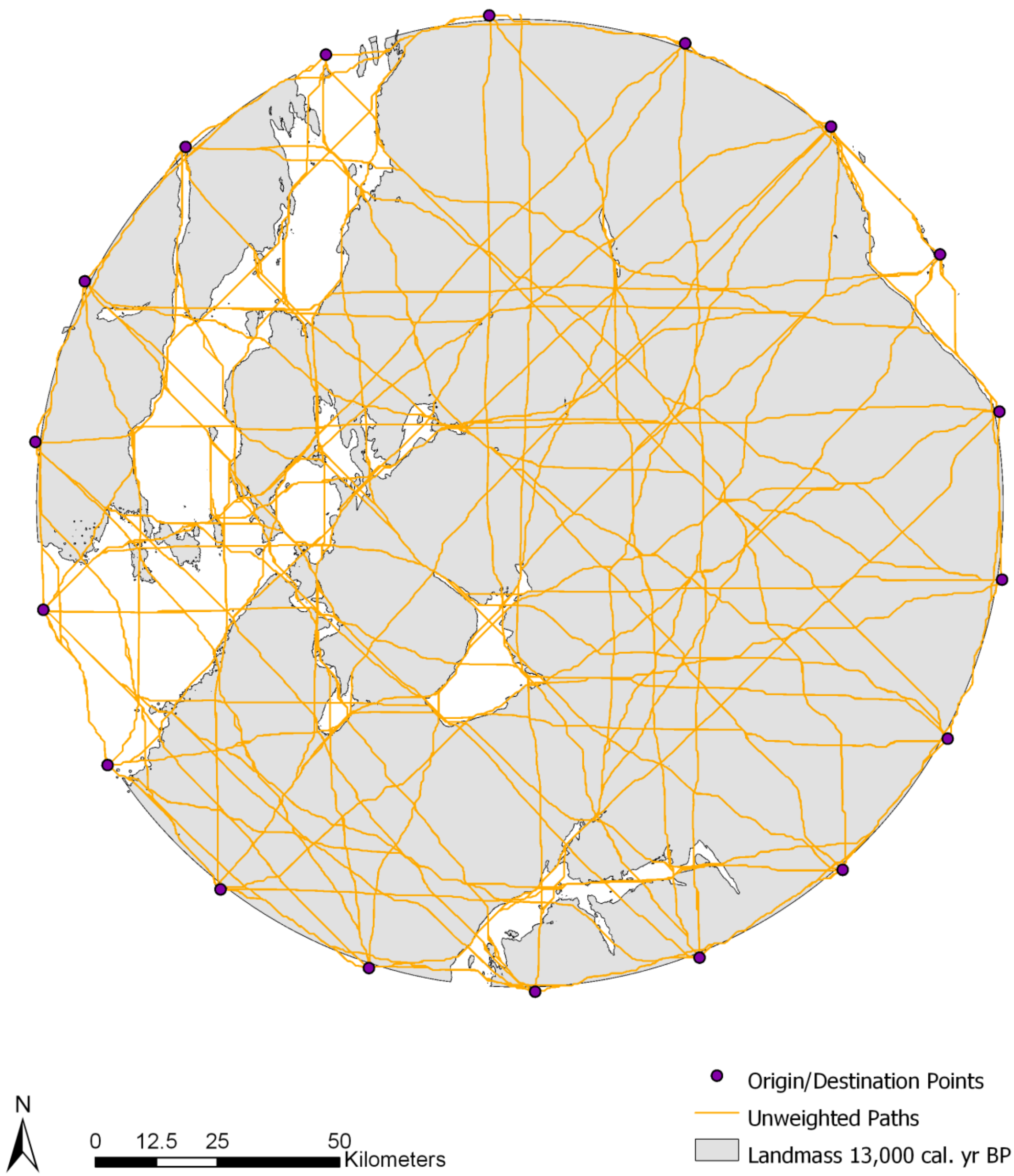
Alexander Archipelago 13,000 cal. yr BP



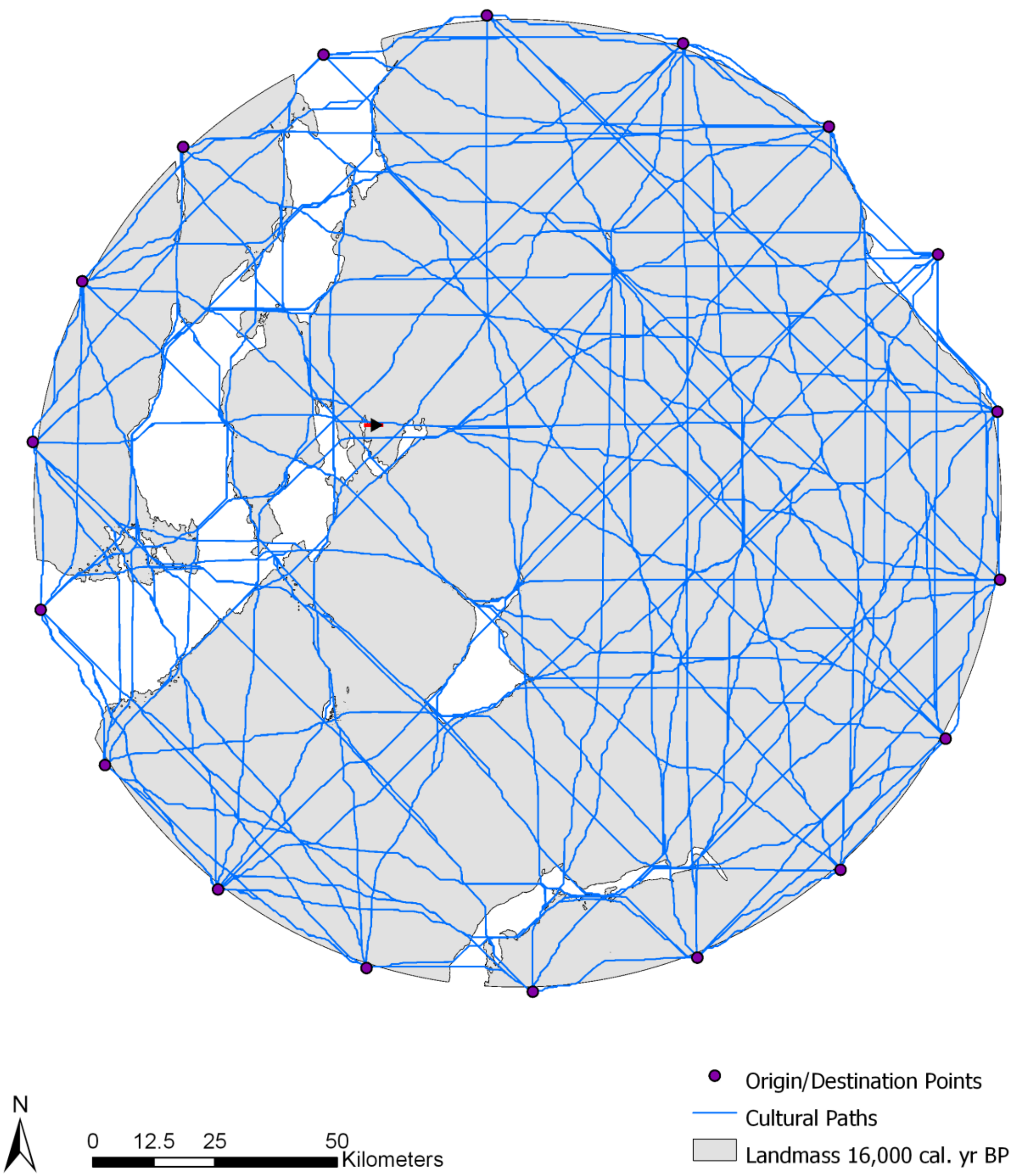
Alexander Archipelago 13,000 cal. yr BP



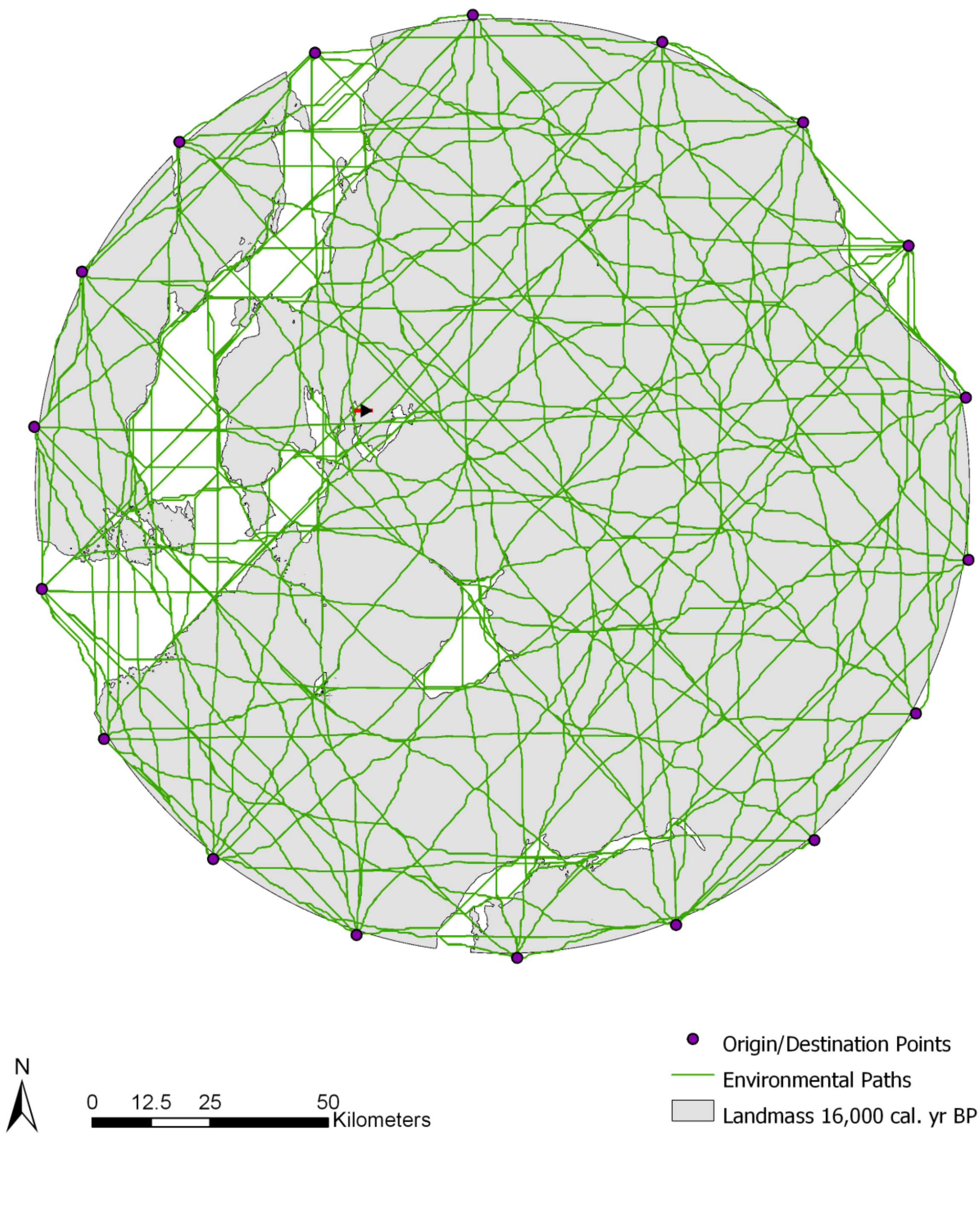
Alexander Archipelago 13,000 cal. yr BP



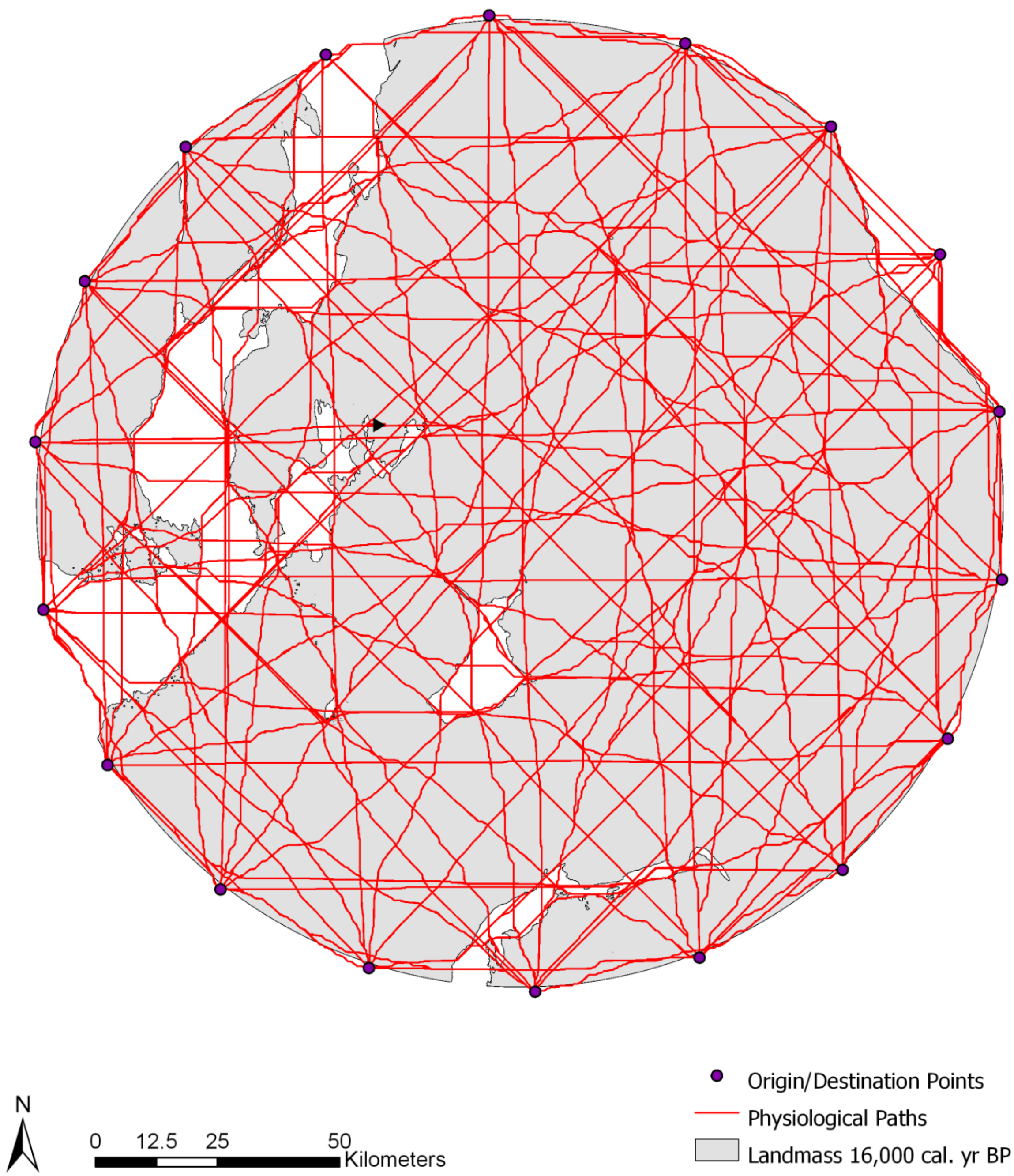
Alexander Archipelago 16,000 cal. yr BP



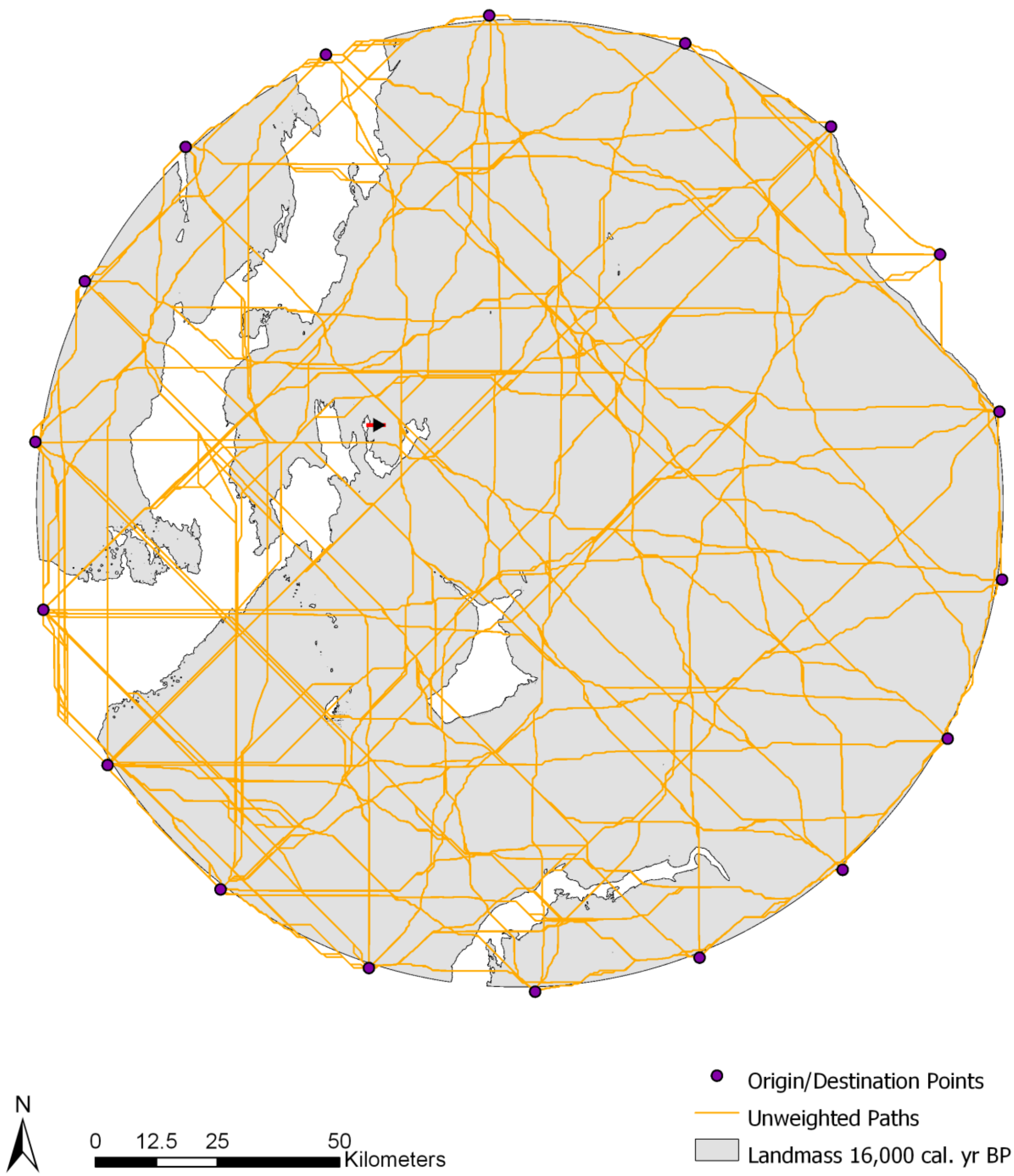
Alexander Archipelago 16,000 cal. yr BP



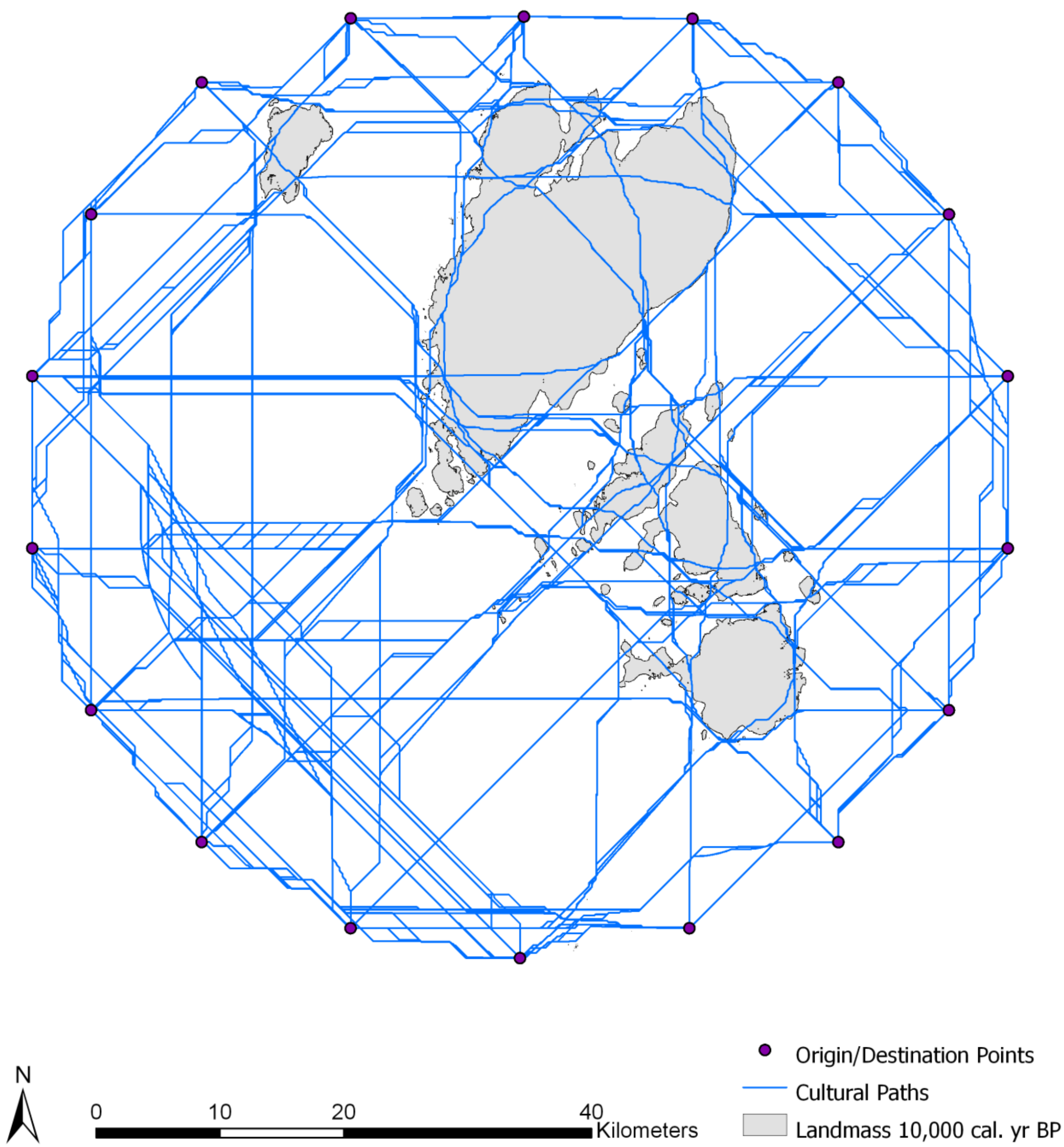
Alexander Archipelago 16,000 cal. yr BP



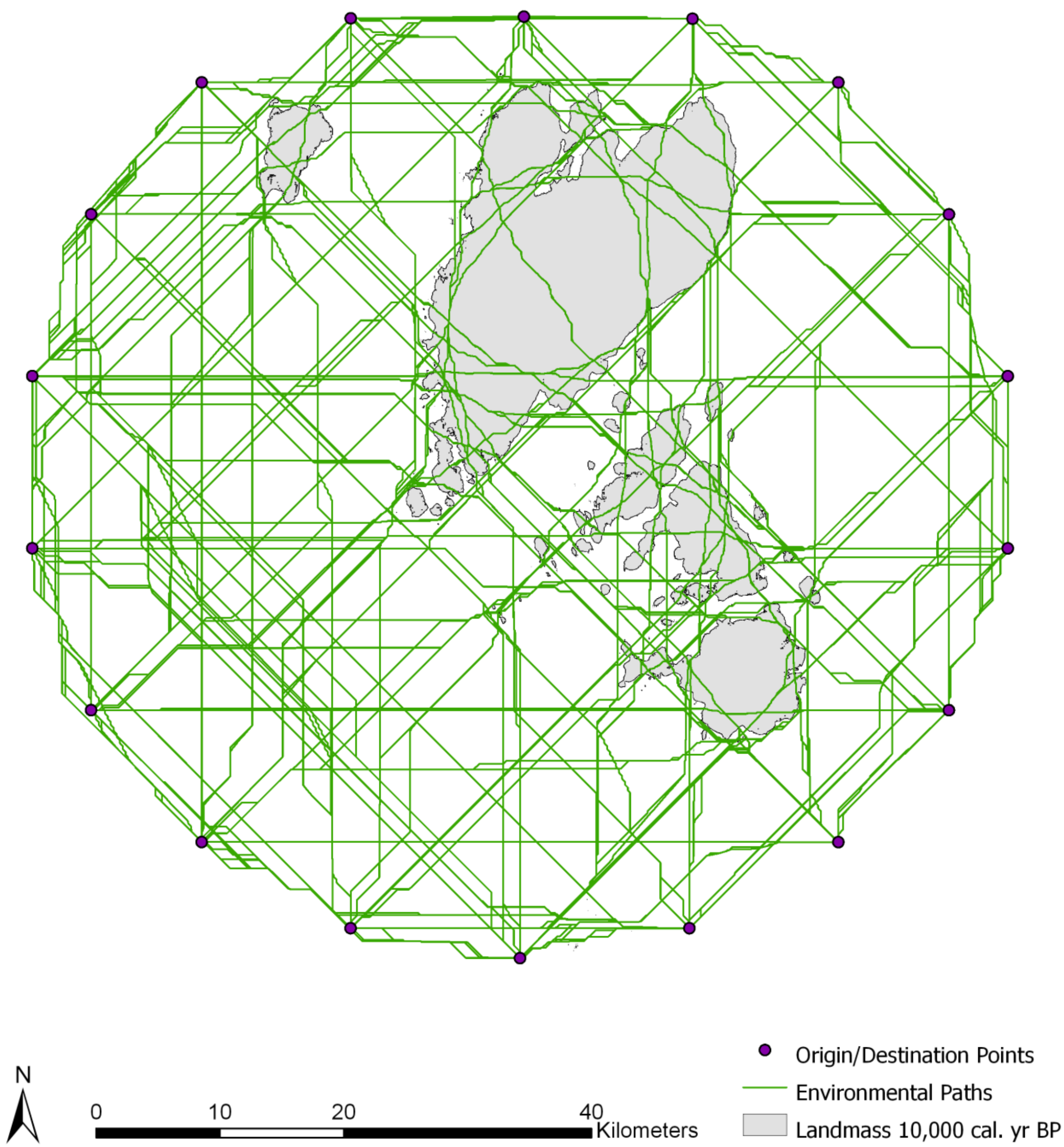
Alexander Archipelago 16,000 cal. yr BP



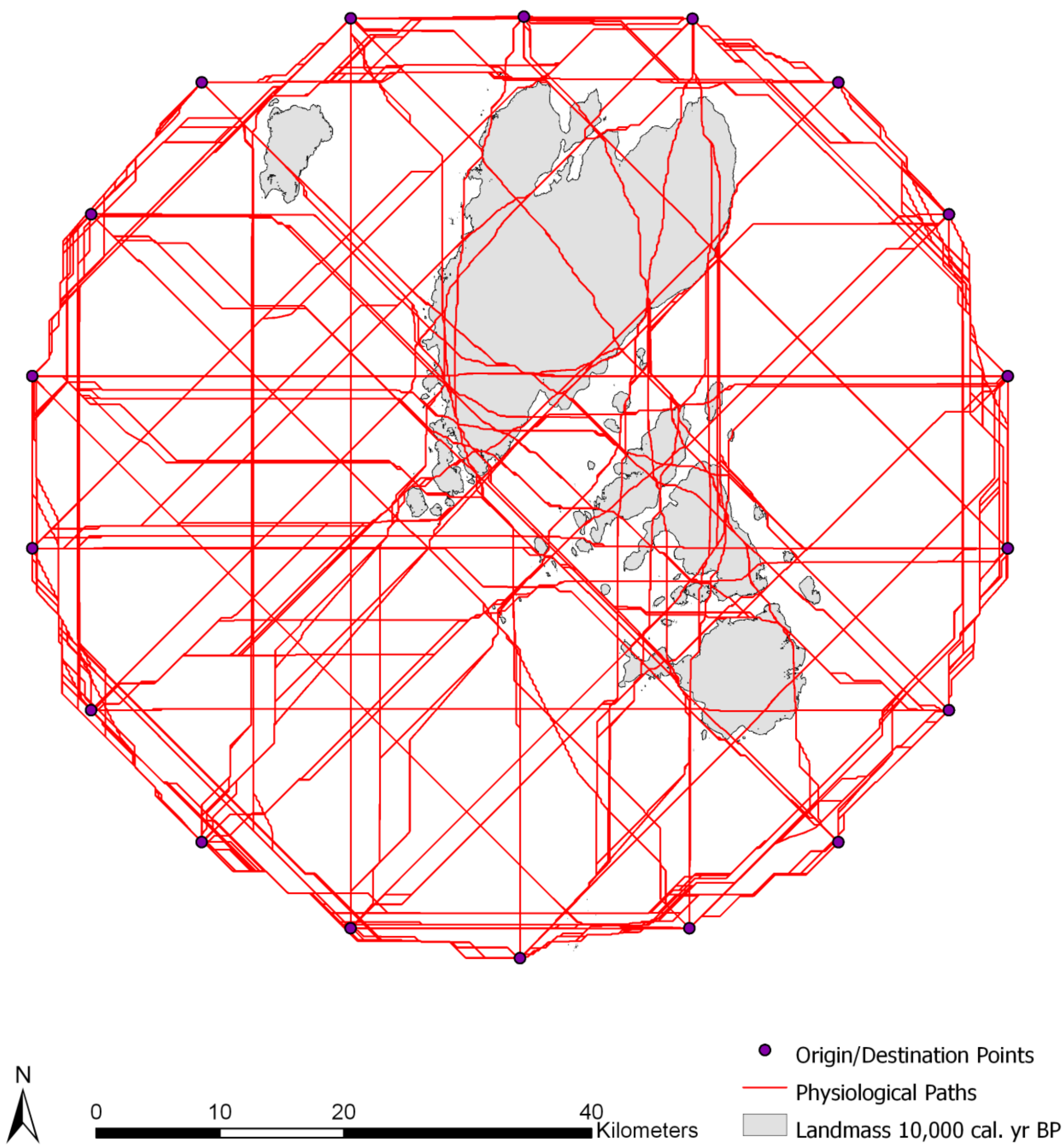
Dundas Archipelago 10,000 cal. yr BP

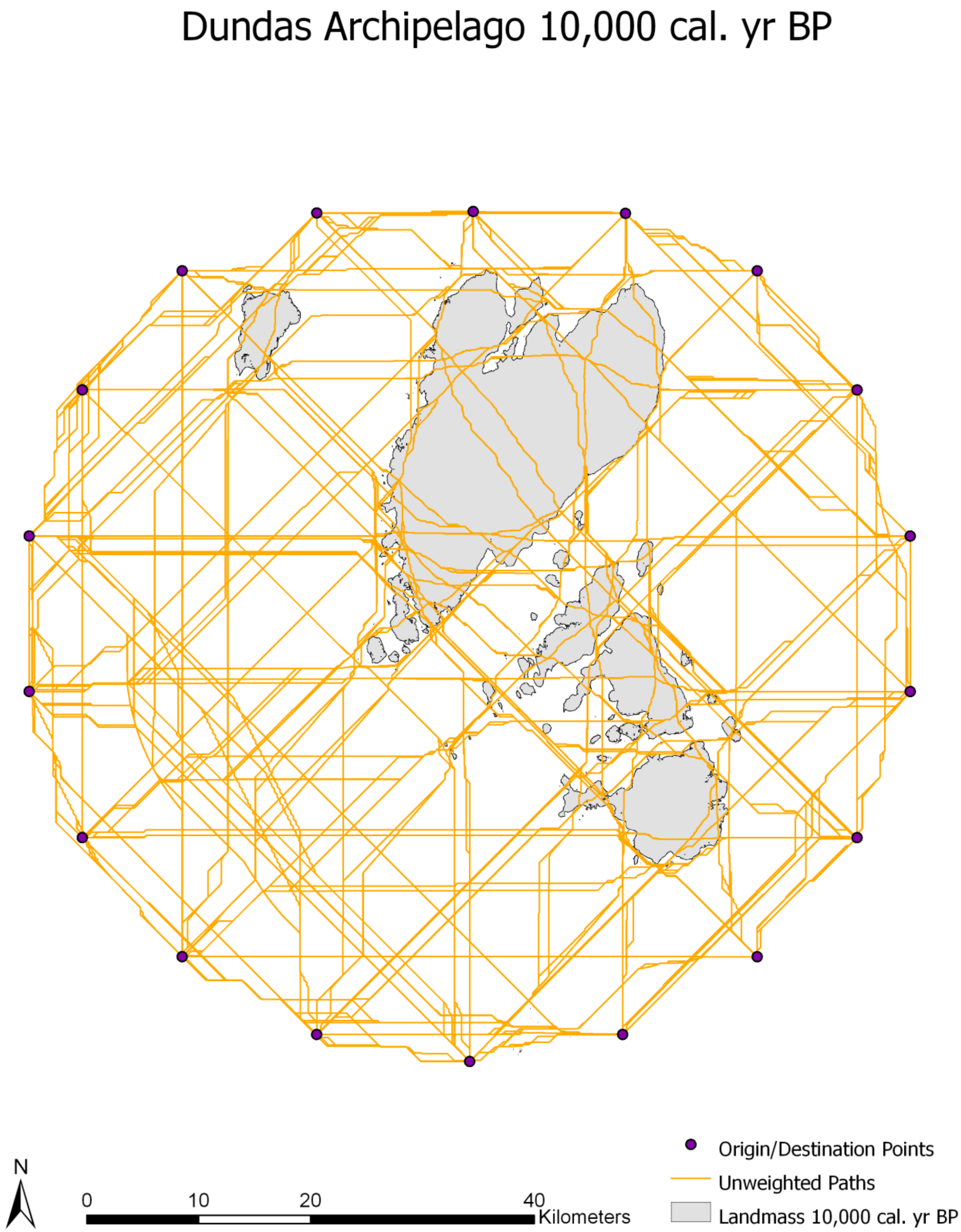


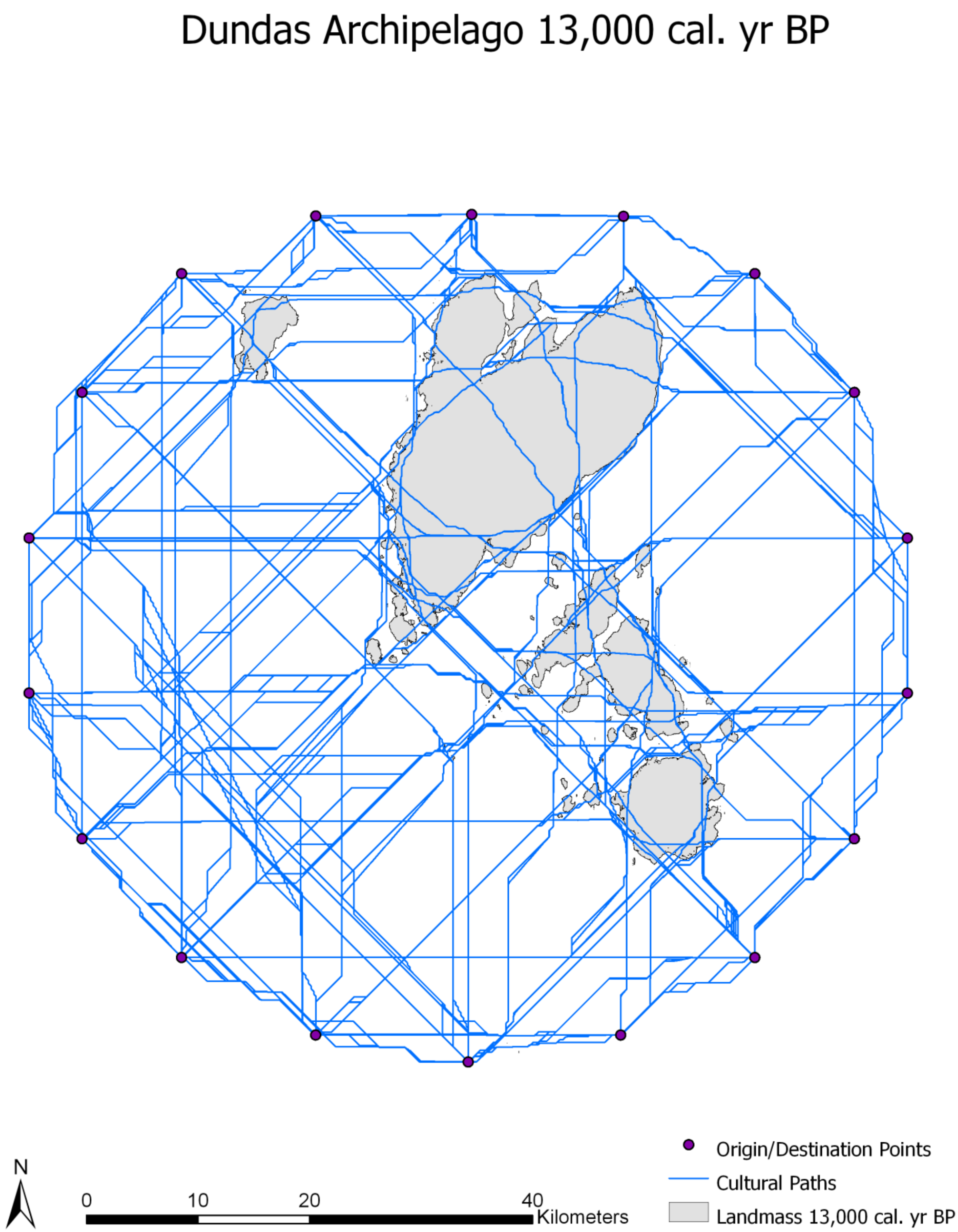
Dundas Archipelago 10,000 cal. yr BP



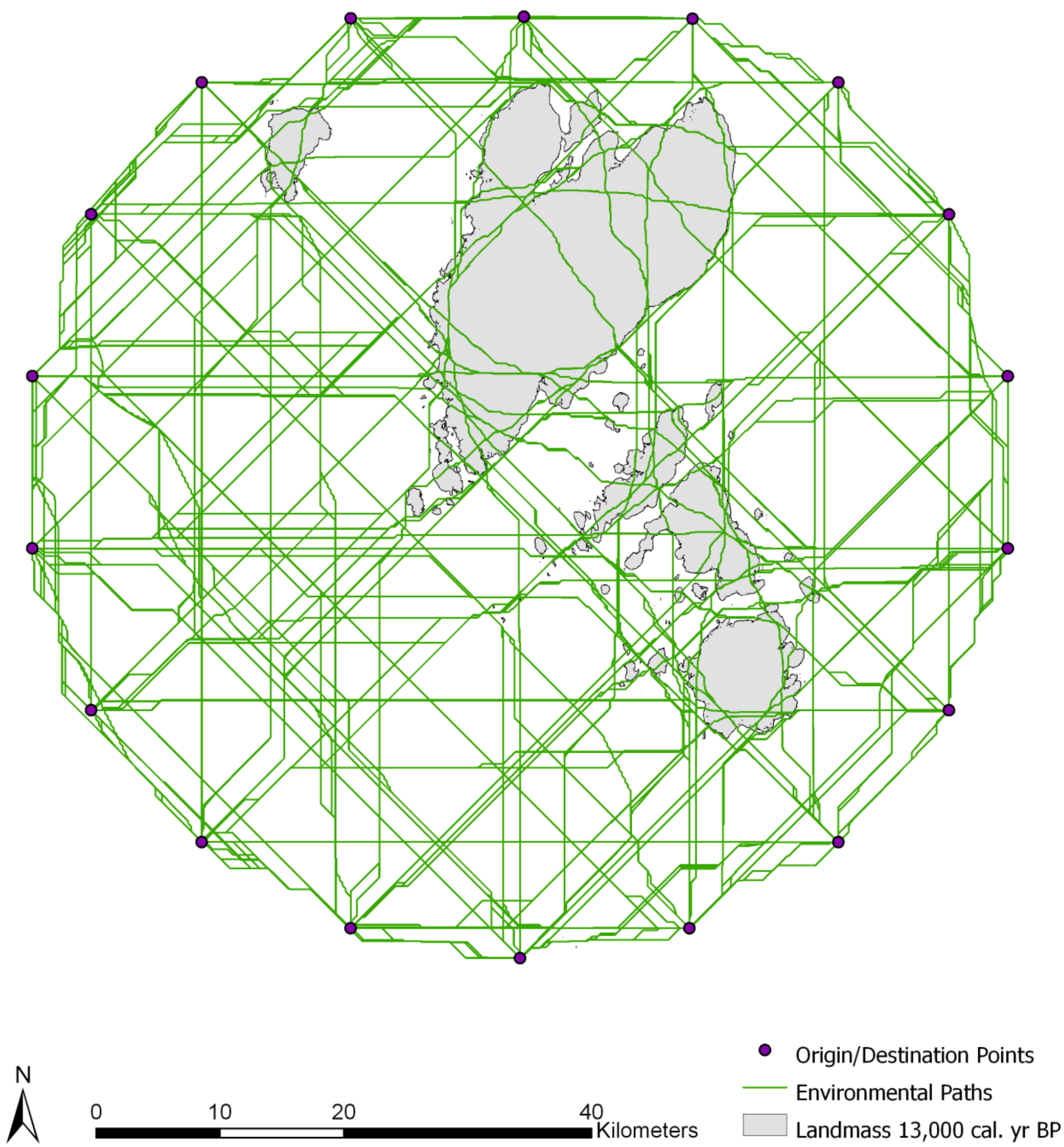
Dundas Archipelago 10,000 cal. yr BP



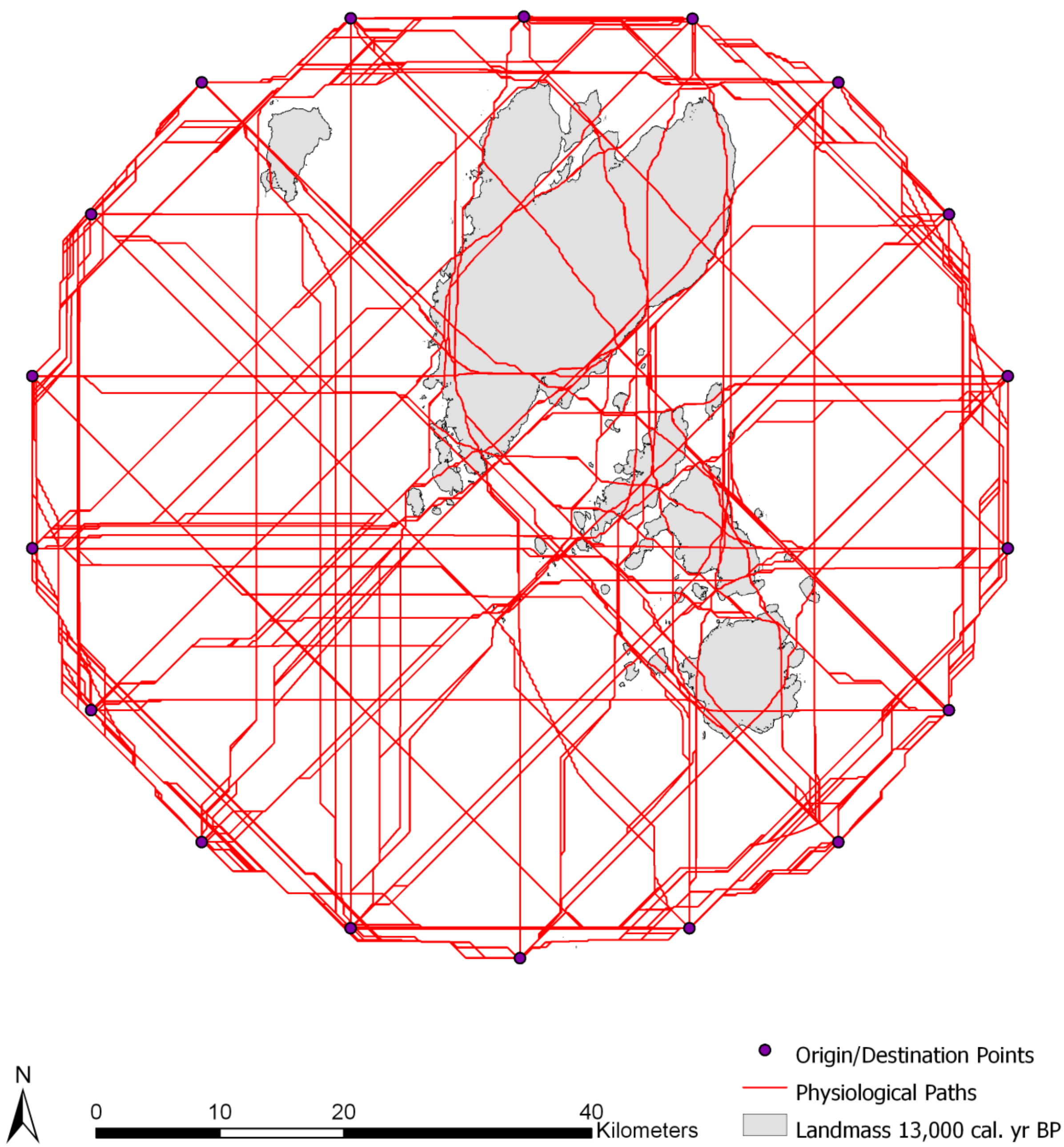

Dundas Archipelago 10,000 cal. yr BP
Origin/Destination Points
Unweighted Paths
Landmass 10,000 cal. yr BP
N
0
10
20
40
Kilometers


Dundas Archipelago 13,000 cal. yr BP
Origin/Destination Points
Cultural Paths
Landmass 13,000 cal. yr BP
N
0
10
20
40
Kilometers

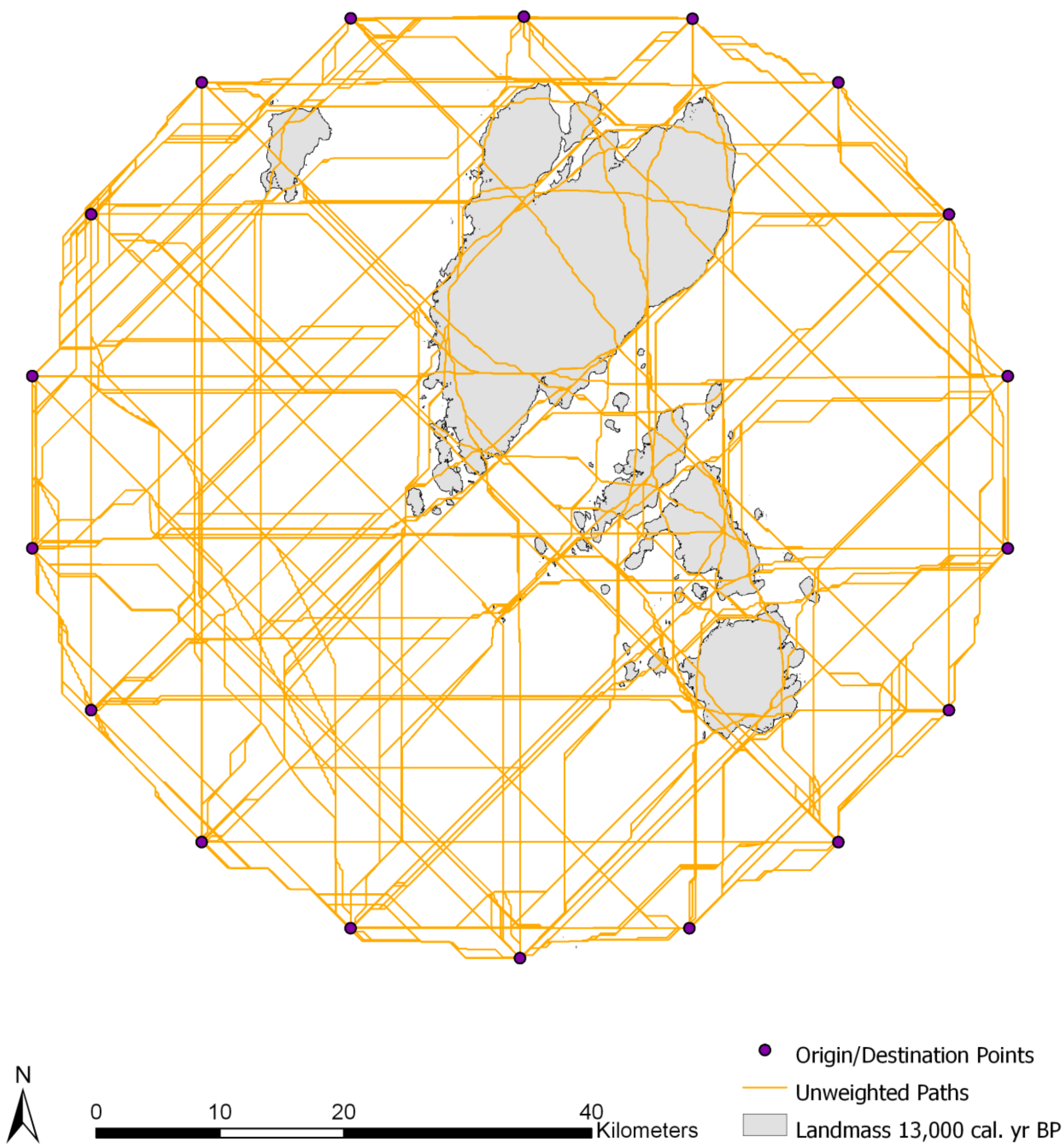
Dundas Archipelago 13,000 cal. yr BP



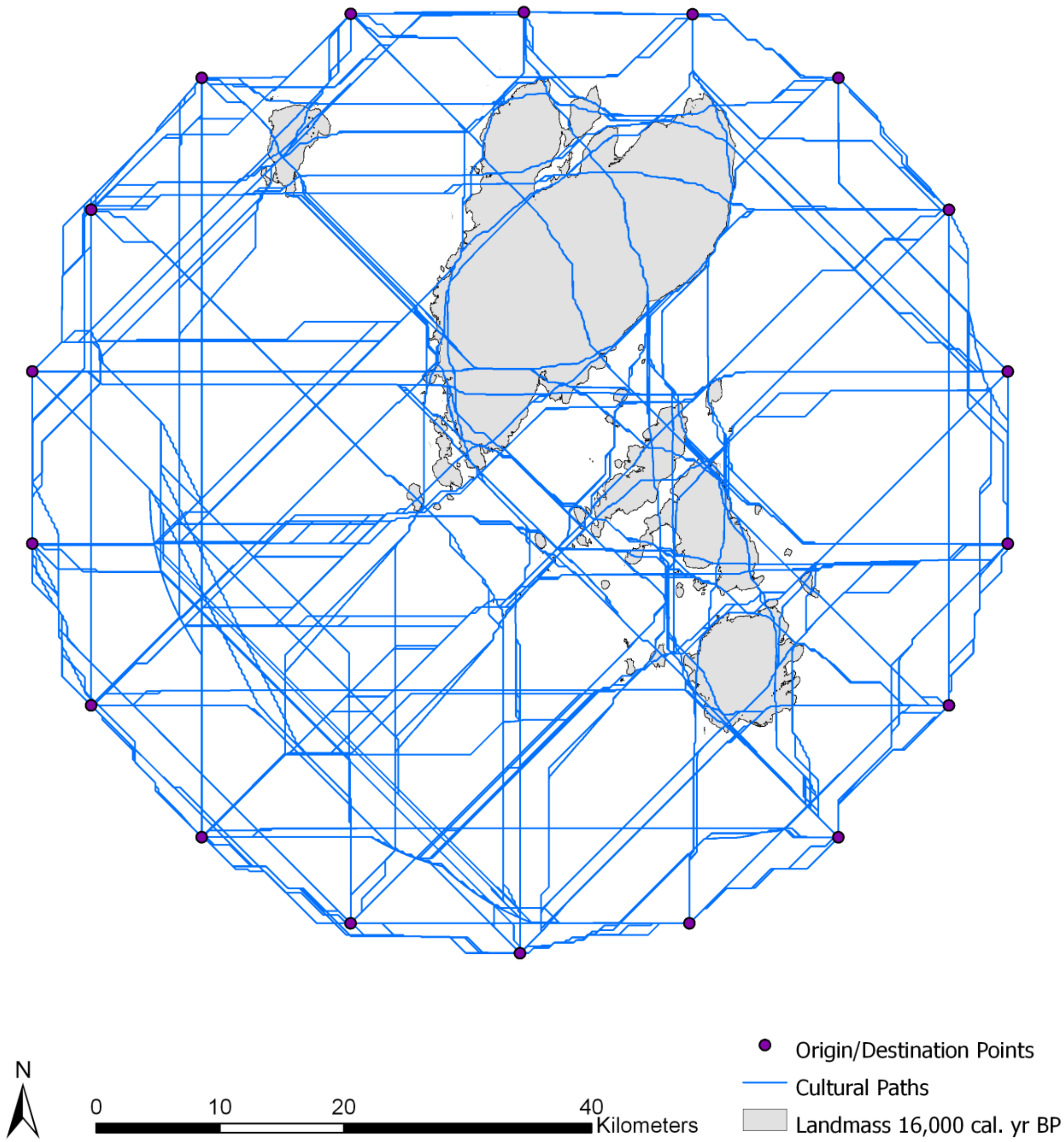
Dundas Archipelago 13,000 cal. yr BP



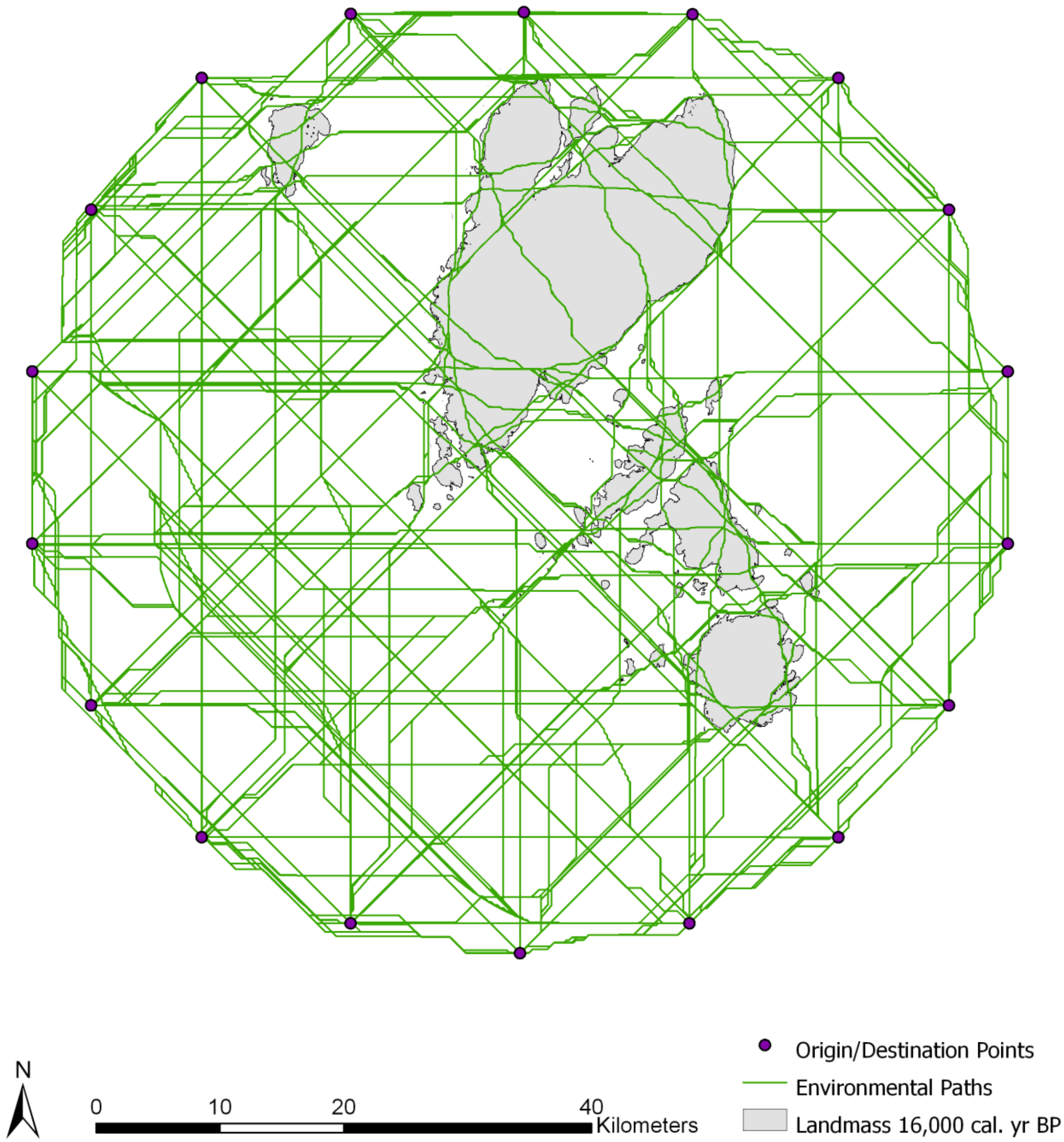
Dundas Archipelago 13,000 cal. yr BP



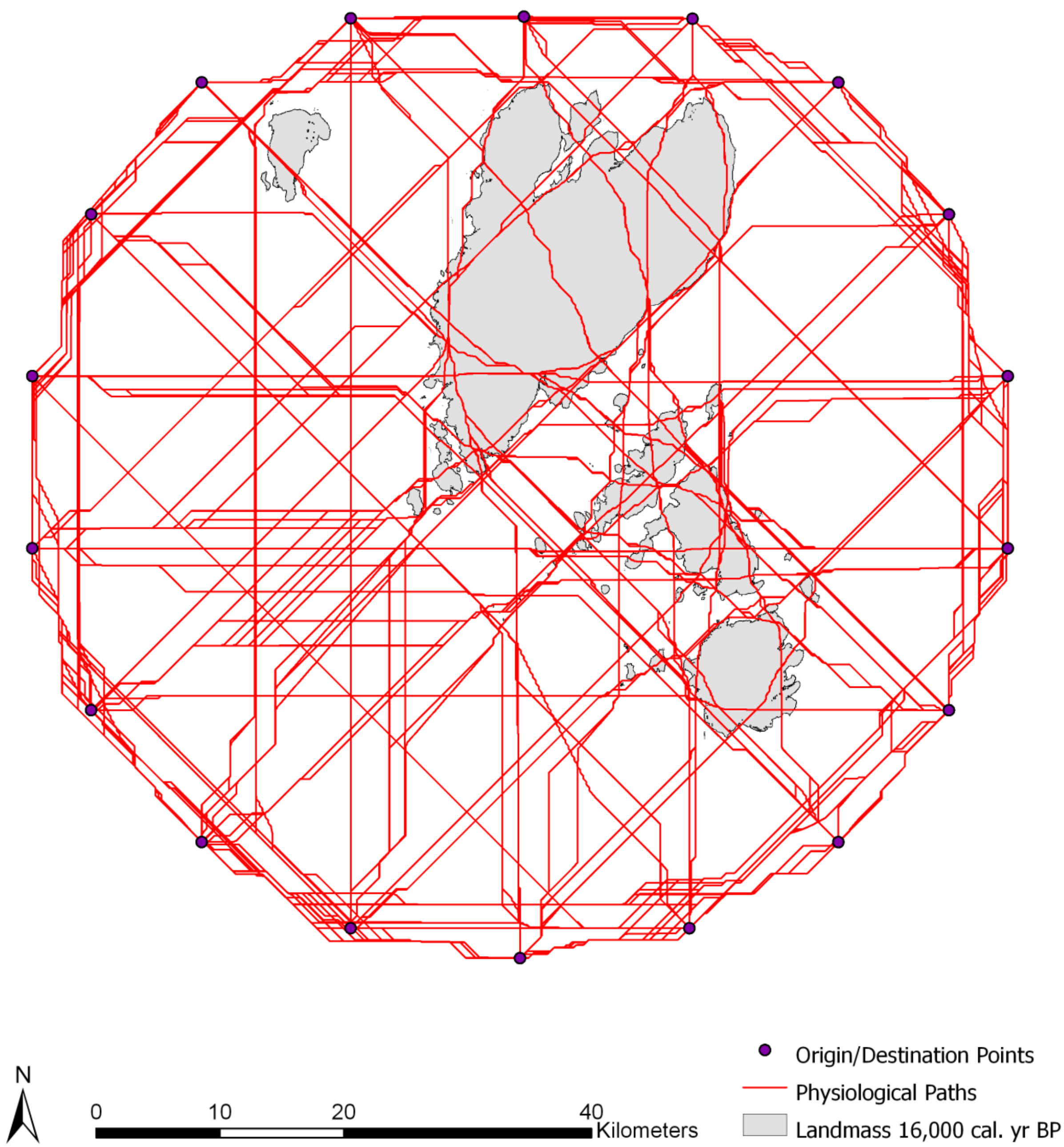
Dundas Archipelago 16,000 cal. yr BP



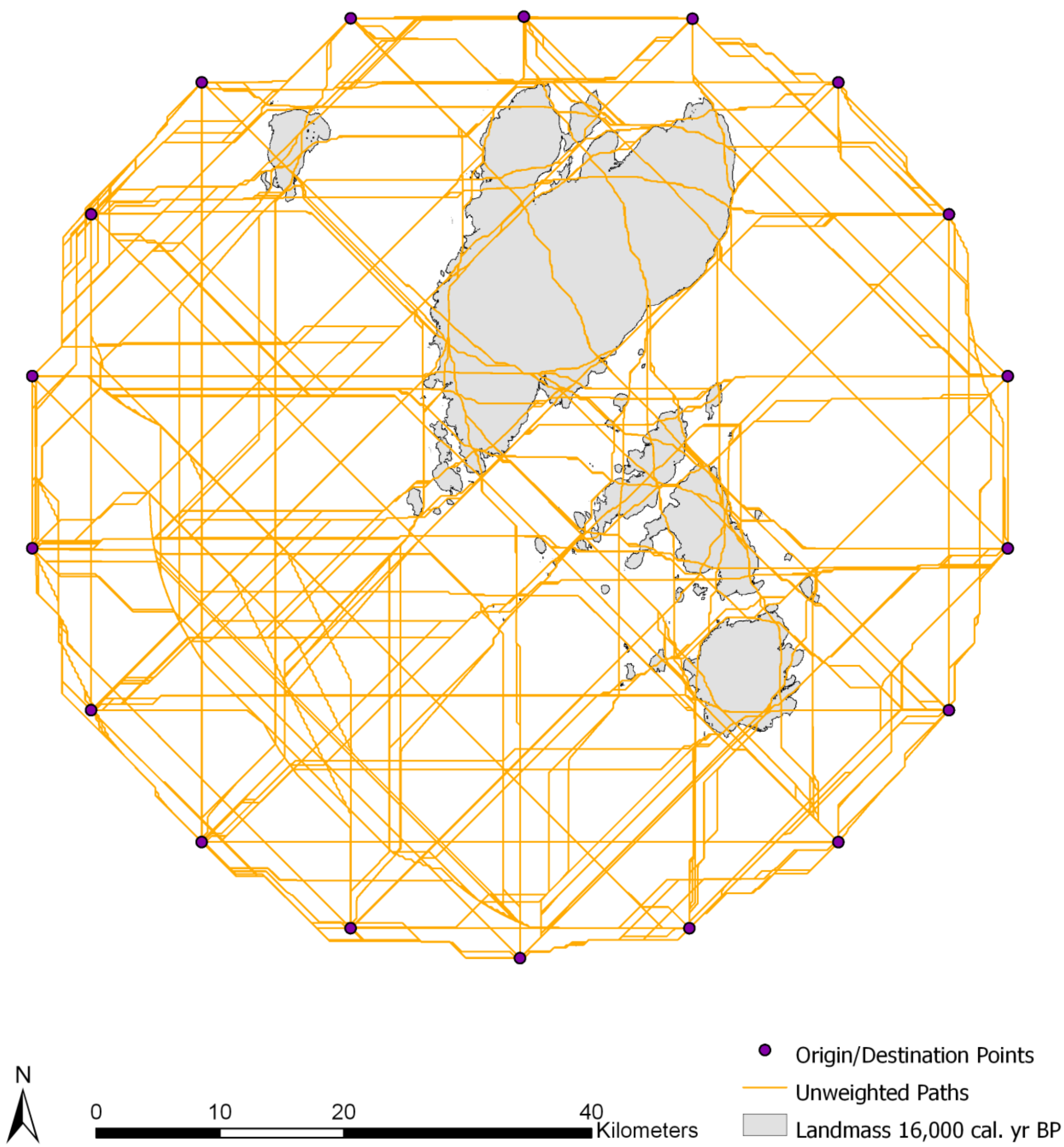
Dundas Archipelago 16,000 cal. yr BP

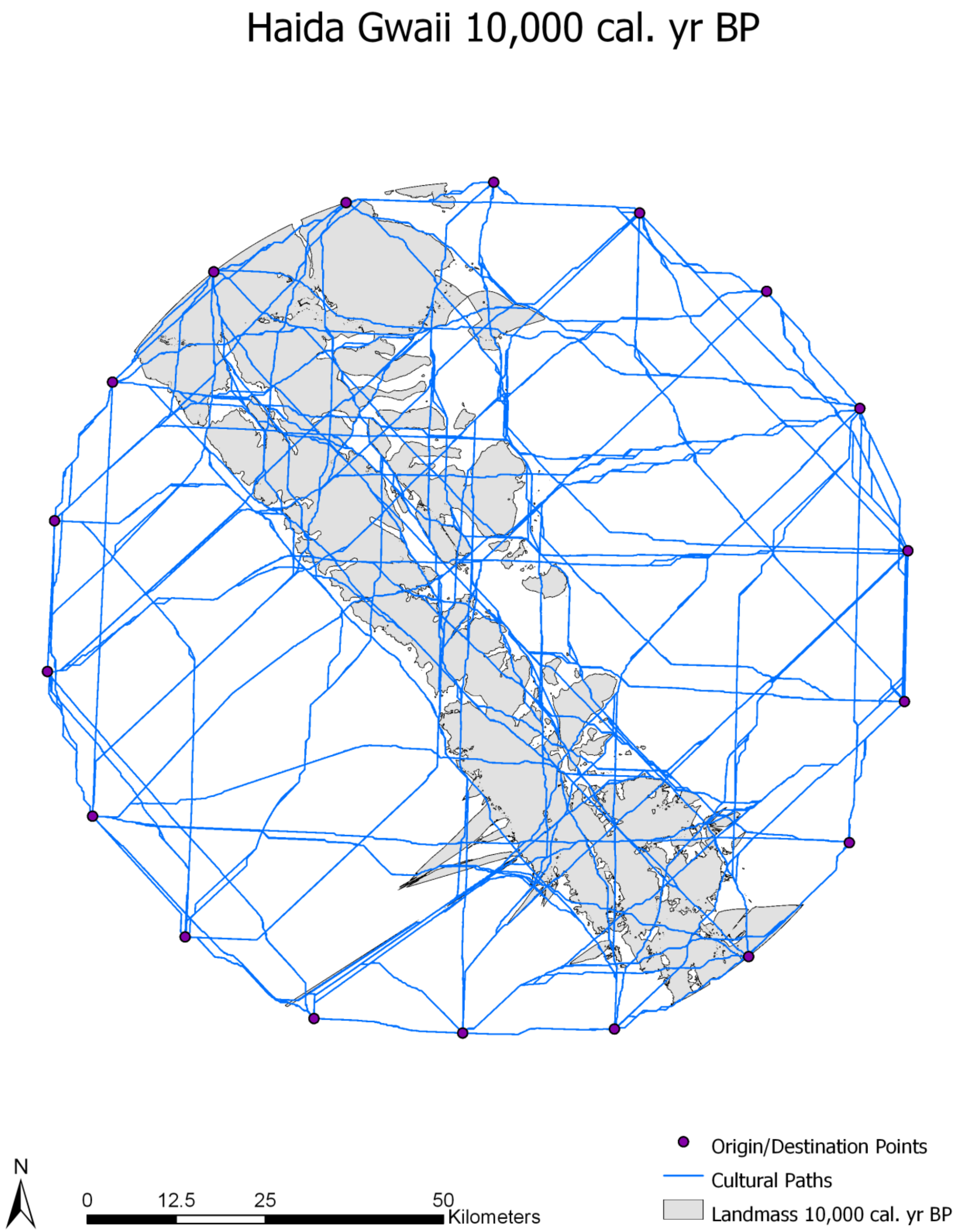


Dundas Archipelago 16,000 cal. yr BP

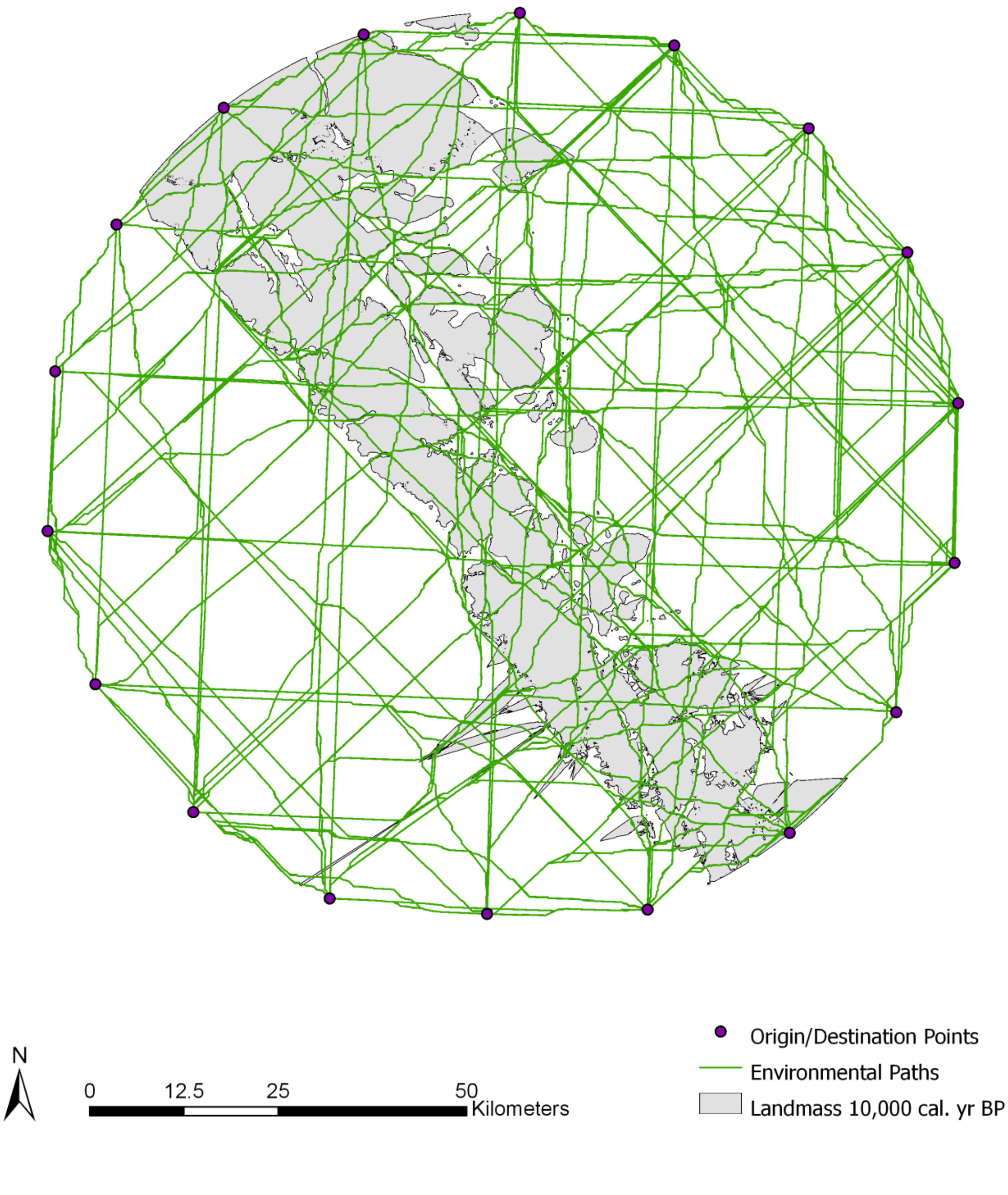


Dundas Archipelago 16,000 cal. yr BP

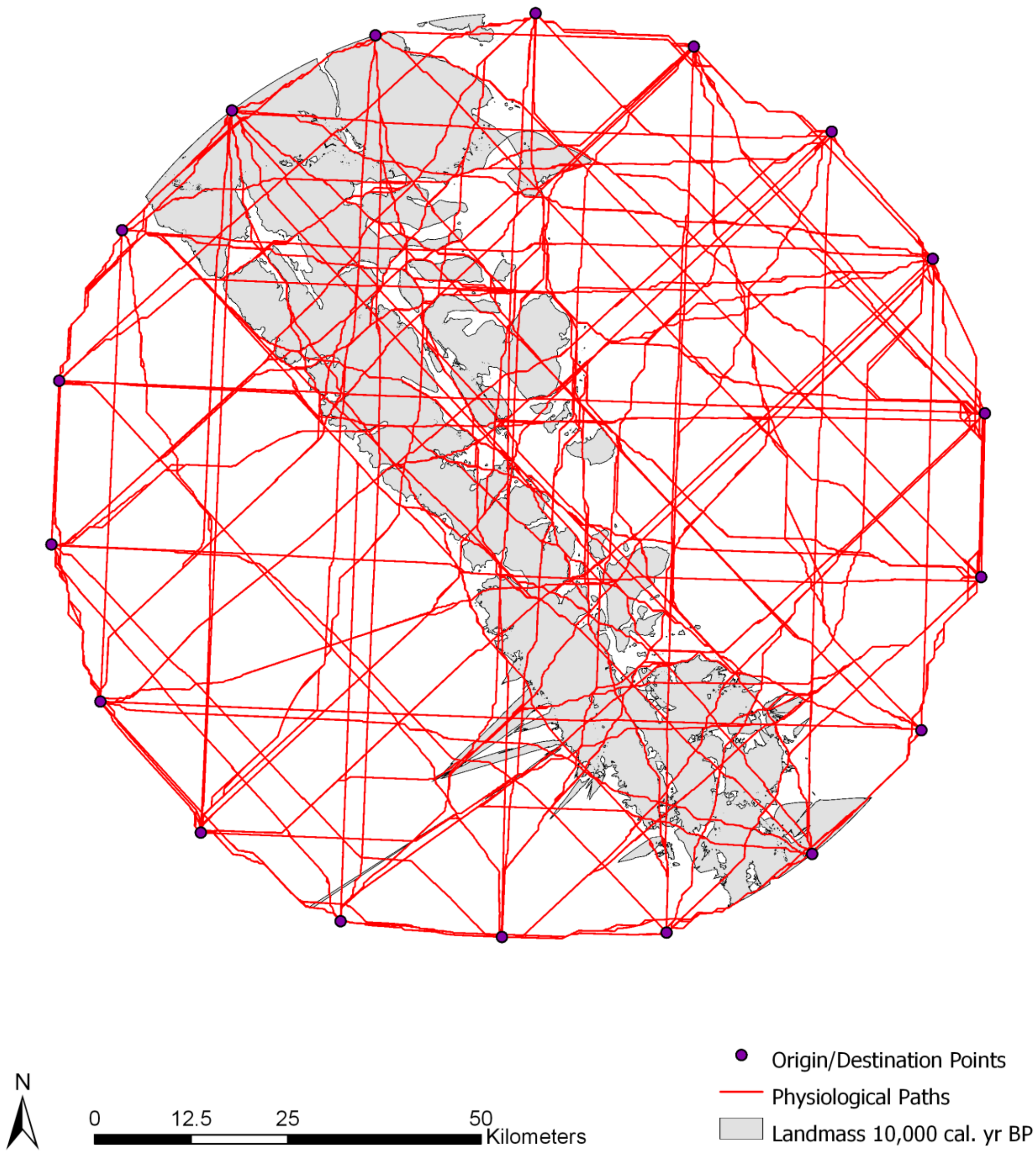



Haida Gwaii 10,000 cal. yr BP
Origin/Destination Points
Cultural Paths
Landmass 10,000 cal. yr BP
N
0
12.5
25
50
Kilometers

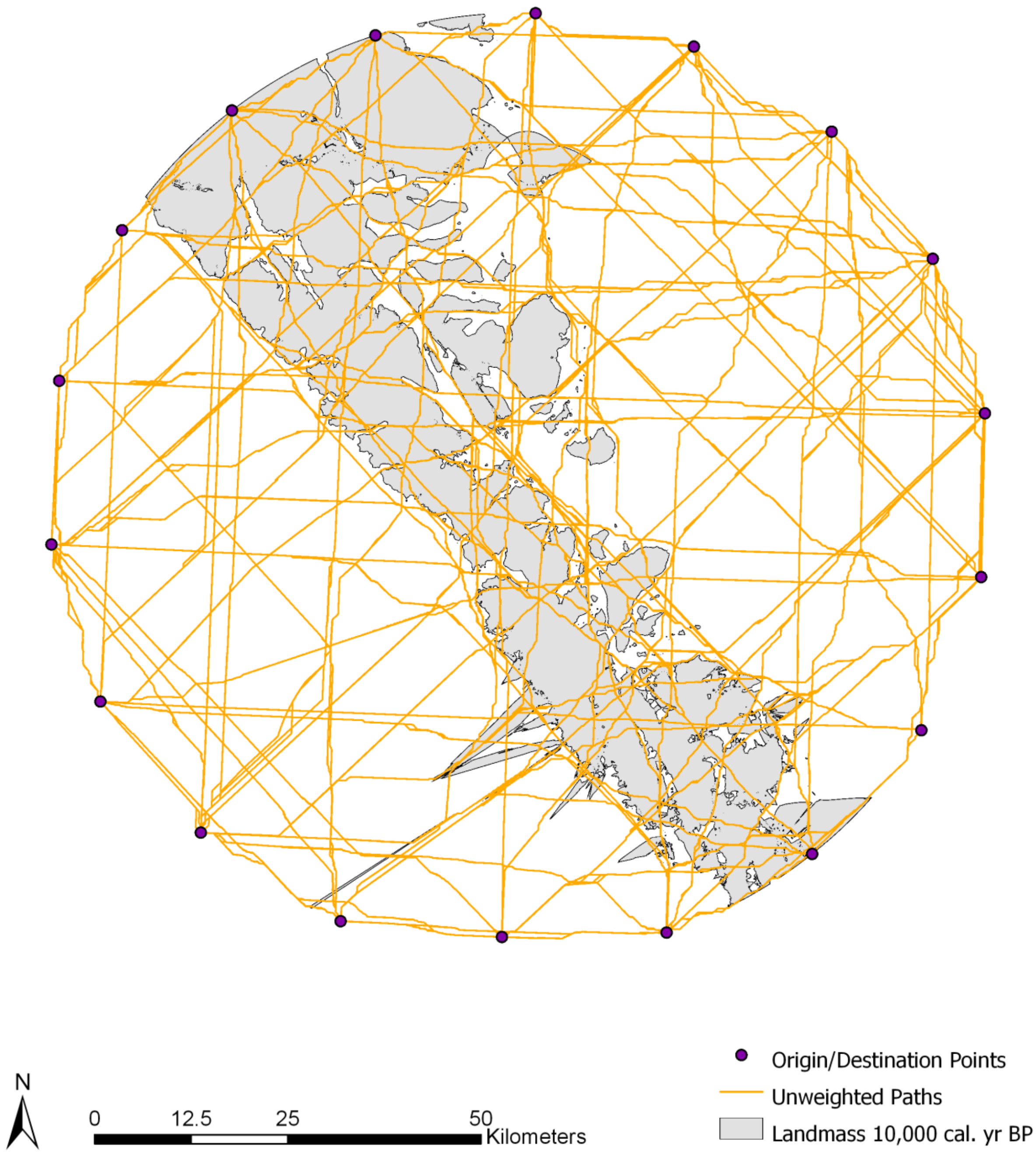
Haida Gwaii 10,000 cal. yr BP



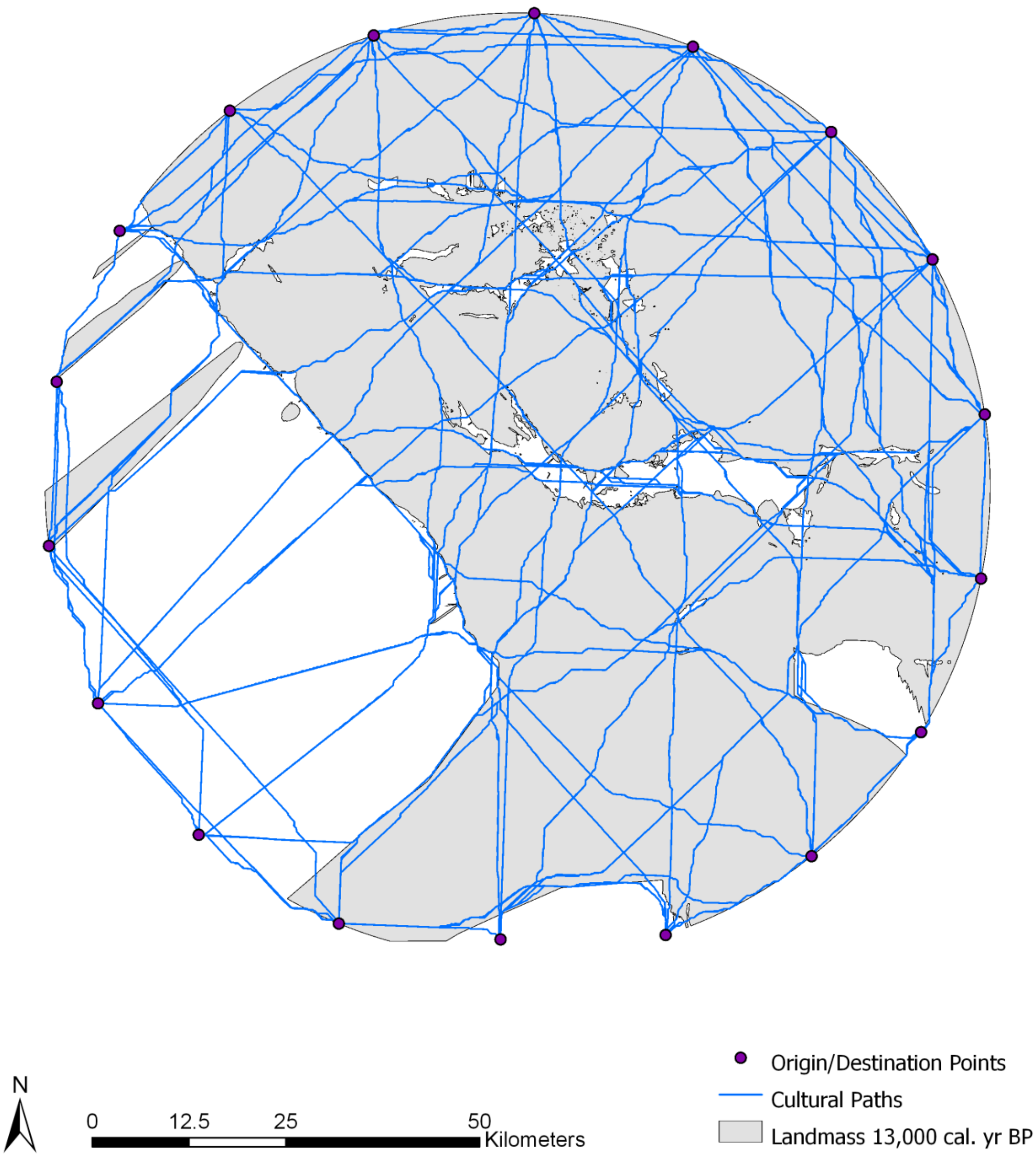
Haida Gwaii 10,000 cal. yr BP



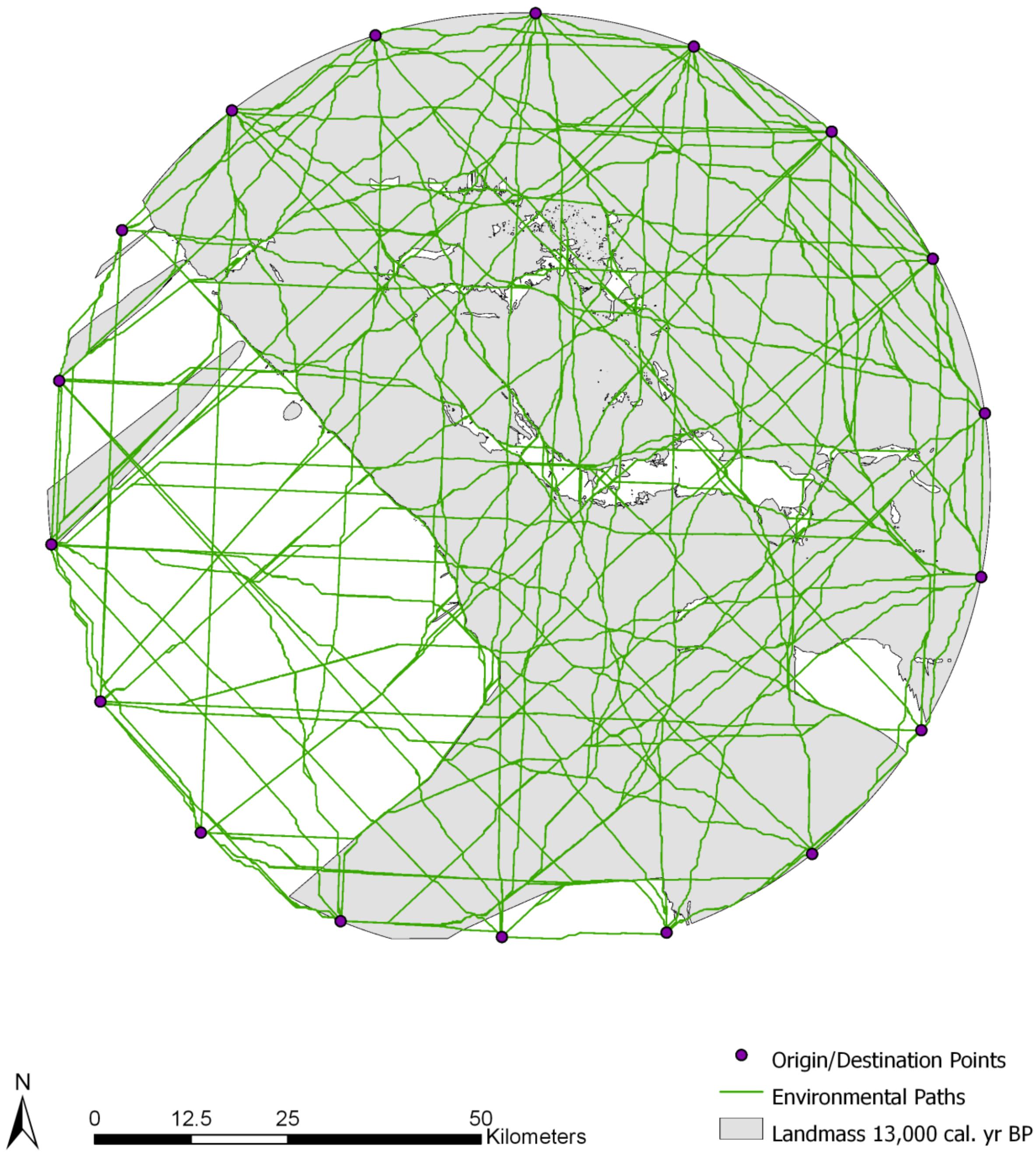
Haida Gwaii 10,000 cal. yr BP



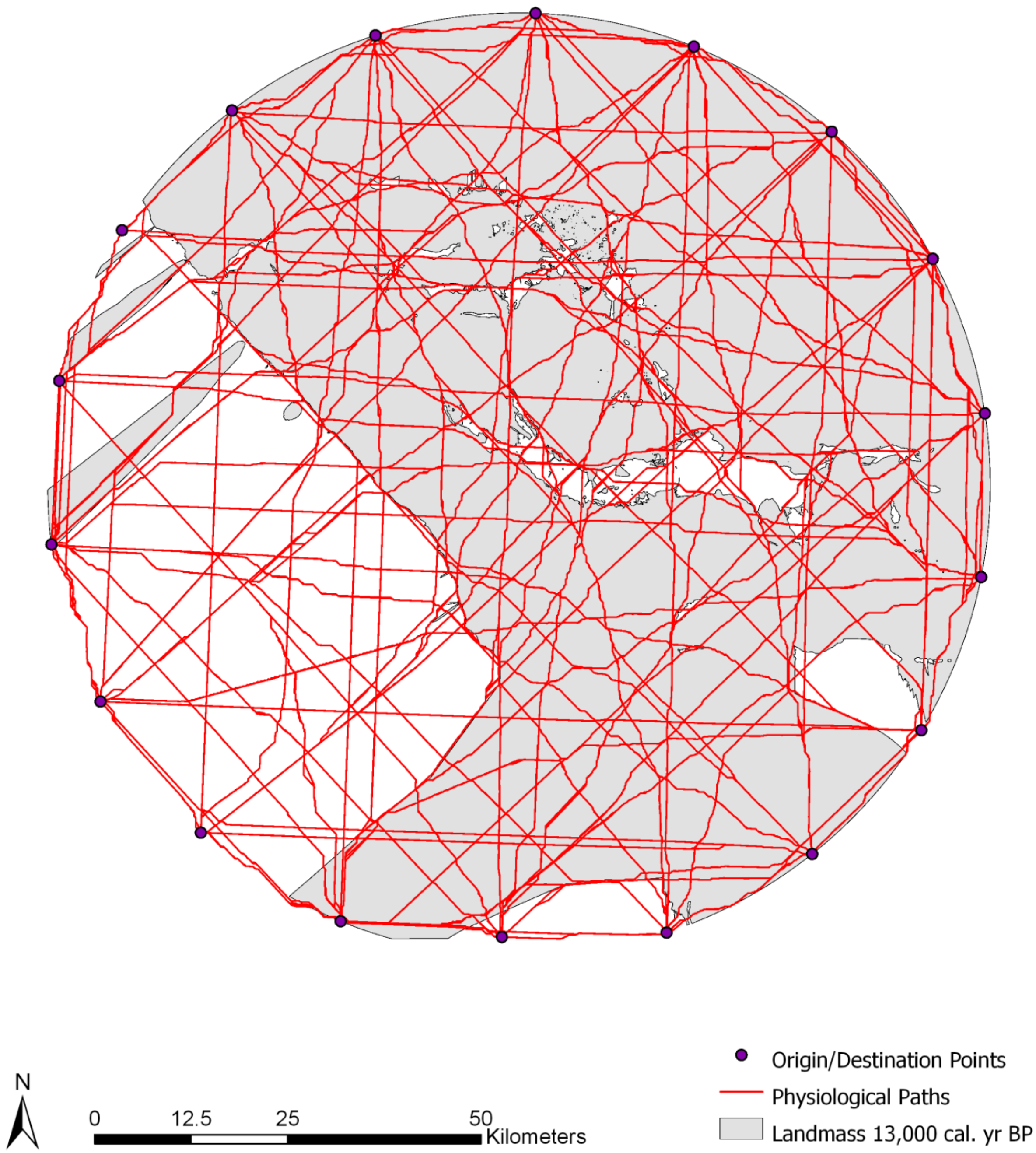
Haida Gwaii 13,000 cal. yr BP



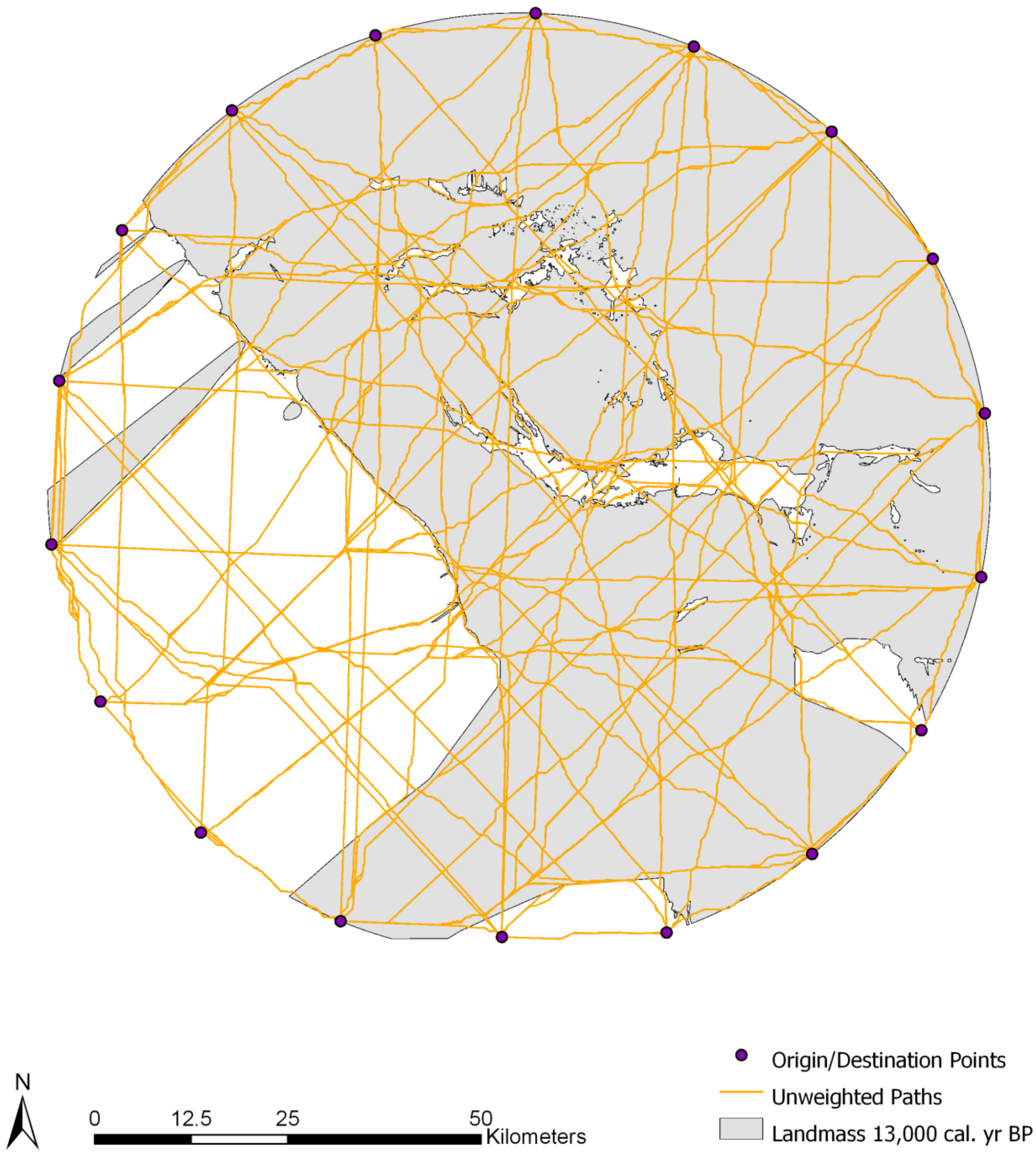
Haida Gwaii 13,000 cal. yr BP



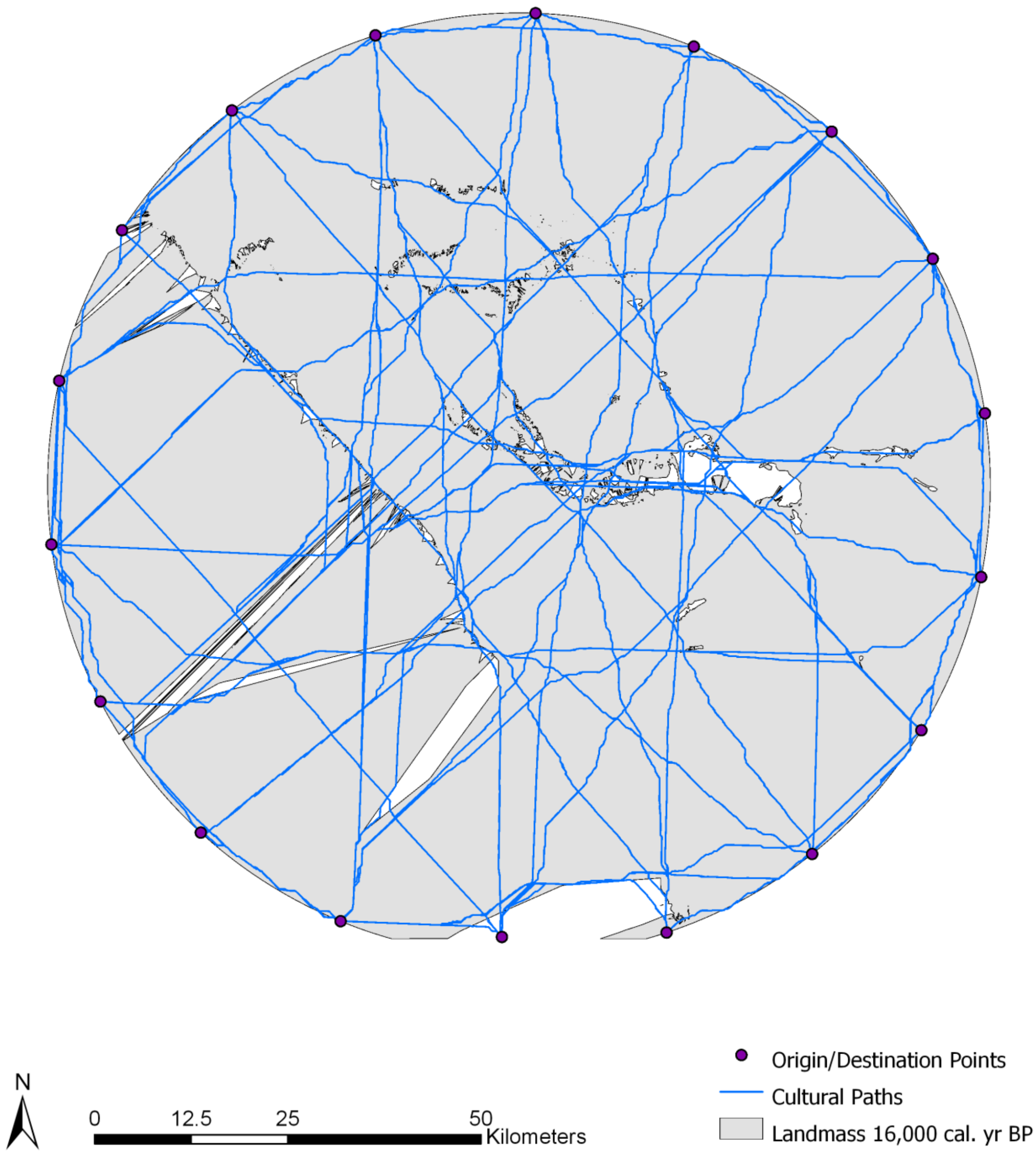
Haida Gwaii 13,000 cal. yr BP



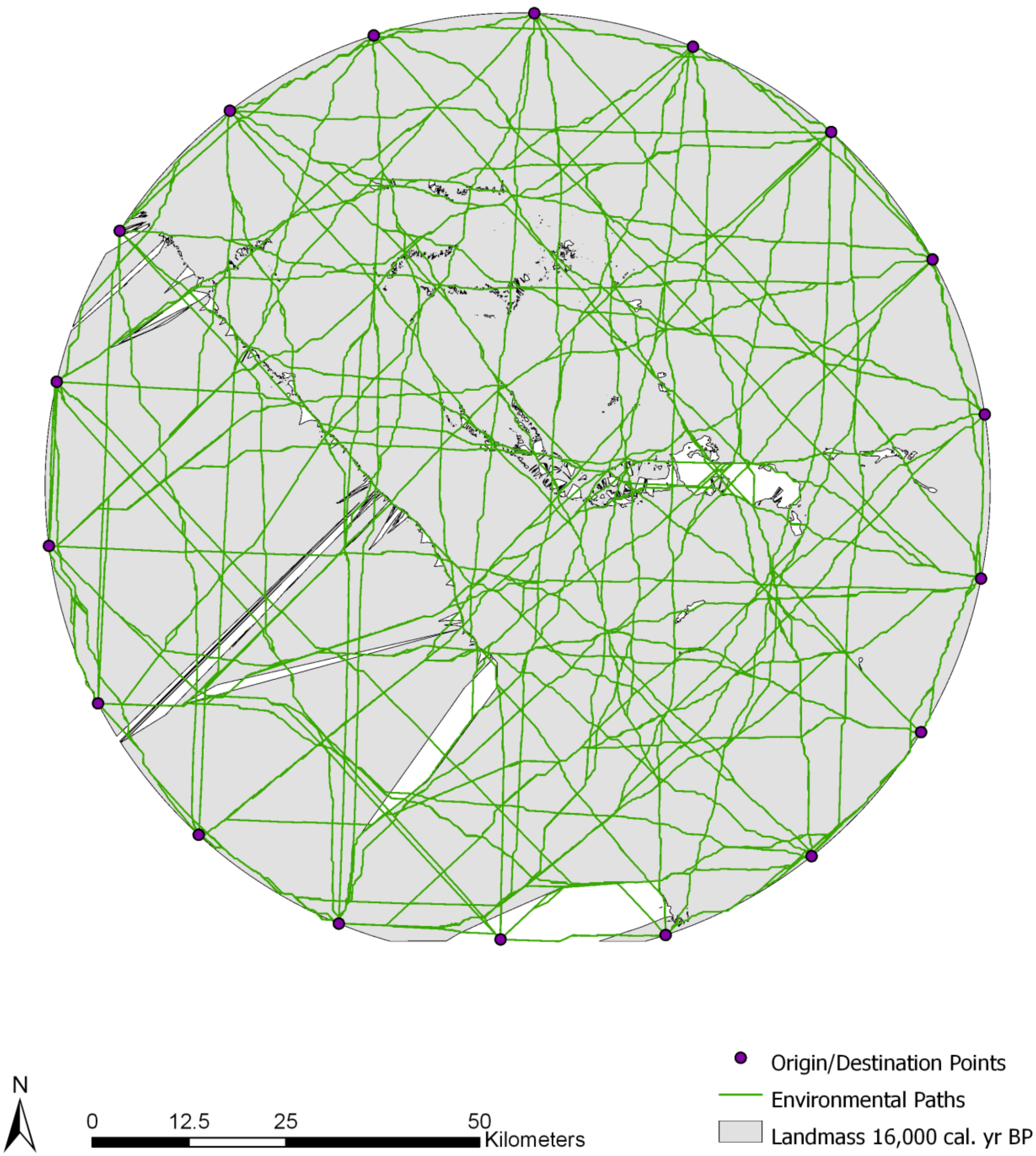
Haida Gwaii 13,000 cal. yr BP



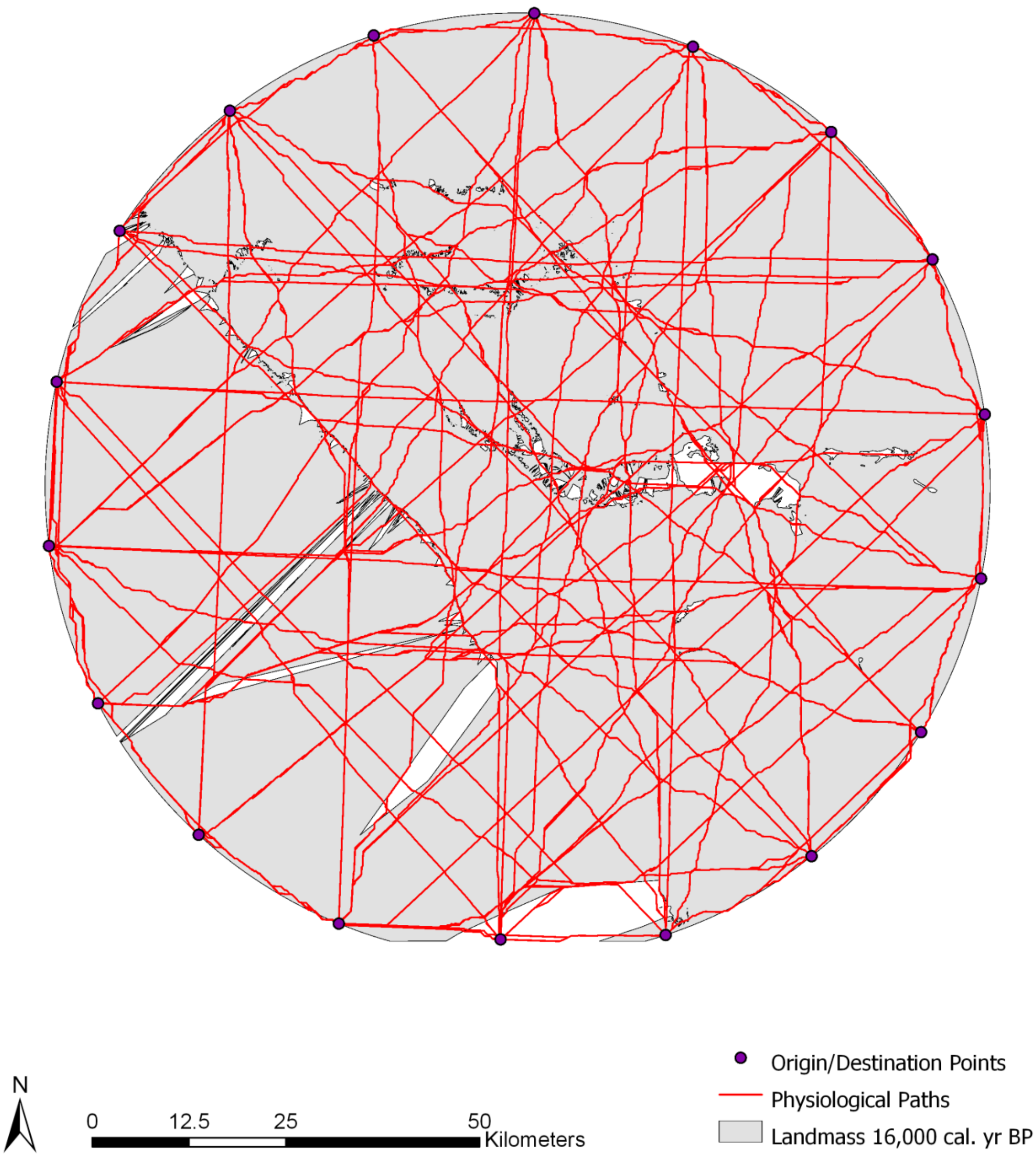
Haida Gwaii 16,000 cal. yr BP

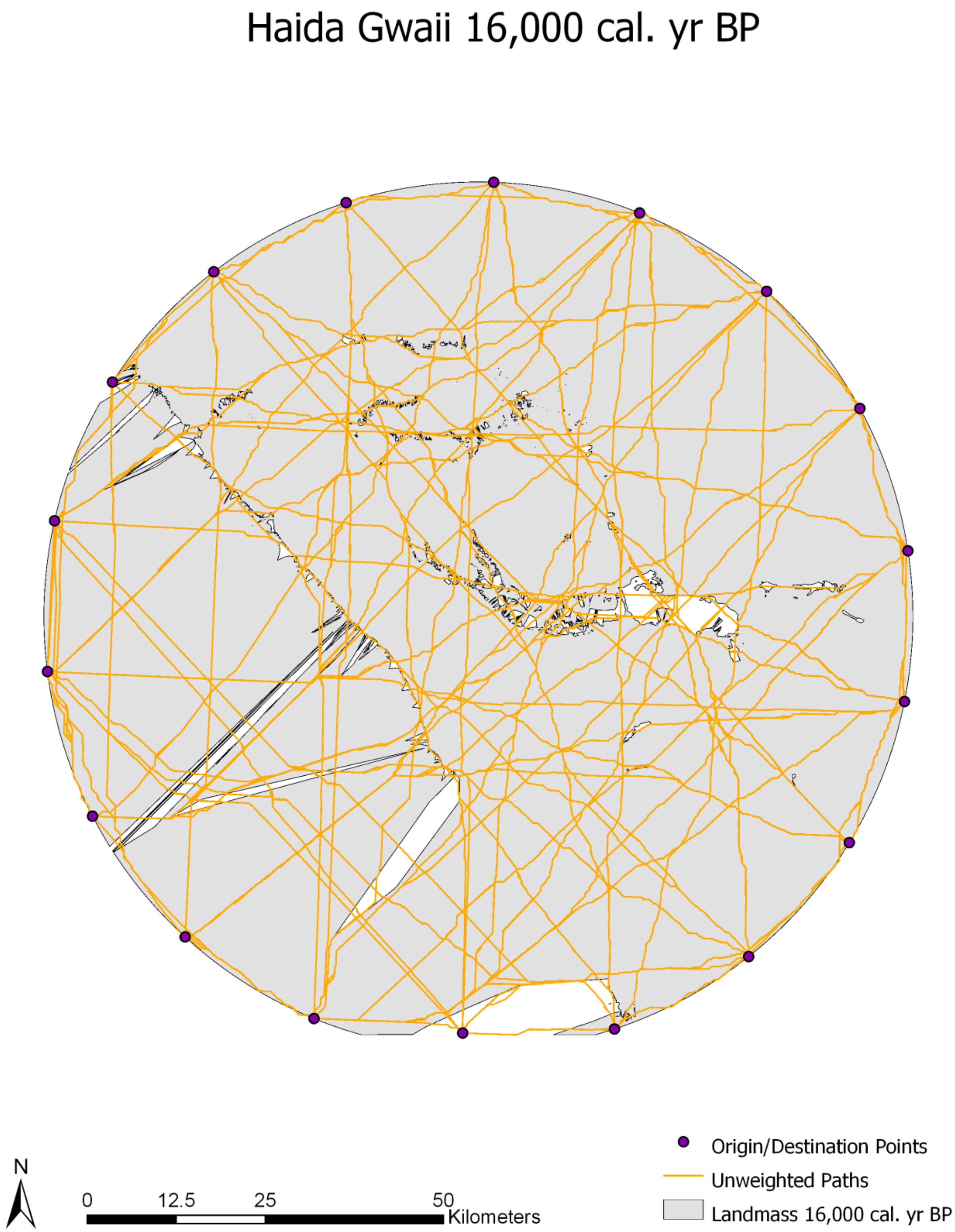


Haida Gwaii 16,000 cal. yr BP



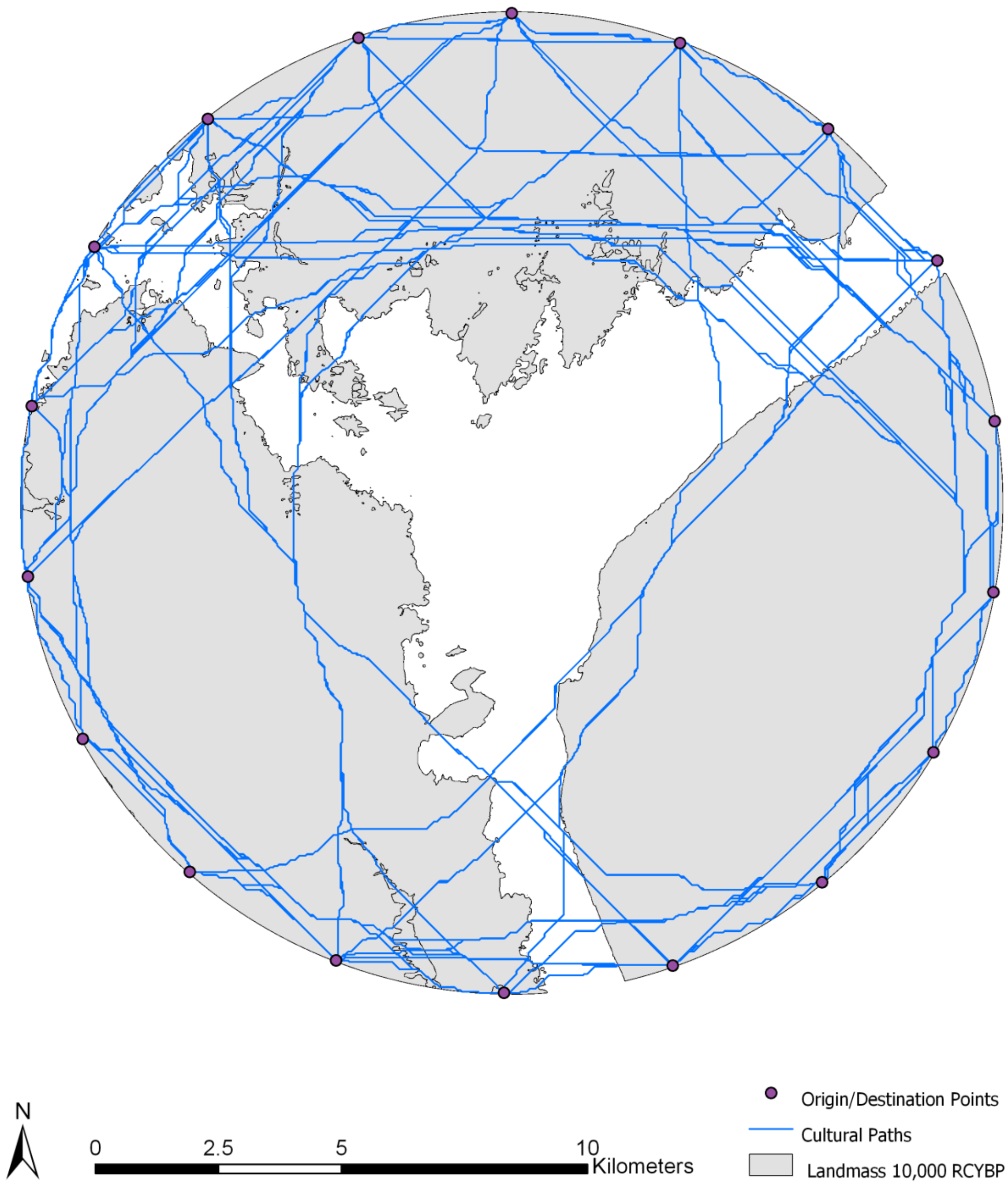
Haida Gwaii 16,000 cal. yr BP



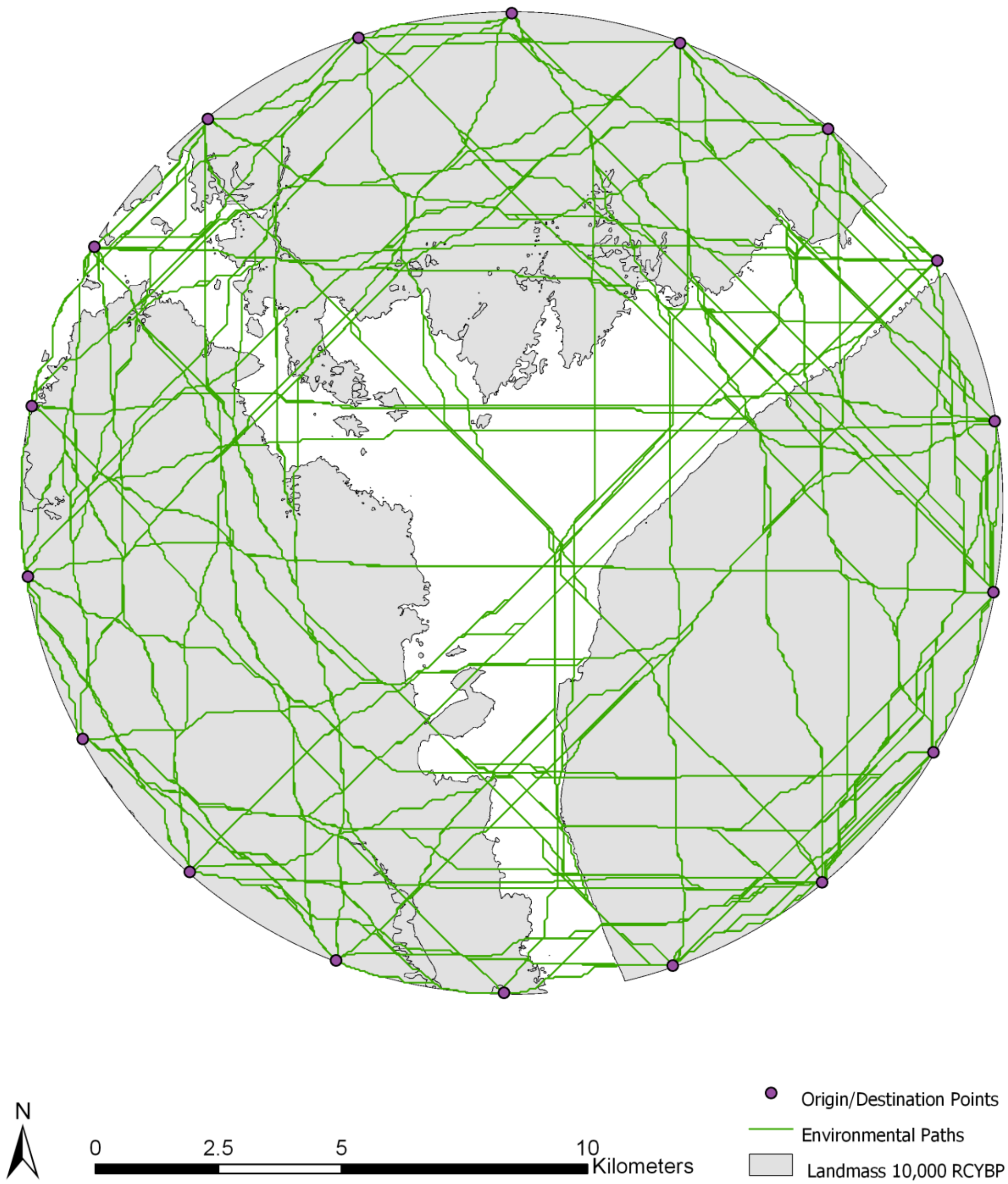


Haida Gwaii 16,000 cal. yr BP
N
0
12.5
25
50
Kilometers
Origin/Destination Points
Unweighted Paths
Landmass 16,000 cal. yr BP

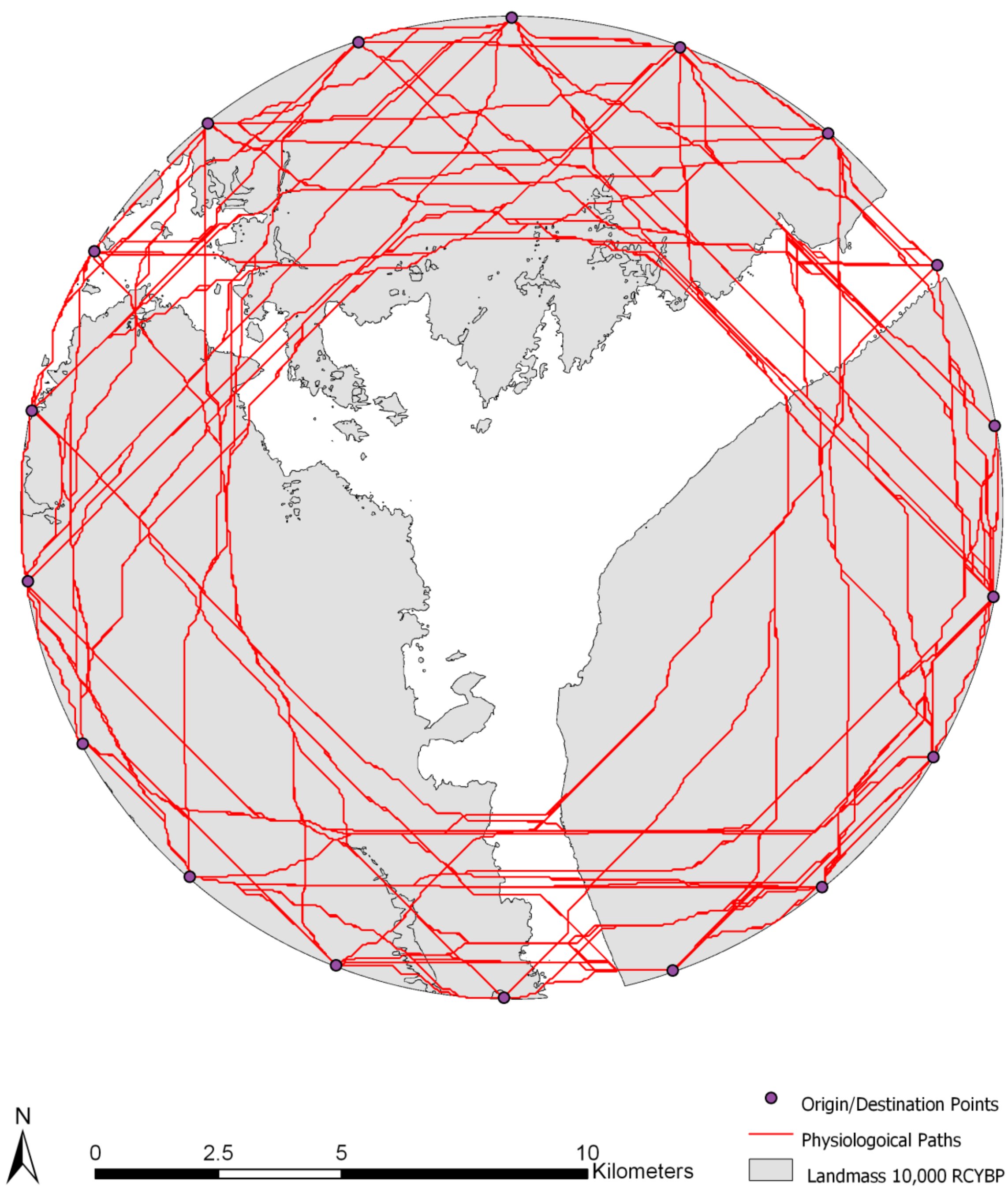
Prince Rupert Harbour 10,000 cal. yr BP



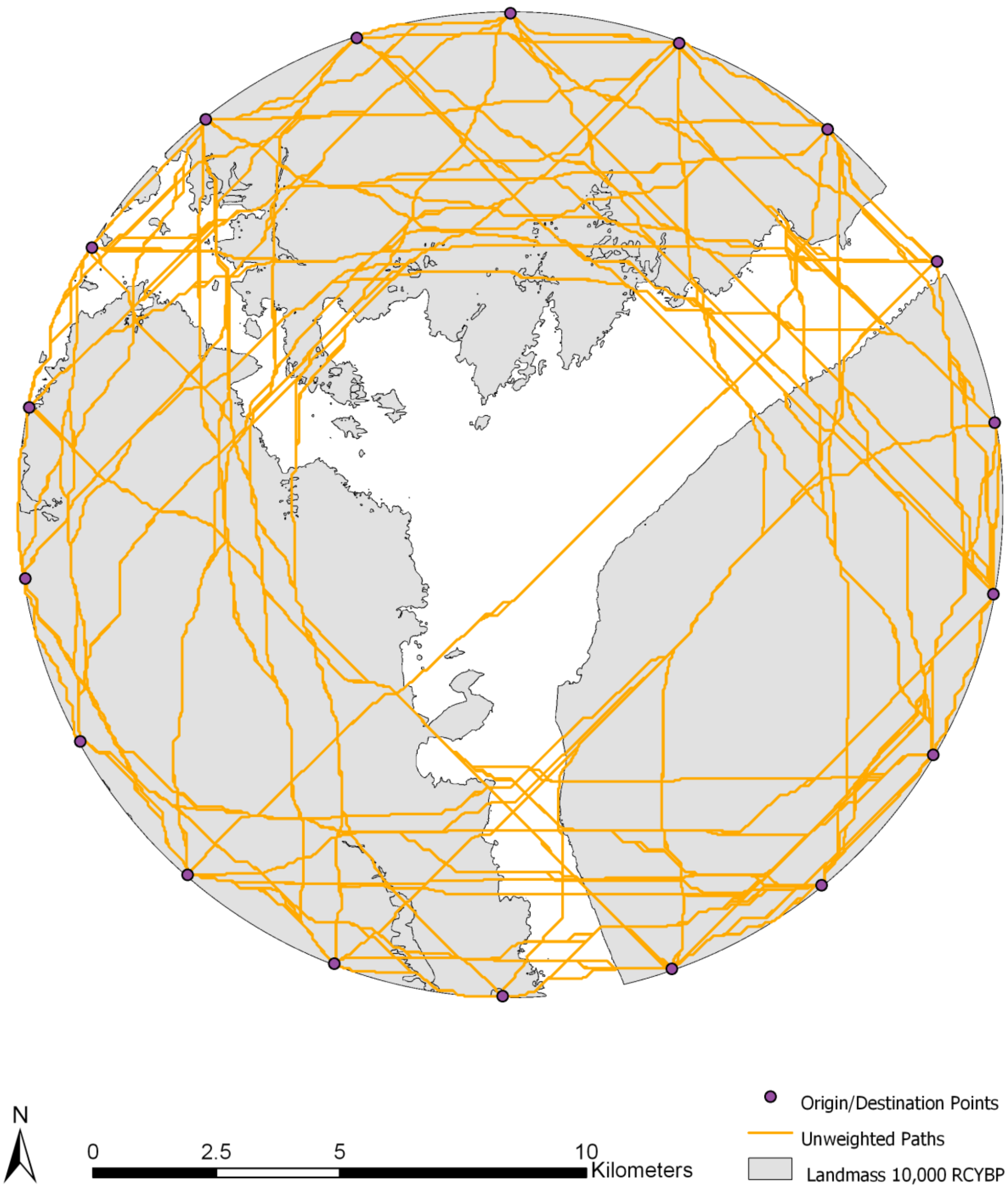
Prince Rupert Harbour 10,000 cal. yr BP



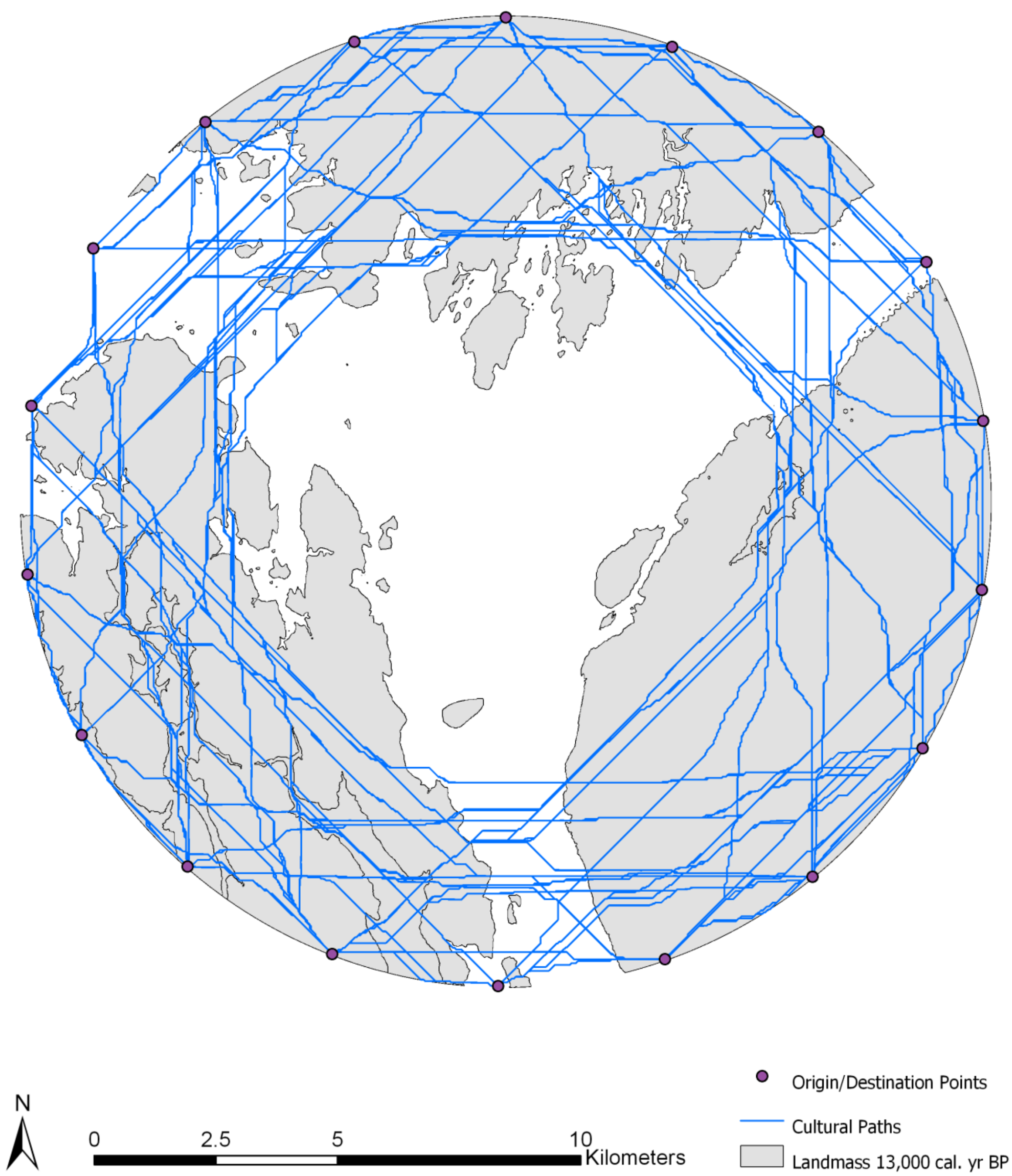
Prince Rupert Harbour 10,000 cal. yr BP



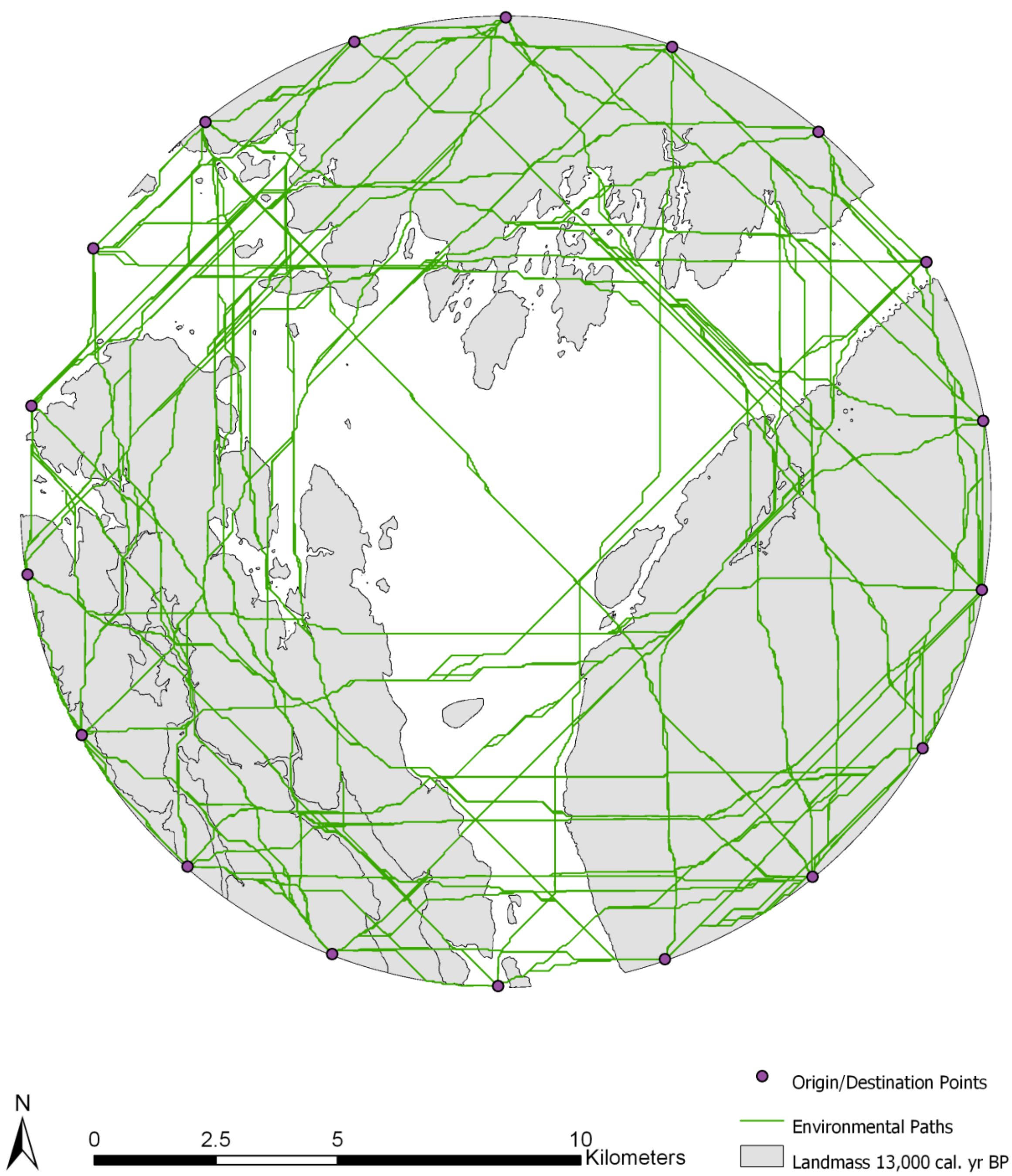
Prince Rupert Harbour 10,000 cal. yr BP



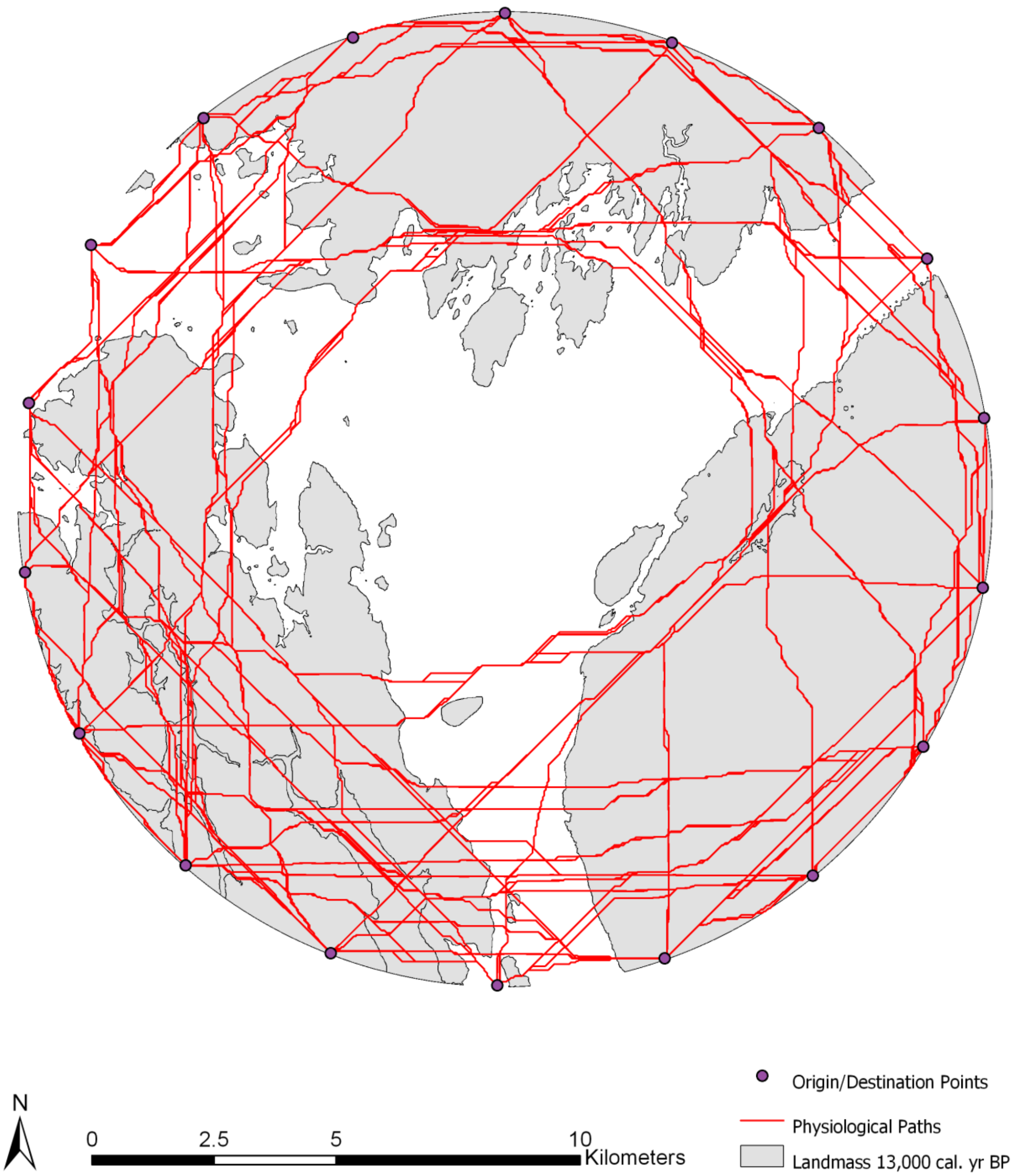
Prince Rupert Harbour 13,000 cal. yr BP



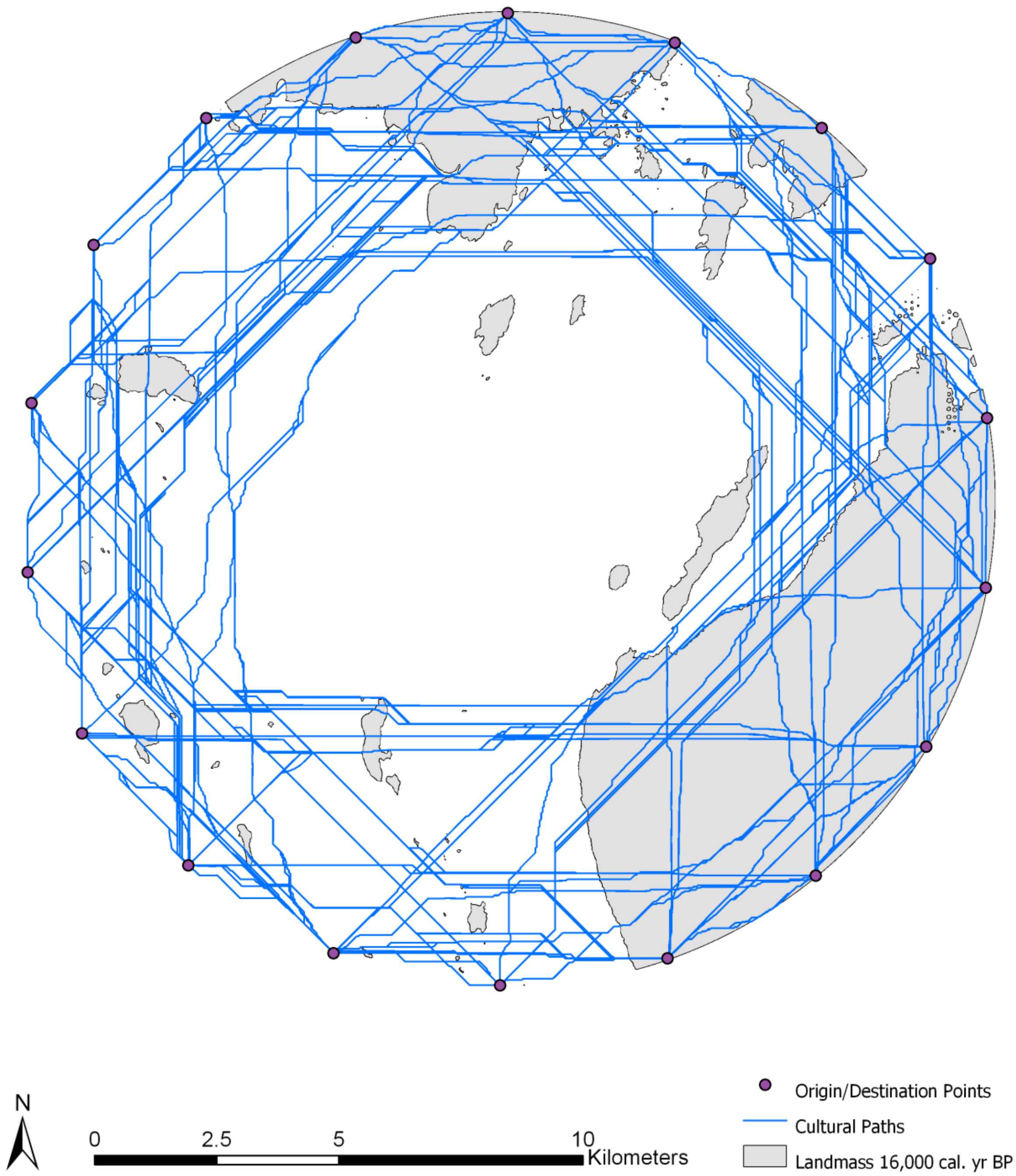
Prince Rupert Harbour 13,000 cal. yr BP



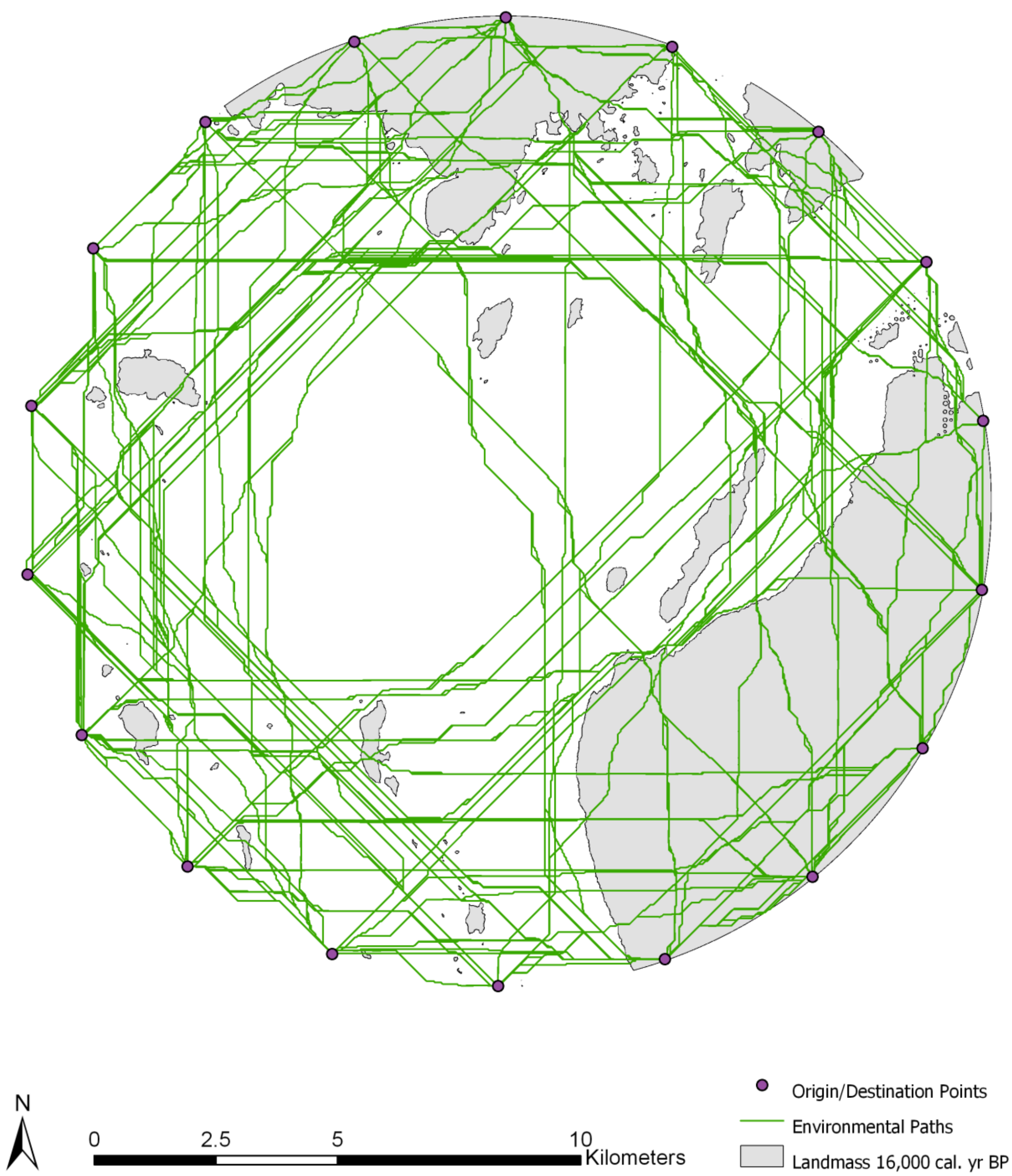
Prince Rupert Harbour 13,000 cal. yr BP

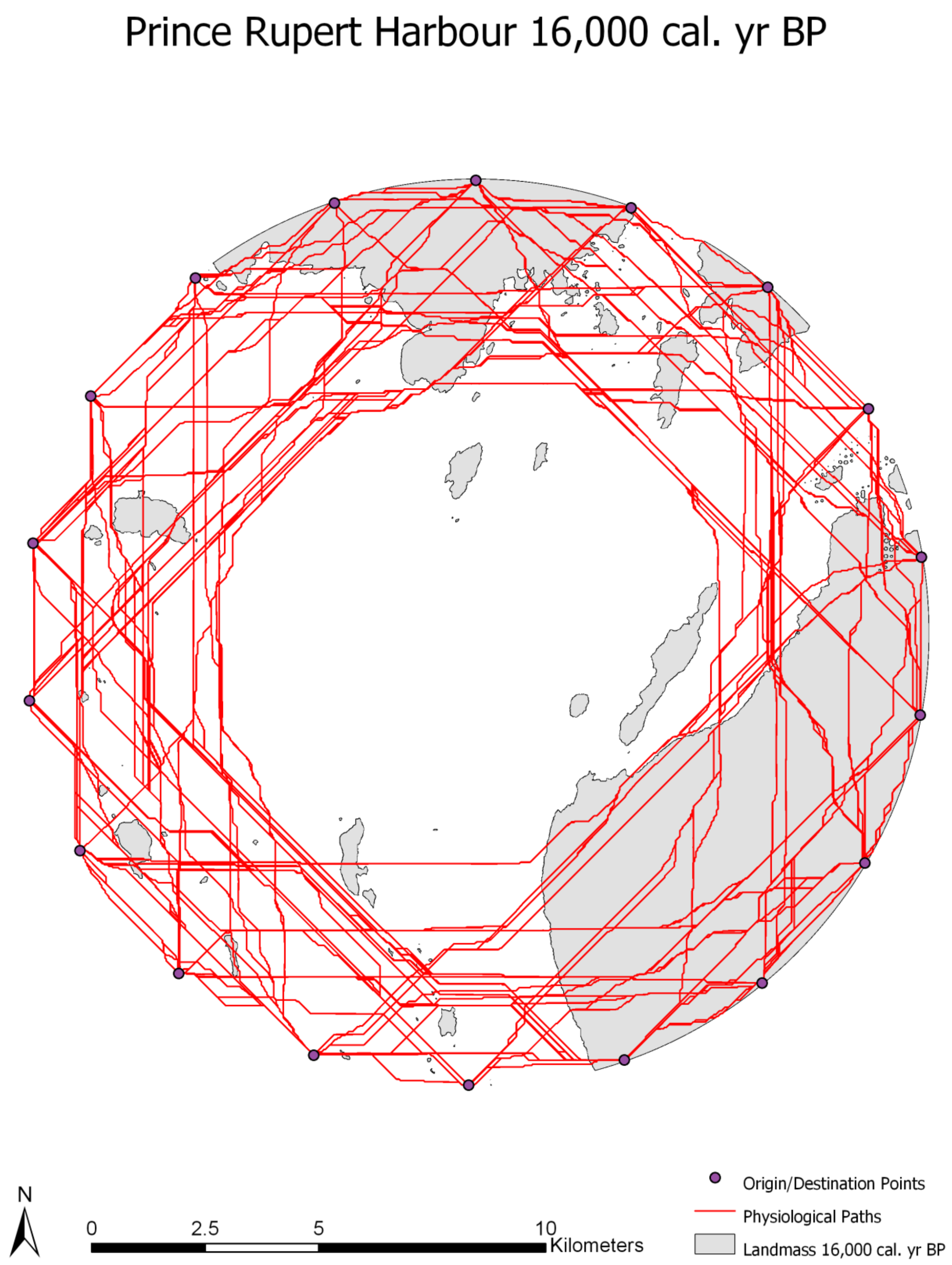


Prince Rupert Harbour 16,000 cal. yr BP

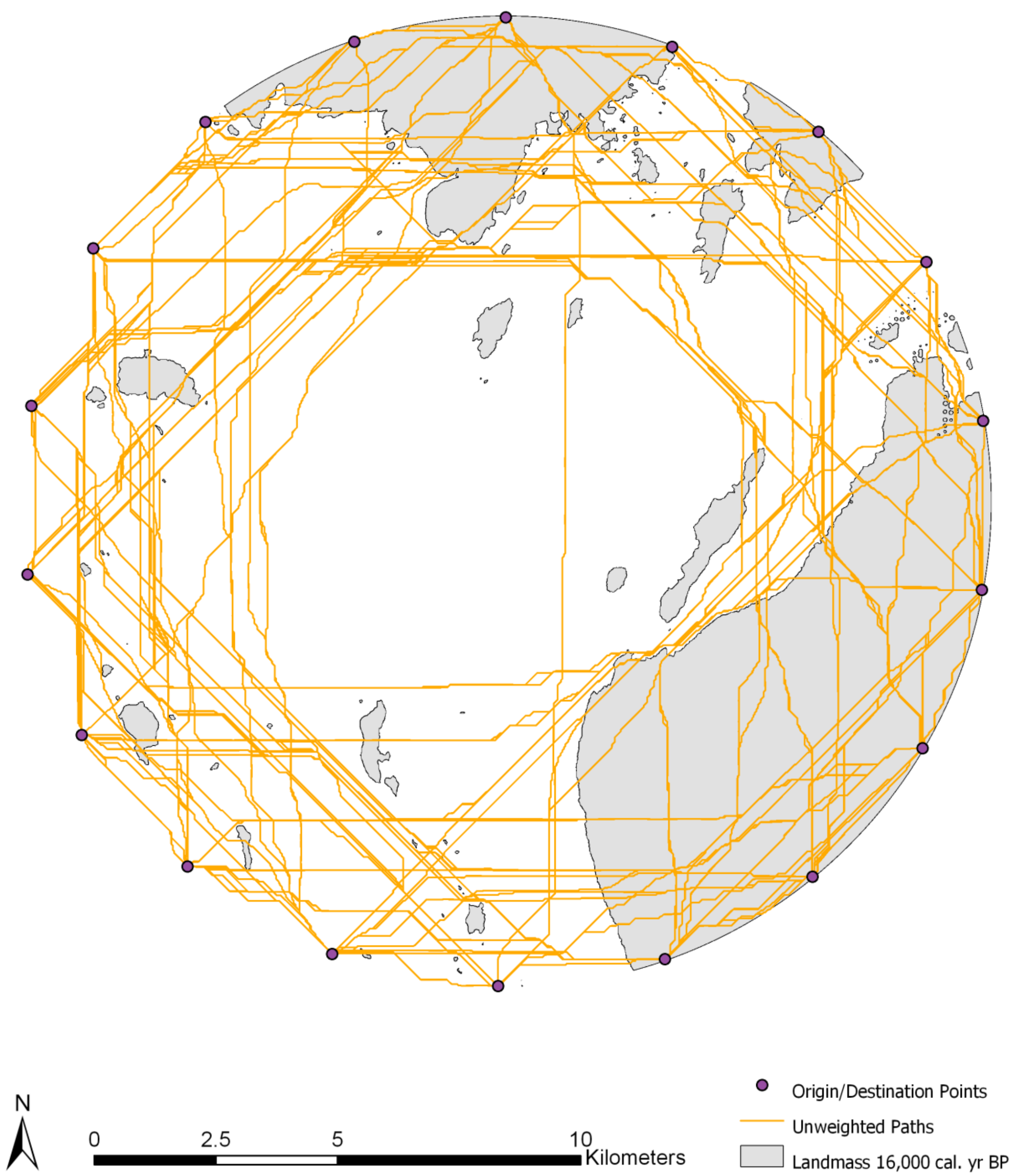


Prince Rupert Harbour 16,000 cal. yr BP

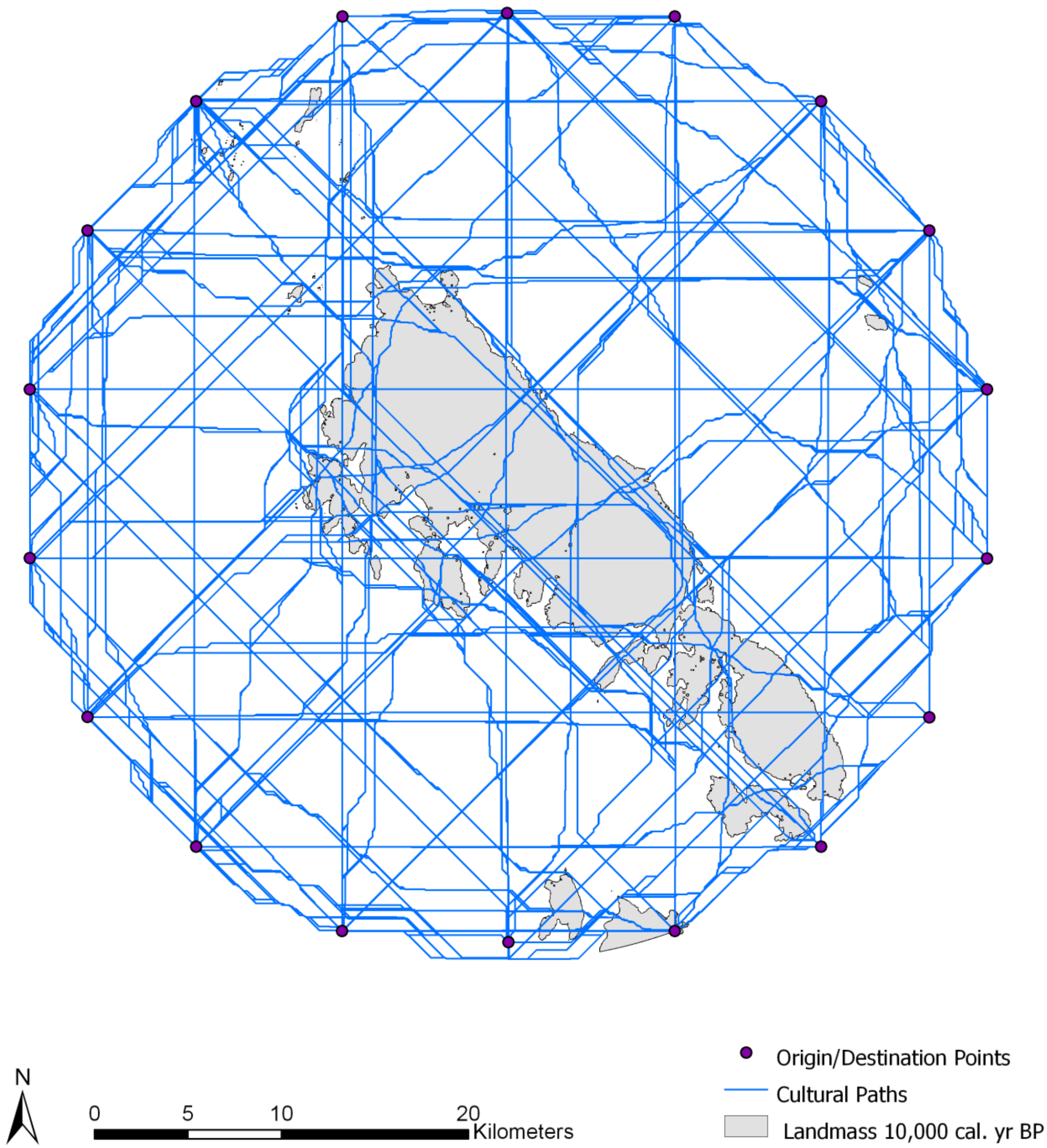



Prince Rupert Harbour 16,000 cal. yr BP
N
0
2.5
5
10
Kilometers
Origin/Destination Points
Physiological Paths
Landmass 16,000 cal. yr BP

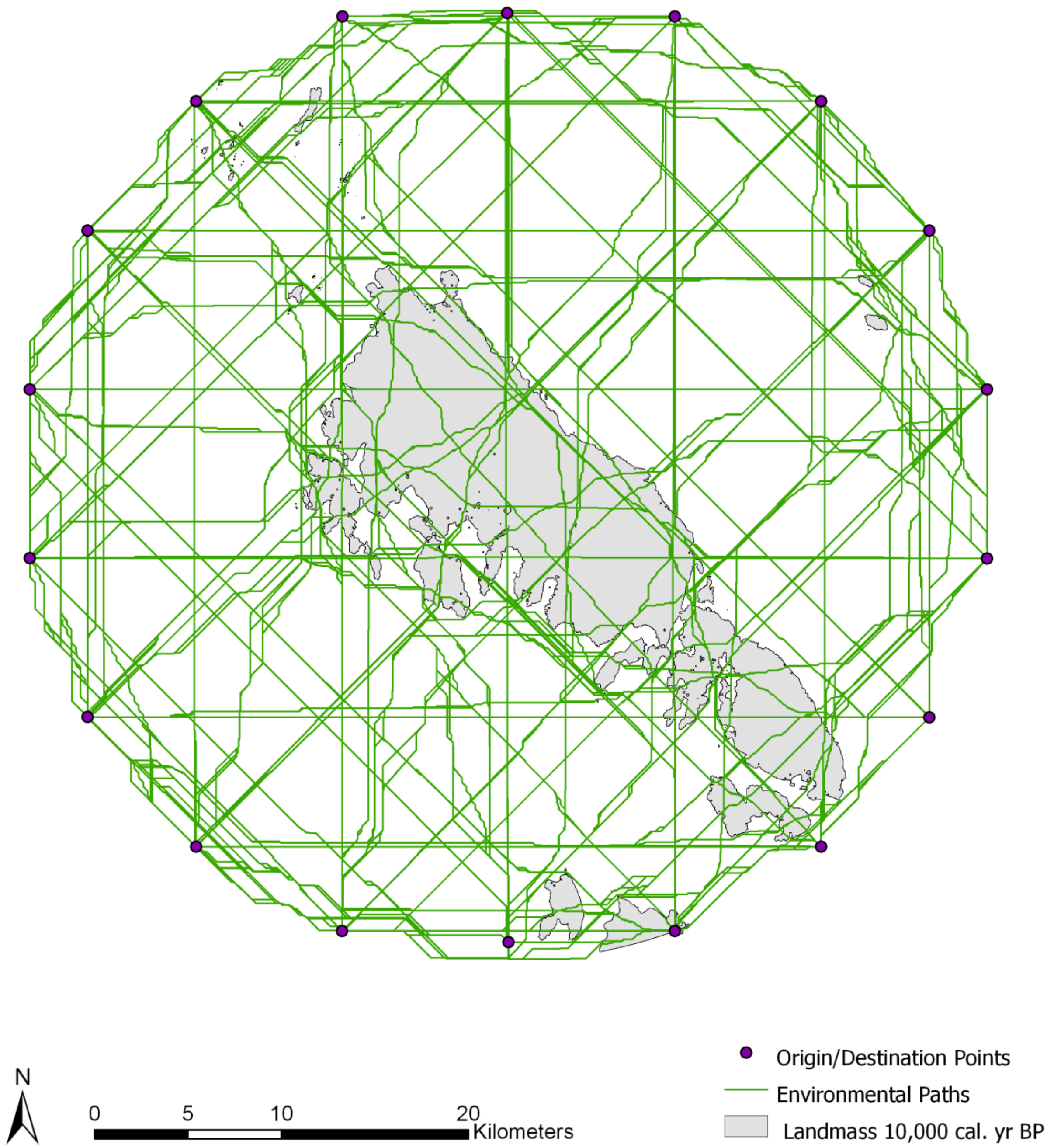
Prince Rupert Harbour 16,000 cal. yr BP



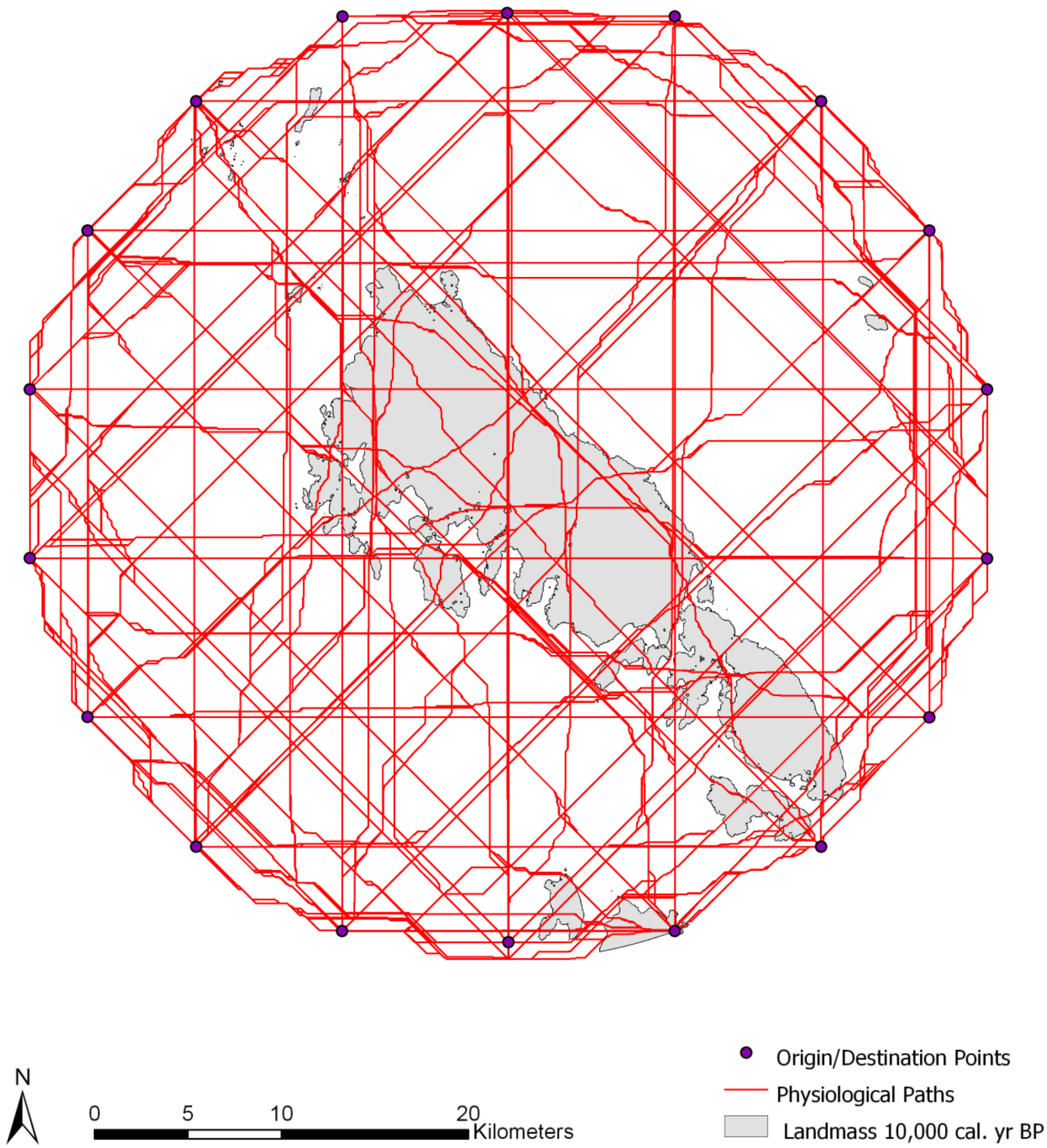
Stephens Island 10,000 cal. yr BP



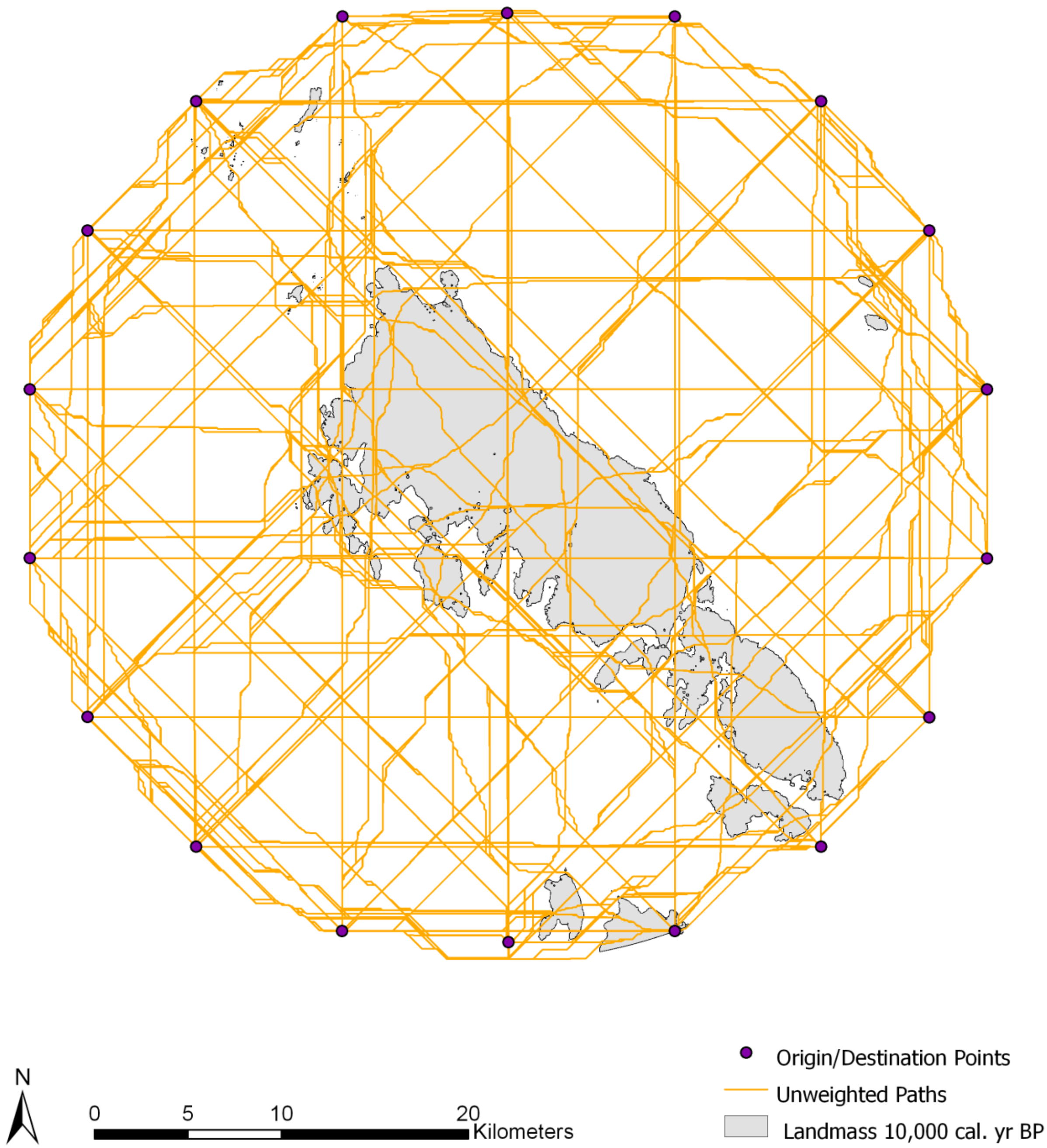
Stephens Island 10,000 cal. yr BP



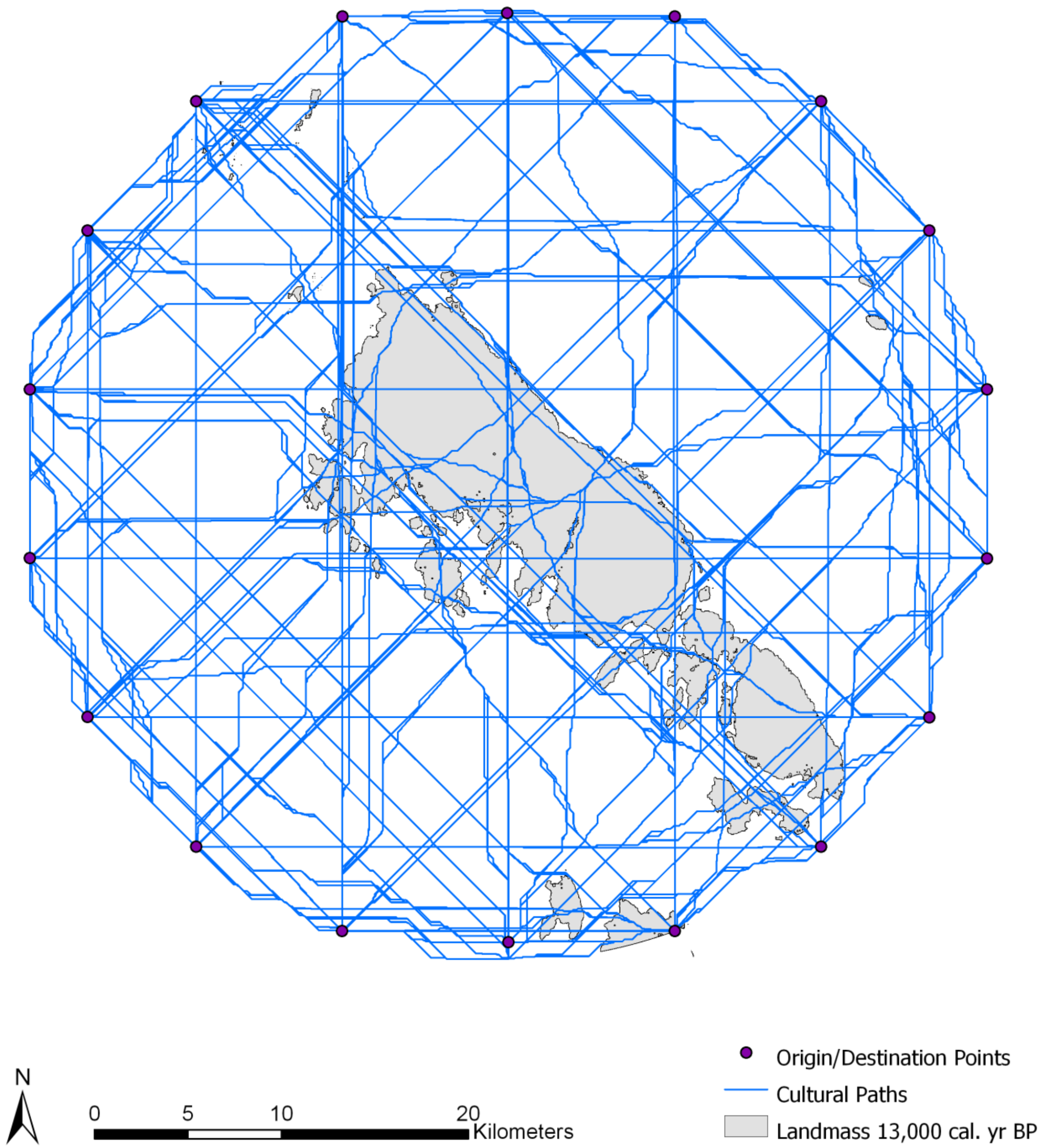
Stephens Island 10,000 cal. yr BP



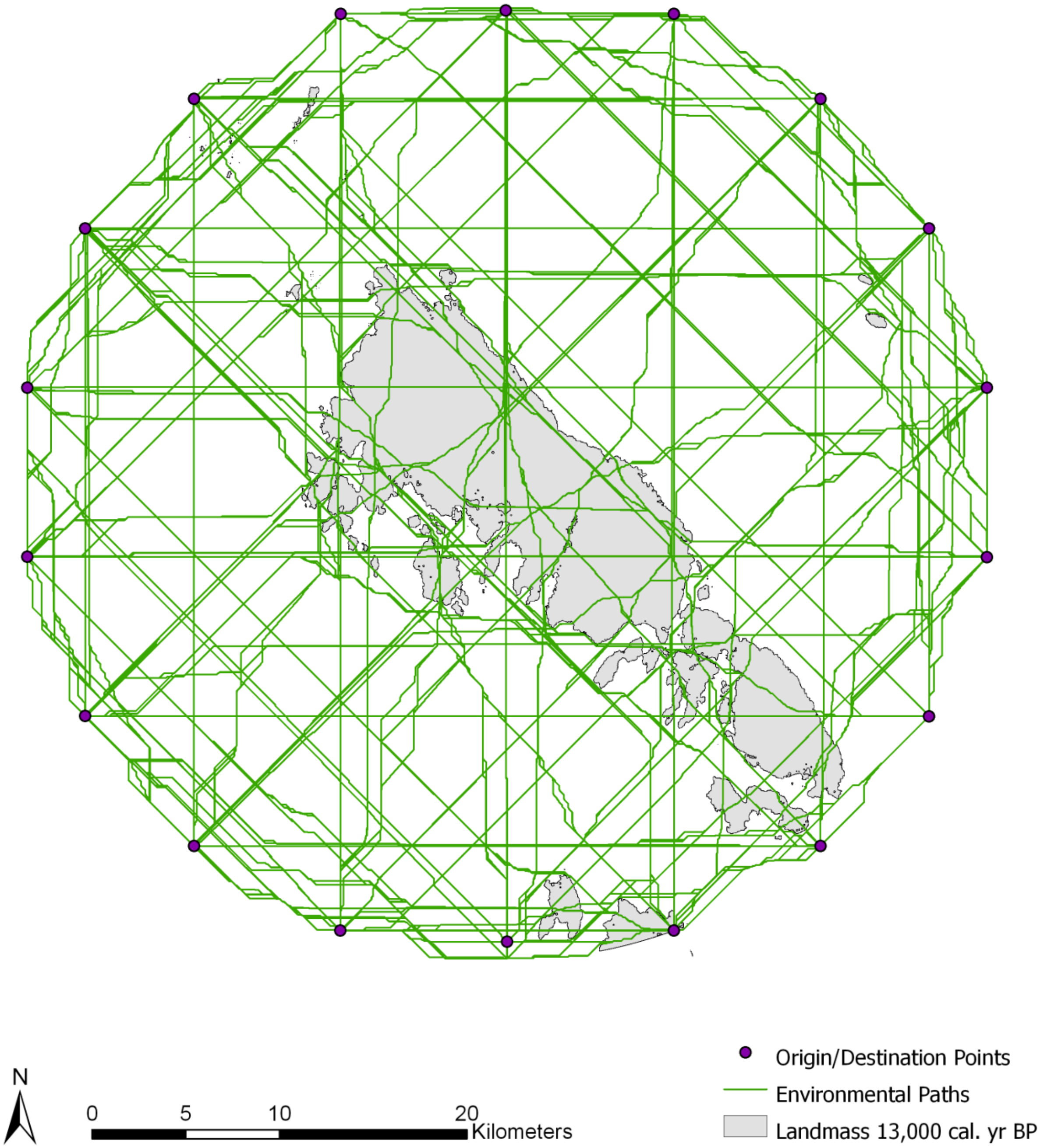
Stephens Island 10,000 cal. yr BP



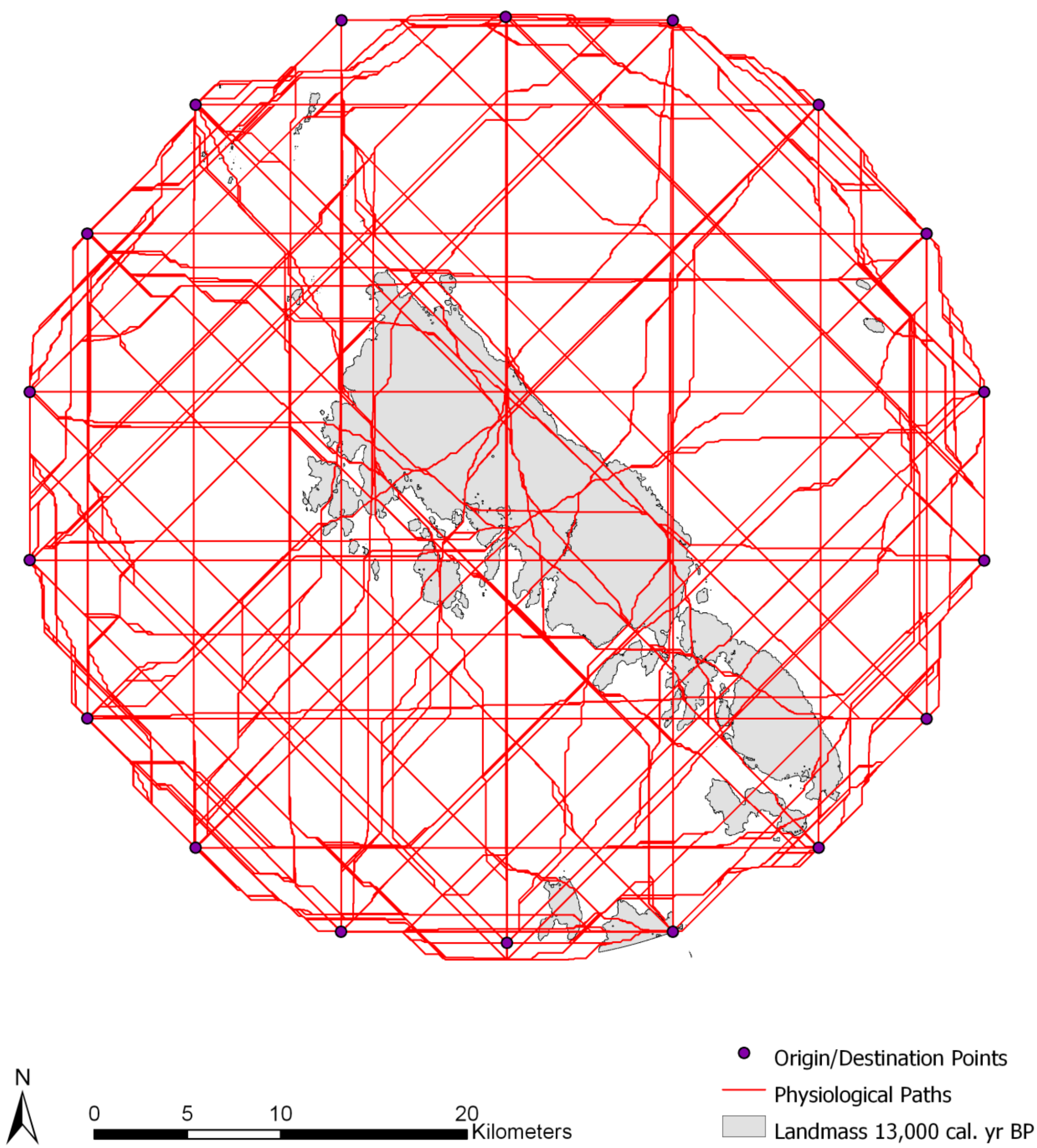
Stephens Island 13,000 cal. yr BP

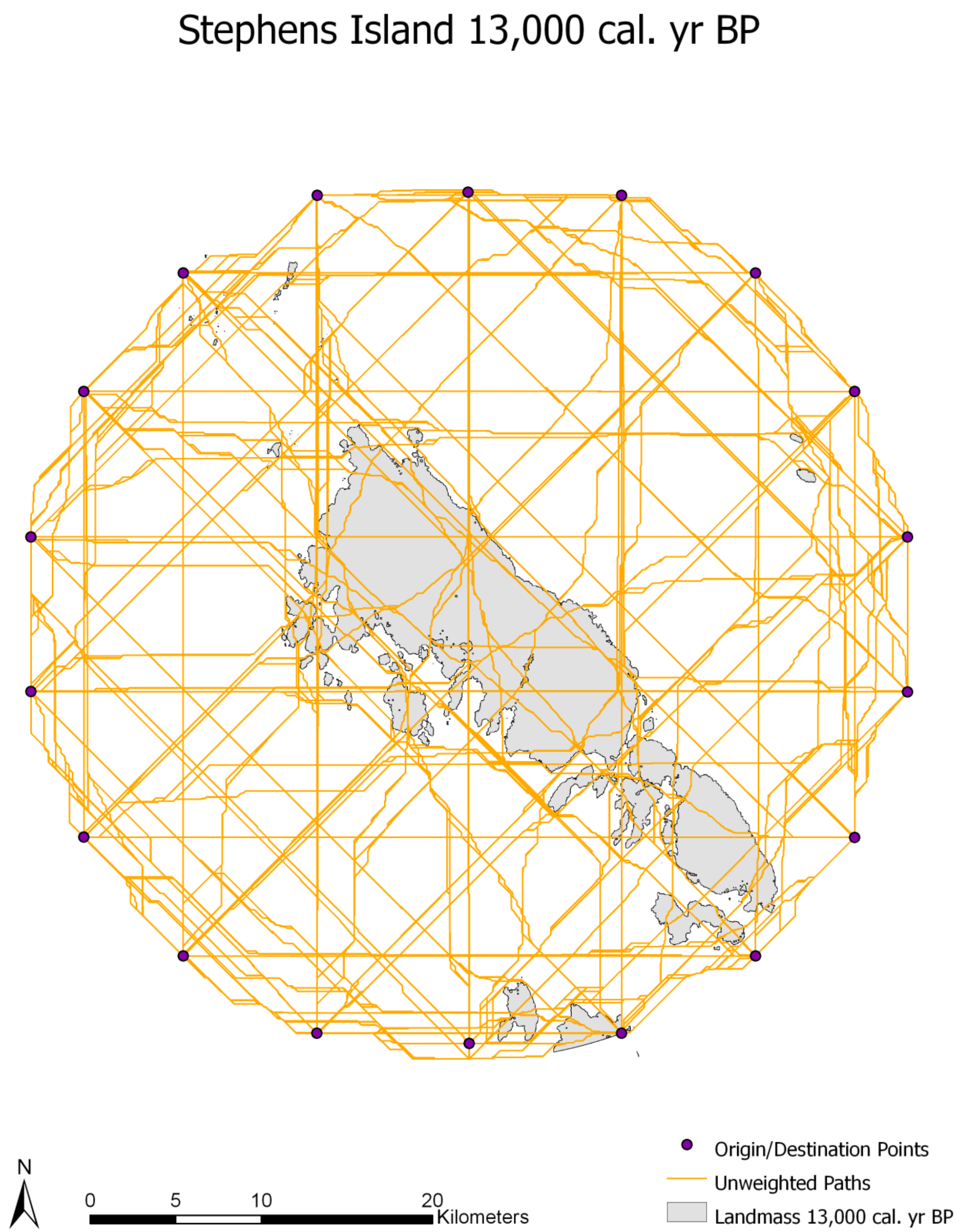


Stephens Island 13,000 cal. yr BP



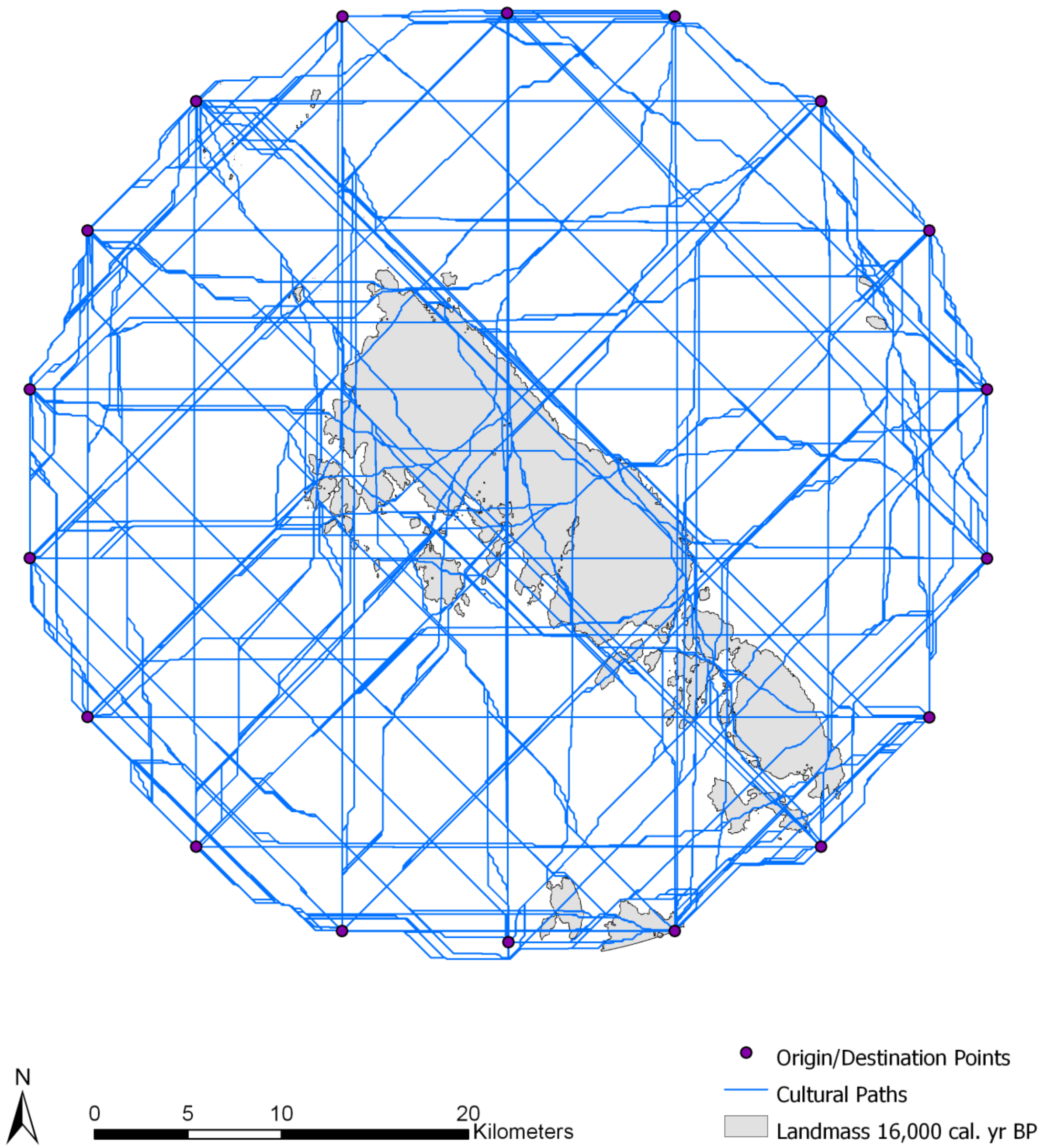
Stephens Island 13,000 cal. yr BP

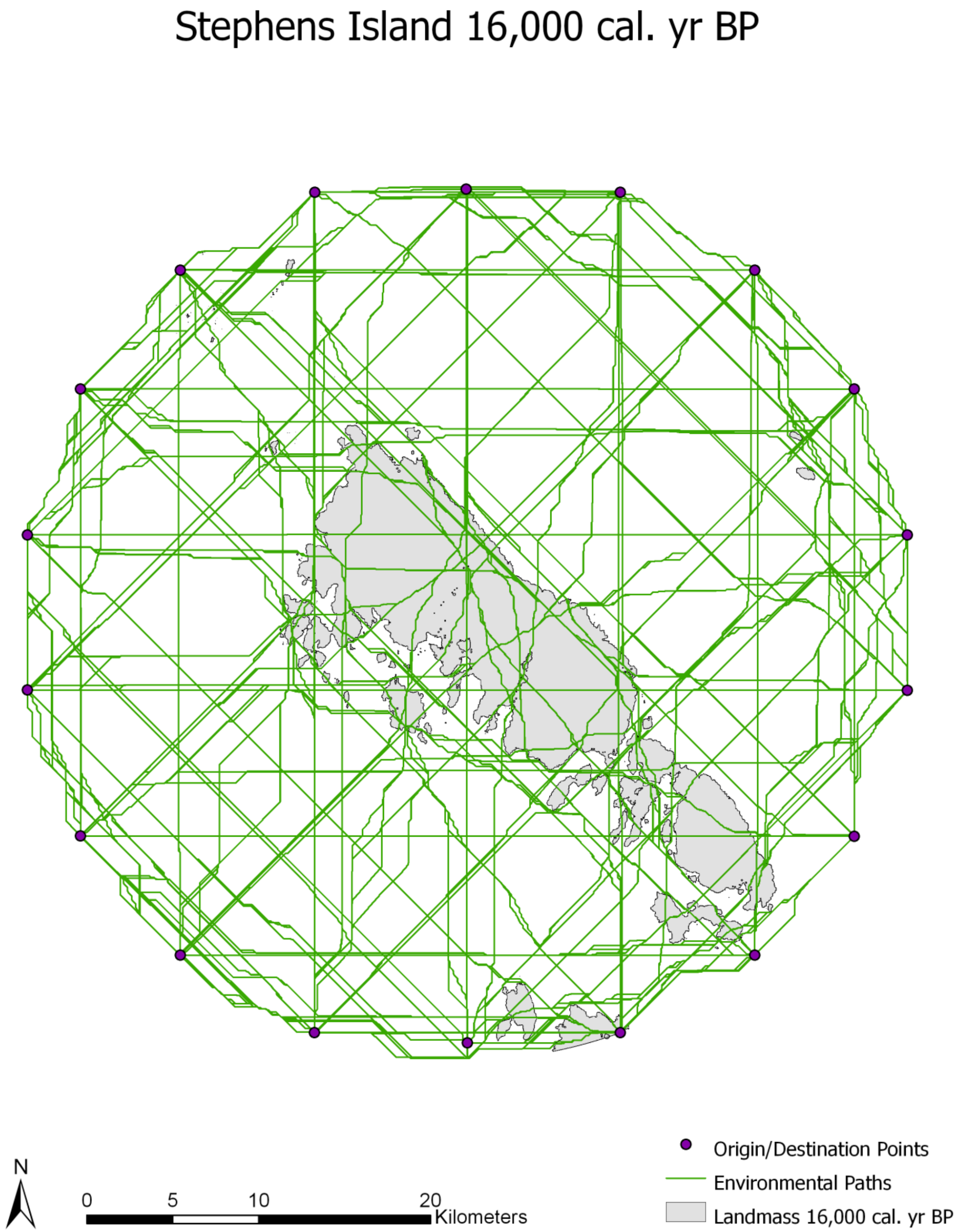




Stephens Island 13,000 cal. yr BP
N
0
5
10
20
Kilometers
Origin/Destination Points
Unweighted Paths
Landmass 13,000 cal. yr BP

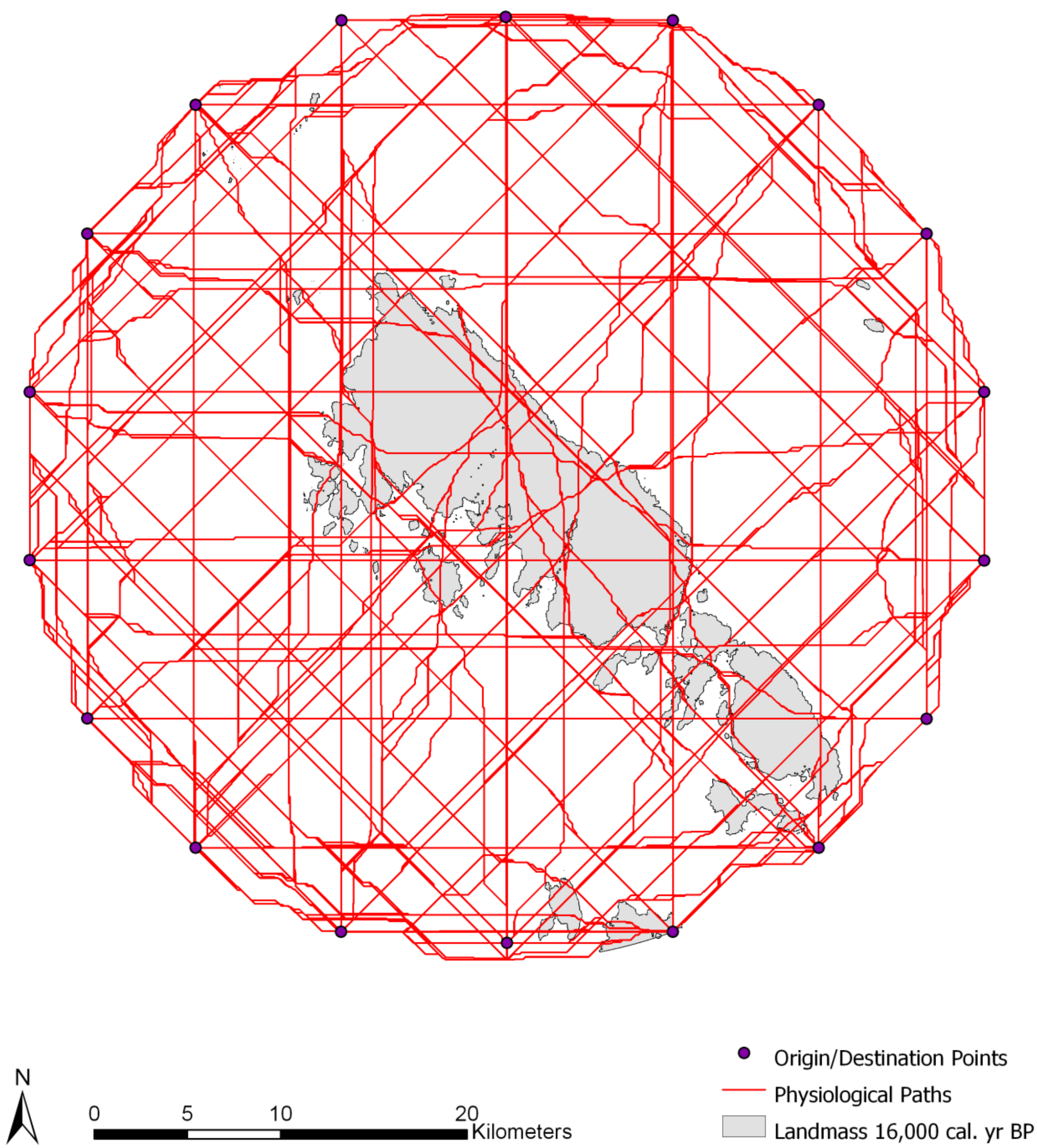
Stephens Island 16,000 cal. yr BP



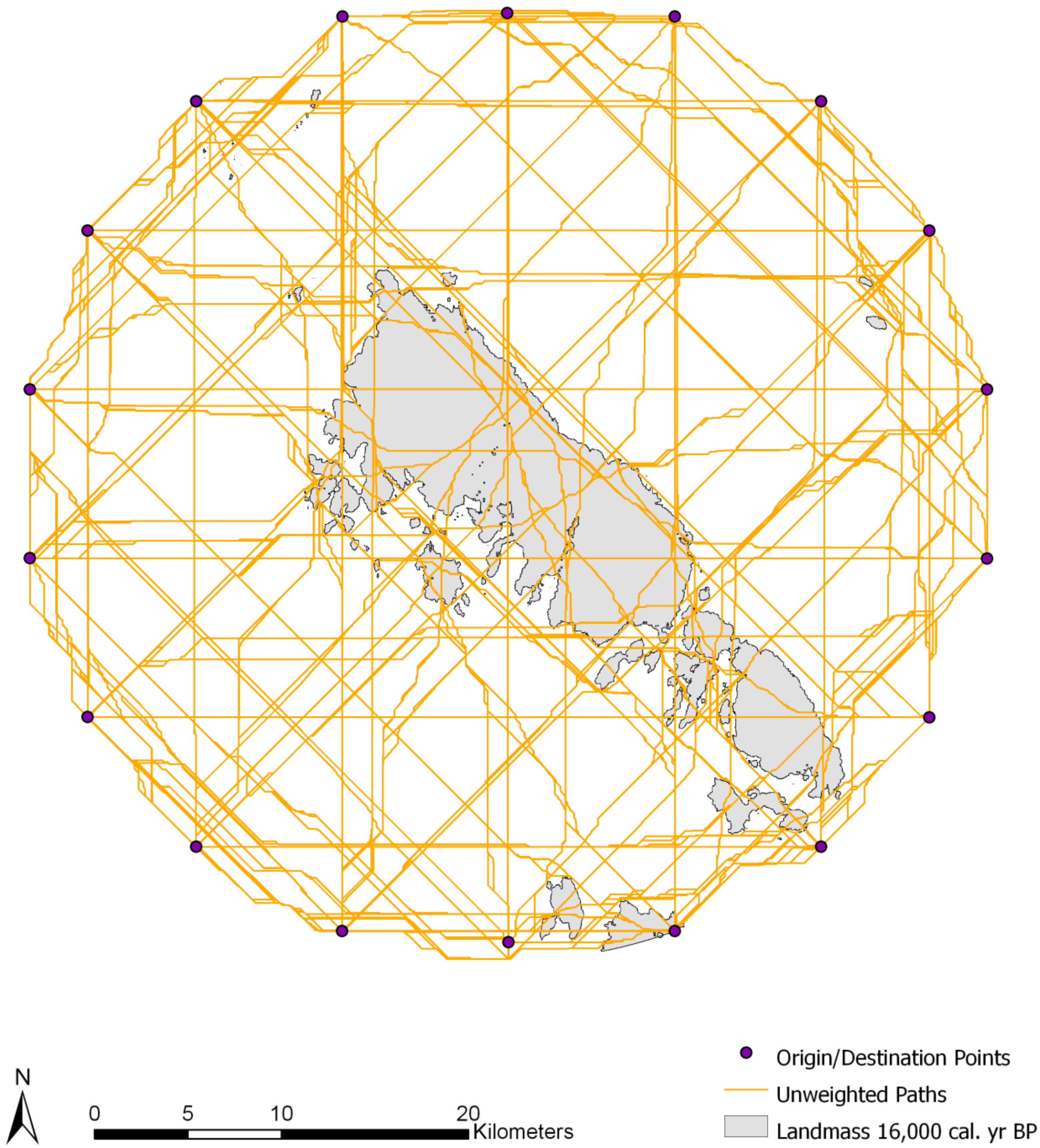


Stephens Island 16,000 cal. yr BP
N
0
5
10
20
Kilometers
Origin/Destination Points
Environmental Paths
Landmass 16,000 cal. yr BP

Stephens Island 16,000 cal. yr BP

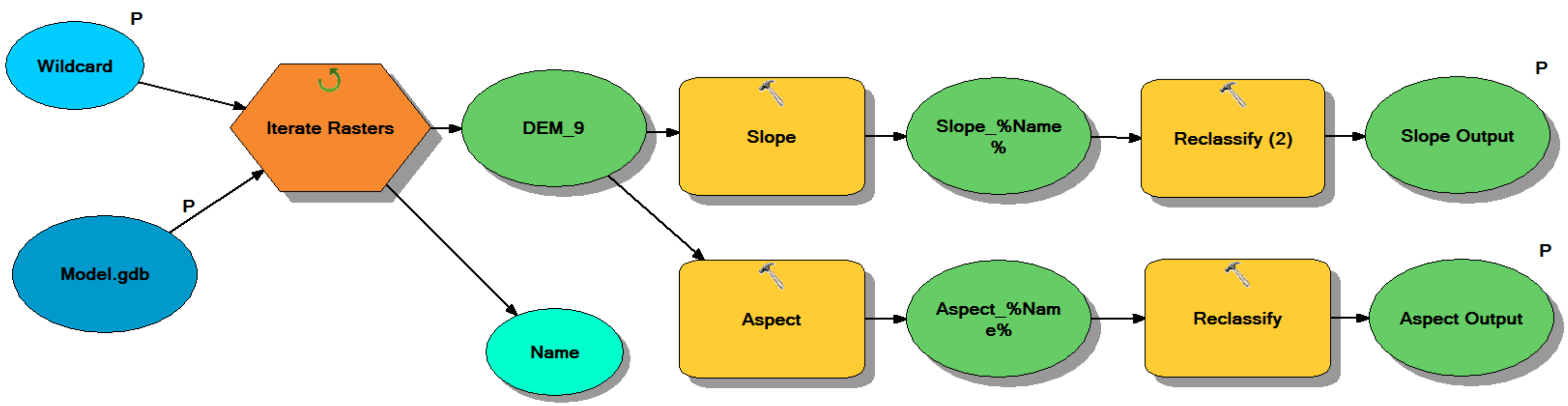


Stephens Island 16,000 cal. yr BP



Appendix D: Workflows and Python Code

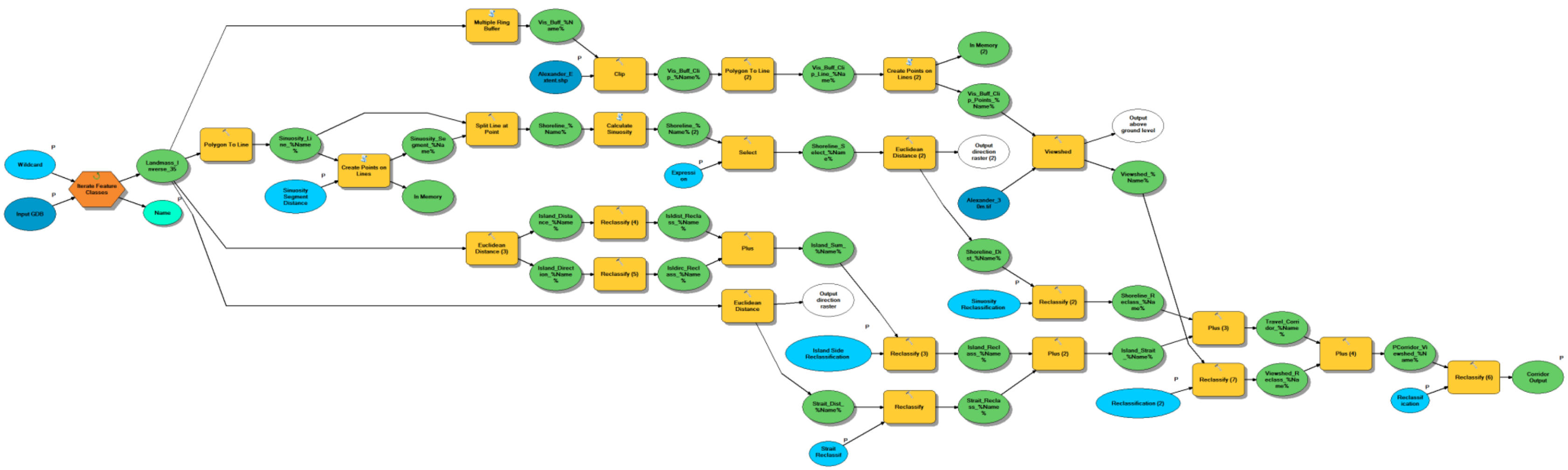
Slope and Aspect Model



```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Aspect_Slope.py
# Created on: 2015-06-22 13:35:28.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Aspect_Slope <Wildcard> <Slope_Output> <Aspect_Output> <Model_gdb>
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
arcpy.CheckOutExtension("3D")

# Load required toolboxes
arcpy.ImportToolbox("Model Functions")

# Set Geoprocessing environments
arcpy.env.extent = "-14955650.3404565 7379657.14342709 -14755650.540356 7579657.14342709"

# Script arguments
Wildcard = arcpy.GetParameterAsText(0)
if Wildcard == '#' or not Wildcard:
    Wildcard = "DEM_*" # provide a default value if unspecified

Slope_Output = arcpy.GetParameterAsText(1)
if Slope_Output == '#' or not Slope_Output:
    Slope_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Slope_Reclass_%Name%" # provide a default value if unspecified

Aspect_Output = arcpy.GetParameterAsText(2)
if Aspect_Output == '#' or not Aspect_Output:
    Aspect_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Aspect_Reclass_%Name%" # provide a default value if unspecified

Model_gdb = arcpy.GetParameterAsText(3)
if Model_gdb == '#' or not Model_gdb:
    Model_gdb = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb" # provide a default value if unspecified

# Local variables:
DEM_9 = Wildcard
```

```
Slope__Name_ = DEM_9
Aspect__Name_ = DEM_9
Name = Wildcard

# Process: Iterate Rasters
arcpy.IterateRasters_mb(Model_gdb, Wildcard, "", "NOT_RECURSIVE")

# Process: Aspect
arcpy.Aspect_3d(DEM_9, Aspect__Name_)

# Process: Reclassify
arcpy.gp.Reclassify_sa(Aspect__Name_, "Value", "-1 180 1;180 360 2", Aspect_Output, "DATA")

# Process: Slope
arcpy.gp.Slope_sa(DEM_9, Slope__Name_, "DEGREE", "1")

# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(Slope__Name_, "Value", "0 2 1;2 90 2", Slope_Output, "NODATA")
```

Near Shore Travel Corridor Model



```python
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Corridor.py
# Created on: 2015-06-22 13:37:13.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Corridor <Wildcard> <Input_GDB> <Name> <Strait_Reclassification> <Sinuosity_Segment_Distance> <Expression> <Sinuosity_Reclassification_> <Corridor_Output> <Island_Side_Reclassification_> <Alexander_Extent_shp> <Reclassification__2_> <Reclassification>
# Description:
# ---------------------------------------------------------------------------

# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
arcpy.CheckOutExtension("3D")

# Load required toolboxes
arcpy.ImportToolbox("Model Functions")
arcpy.ImportToolbox("C:/Users/Rgustas/Dropbox/Thesis/Data/Subregions/Alexander/Model/Sinuosity.pyt")
arcpy.ImportToolbox("C:/Users/Rgustas/Dropbox/Thesis/Data/Subregions/Alexander/Model/CreatePointsLines.tbx")

# Set Geoprocessing environments
arcpy.env.extent = "-14955650.3404565 7379657.14342709 -14755650.540356 7579657.14342709"

# Script arguments
Wildcard = arcpy.GetParameterAsText(0)
if Wildcard == '#' or not Wildcard:
    Wildcard = "Landmass_Inverse_150" # provide a default value if unspecified

Input_GDB = arcpy.GetParameterAsText(1)
if Input_GDB == '#' or not Input_GDB:
    Input_GDB = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb" # provide a default value if unspecified

Name = arcpy.GetParameterAsText(2)
if Name == '#' or not Name:
    Name = "Landmass_Inverse_150" # provide a default value if unspecified

Strait_Reclassification = arcpy.GetParameterAsText(3)
```

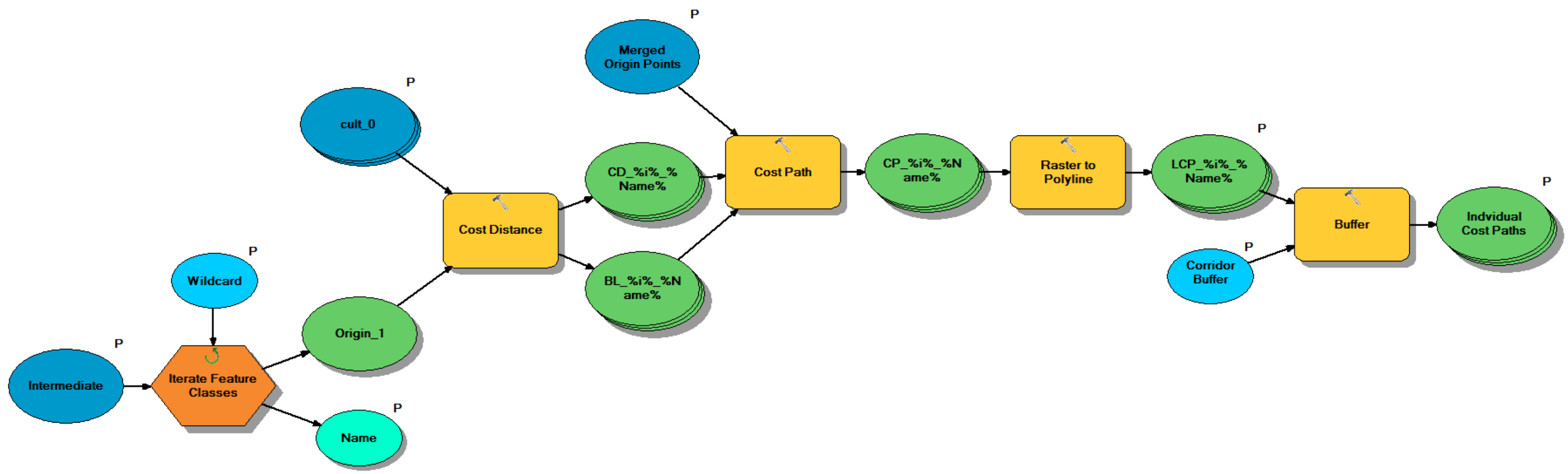
```
if Strait_Reclassification == '#' or not Strait_Reclassification:
    Strait_Reclassification = "0 2000 1;2000 250000 2" # provide a default value if unspecified

Sinuosity_Segment_Distance = arcpy.GetParameterAsText(4)
if Sinuosity_Segment_Distance == '#' or not Sinuosity_Segment_Distance:
    Sinuosity_Segment_Distance = "1000" # provide a default value if unspecified

Expression = arcpy.GetParameterAsText(5)
if Expression == '#' or not Expression:
    Expression = "\"sinuosity\" > 0.5" # provide a default value if unspecified

Sinuosity_Reclassification_ = arcpy.GetParameterAsText(6)
if Sinuosity_Reclassification_ == '#' or not Sinuosity_Reclassification_:
    Sinuosity_Reclassification_ = "0 1000 1;1000 2000 2;2000 250000 3" # provide a default value if unspecified

Corridor_Output = arcpy.GetParameterAsText(7)
if Corridor_Output == '#' or not Corridor_Output:
    Corridor_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\TravCorr_Reclass_Landmass_Inverse_%Name%" # provide a default value if unspecified

Island_Side_Reclassification_ = arcpy.GetParameterAsText(8)
if Island_Side_Reclassification_ == '#' or not Island_Side_Reclassification_:
    Island_Side_Reclassification_ = "2 3 1;3 4 2;4 5 3" # provide a default value if unspecified

Alexander_Extent_shp = arcpy.GetParameterAsText(9)
if Alexander_Extent_shp == '#' or not Alexander_Extent_shp:
    Alexander_Extent_shp = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Alexander_Extent.shp" # provide a default value if unspecified

Reclassification__2_ = arcpy.GetParameterAsText(10)
if Reclassification__2_ == '#' or not Reclassification__2_:
    Reclassification__2_ = "0 3 1;3 13 2;13 63 3" # provide a default value if unspecified

Reclassification = arcpy.GetParameterAsText(11)
if Reclassification == '#' or not Reclassification:
    Reclassification = "4 5 1;5 6 2;6 7 3;7 8 4;8 9 5;9 10 6;10 11 7" # provide a default value if unspecified

# Local variables:
Landmass_Inverse_35 = Input_GDB
Strait_Dist__Name_ = Landmass_Inverse_35
Strait_Reclass__Name_ = Strait_Dist__Name_
Island_Strait__Name_ = Strait_Reclass__Name_
Travel_Corridor__Name_ = Island_Strait__Name_
PCorridor_Viewshed__Name_ = Travel_Corridor__Name_
Output_direction_raster = Landmass_Inverse_35
```

```
Sinuosity_Line__Name_ = Landmass_Inverse_35
Sinuosity_Segment__Name_ = Sinuosity_Line__Name_
Shoreline__Name_ = Sinuosity_Segment__Name_
Shoreline__Name___2_ = Shoreline__Name_
Shoreline_Select__Name_ = Shoreline__Name___2_
Shoreline_Dist__Name_ = Shoreline_Select__Name_
Shoreline_Reclass__Name_ = Shoreline_Dist__Name_
Output_direction_raster__2_ = Shoreline_Select__Name_
In_Memory = Sinuosity_Line__Name_
Island_Distance__Name_ = Landmass_Inverse_35
Isldist_Reclass__Name_ = Island_Distance__Name_
Island_Sum__Name_ = Isldist_Reclass__Name_
Island_Reclass__Name_ = Island_Sum__Name_
Island_Direction__Name_ = Landmass_Inverse_35
Isldirc_Reclass__Name_ = Island_Direction__Name_
Vis_Buff__Name_ = Landmass_Inverse_35
Vis_Buff_Clip__Name_ = Vis_Buff__Name_
Vis_Buff_Clip_Line__Name_ = Vis_Buff_Clip__Name_
Vis_Buff_Clip_Points__Name_ = Vis_Buff_Clip_Line__Name_
Viewshed__Name_ = Vis_Buff_Clip_Points__Name_
Viewshed_Reclass__Name_ = Viewshed__Name_
Output_above_ground_level_raster = Vis_Buff_Clip_Points__Name_
In_Memory__2_ = Vis_Buff_Clip_Line__Name_
Alexander_30m_tif = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Alexander_30m.tif"

# Process: Iterate Feature Classes
arcpy.IterateFeatureClasses_mb(Input_GDB, Wildcard, "POLYGON", "NOT_RECURSIVE")

# Process: Euclidean Distance
arcpy.gp.EucDistance_sa(Landmass_Inverse_35, Strait_Dist__Name_, "", "30", Output_direction_raster)

# Process: Polygon To Line
arcpy.PolygonToLine_management(Landmass_Inverse_35, Sinuosity_Line__Name_, "IDENTIFY_NEIGHBORS")

# Process: Create Points on Lines
arcpy.CreatePointsLines_CreatePointsLines(Sinuosity_Line__Name_, "INTERVAL", "NO", "", Sinuosity_Segment_Distance, "NO", Sinuosity_Segment__Name_)

# Process: Split Line at Point
arcpy.SplitLineAtPoint_management(Sinuosity_Line__Name_, Sinuosity_Segment__Name_, Shoreline__Name_, "")

# Process: Calculate Sinuosity
arcpy.CalculateSinuosity_sample(Shoreline__Name_, "sinuosity")

# Process: Select
```

```
arcpy.Select_analysis(Shoreline__Name___2_, Shoreline_Select__Name_, Expression)
# Process: Euclidean Distance (2)
arcpy.gp.EucDistance_sa(Shoreline_Select__Name_, Shoreline_Dist__Name_, "", "30", Output_direction_raster__2_)
# Process: Multiple Ring Buffer
arcpy.MultipleRingBuffer_analysis(Landmass_Inverse_35, Vis_Buff__Name_, "5000", "Default", "distance", "ALL", "FULL")
# Process: Clip
arcpy.Clip_analysis(Vis_Buff__Name_, Alexander_Extent_shp, Vis_Buff_Clip__Name_, "")
# Process: Polygon To Line (2)
arcpy.PolygonToLine_management(Vis_Buff_Clip__Name_, Vis_Buff_Clip_Line__Name_, "IDENTIFY_NEIGHBORS")
# Process: Create Points on Lines (2)
arcpy.CreatePointsLines_CreatePointsLines(Vis_Buff_Clip_Line__Name_, "INTERVAL", "NO", "", "5000", "END", Vis_Buff_Clip_Points__Name_)
# Process: Viewshed
arcpy.gp.Viewshed_sa(Alexander_30m_tif, Vis_Buff_Clip_Points__Name_, Viewshed__Name_, "1", "FLAT_EARTH", "0.13", Output_above_ground_level_raster)
# Process: Reclassify (7)
arcpy.gp.Reclassify_sa(Viewshed__Name_, "Value", Reclassification__2_, Viewshed_Reclass__Name_, "DATA")
# Process: Reclassify
arcpy.gp.Reclassify_sa(Strait_Dist__Name_, "Value", Strait_Reclassification, Strait_Reclass__Name_, "DATA")
# Process: Euclidean Distance (3)
arcpy.gp.EucDistance_sa(Landmass_Inverse_35, Island_Distance__Name_, "", "30", Island_Direction__Name_)
# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(Island_Distance__Name_, "Value", "0 8508.3038330078125 1;8508.3038330078125 20760.261352539063 2;20760.261352539063 250000 3", Isldist_Reclass__Name_, "DATA")
# Process: Reclassify (5)
arcpy.Reclassify_3d(Island_Direction__Name_, "Value", "0 180 1;180 360 2", Isldirc_Reclass__Name_, "DATA")
# Process: Plus
arcpy.gp.Plus_sa(Isldist_Reclass__Name_, Isldirc_Reclass__Name_, Island_Sum__Name_)
# Process: Reclassify (3)
arcpy.gp.Reclassify_sa(Island_Sum__Name_, "Value", Island_Side_Reclassification_, Island_Reclass__Name_, "DATA")
# Process: Plus (2)
arcpy.gp.Plus_sa(Strait_Reclass__Name_, Island_Reclass__Name_, Island_Strait__Name_)
```

```
# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(Shoreline_Dist__Name_, "Value", Sinuosity_Reclassification_, Shoreline_Reclass__Name_, "DATA")

# Process: Plus (3)
arcpy.gp.Plus_sa(Island_Strait__Name_, Shoreline_Reclass__Name_, Travel_Corridor__Name_)

# Process: Plus (4)
arcpy.Plus_3d(Viewshed_Reclass__Name_, Travel_Corridor__Name_, PCorridor_Viewshed__Name_)

# Process: Reclassify (6)
arcpy.Reclassify_3d(PCorridor_Viewshed__Name_, "Value", Reclassification, Corridor_Output, "DATA")
```

Least Cost Analysis Model



```python
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Corridor.py
# Created on: 2015-06-22 13:37:13.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Corridor <Wildcard> <Input_GDB> <Name> <Strait_Reclassification> <Sinuosity_Segment_Distance> <Expression> <Sinuosity_Reclassification_> <Corridor_Output> <Island_Side_Reclassification_> <Alexander_Extent_shp> <Reclassification__2_> <Reclassification>
# Description:
# ---------------------------------------------------------------------------

# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
arcpy.CheckOutExtension("3D")

# Load required toolboxes
arcpy.ImportToolbox("Model Functions")
arcpy.ImportToolbox("C:/Users/Rgustas/Dropbox/Thesis/Data/Subregions/Alexander/Model/Sinuosity.pyt")
arcpy.ImportToolbox("C:/Users/Rgustas/Dropbox/Thesis/Data/Subregions/Alexander/Model/CreatePointsLines.tbx")

# Set Geoprocessing environments
arcpy.env.extent = "-14955650.3404565 7379657.14342709 -14755650.540356 7579657.14342709"

# Script arguments
Wildcard = arcpy.GetParameterAsText(0)
if Wildcard == '#' or not Wildcard:
    Wildcard = "Landmass_Inverse_150" # provide a default value if unspecified

Input_GDB = arcpy.GetParameterAsText(1)
if Input_GDB == '#' or not Input_GDB:
    Input_GDB = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb" # provide a default value if unspecified

Name = arcpy.GetParameterAsText(2)
if Name == '#' or not Name:
    Name = "Landmass_Inverse_150" # provide a default value if unspecified

Strait_Reclassification = arcpy.GetParameterAsText(3)
if Strait_Reclassification == '#' or not Strait_Reclassification:
```

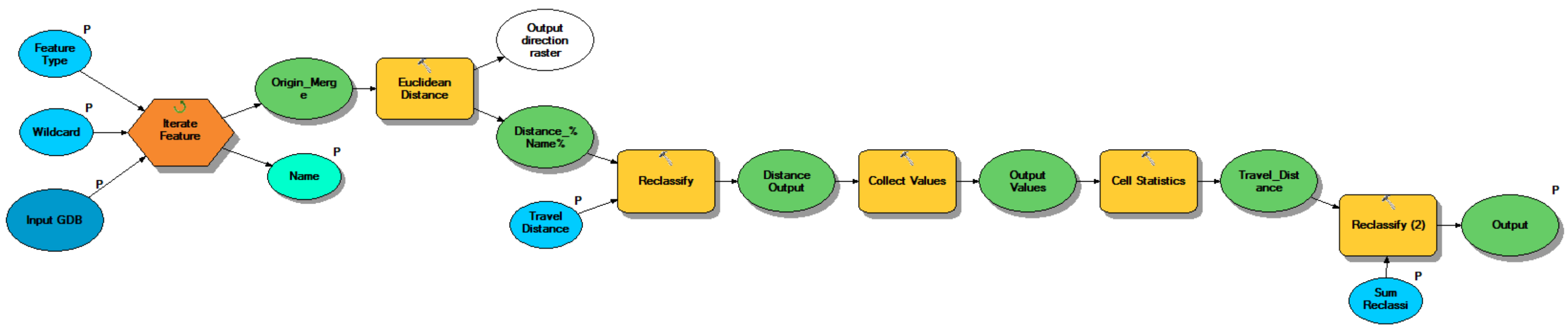
```
    Strait_Reclassification = "0 2000 1;2000 250000 2" # provide a default value if unspecified

Sinuosity_Segment_Distance = arcpy.GetParameterAsText(4)
if Sinuosity_Segment_Distance == '#' or not Sinuosity_Segment_Distance:
    Sinuosity_Segment_Distance = "1000" # provide a default value if unspecified

Expression = arcpy.GetParameterAsText(5)
if Expression == '#' or not Expression:
    Expression = "\"sinuosity\" > 0.5" # provide a default value if unspecified

Sinuosity_Reclassification_ = arcpy.GetParameterAsText(6)
if Sinuosity_Reclassification_ == '#' or not Sinuosity_Reclassification_:
    Sinuosity_Reclassification_ = "0 1000 1;1000 2000 2;2000 250000 3" # provide a default value if unspecified

Corridor_Output = arcpy.GetParameterAsText(7)
if Corridor_Output == '#' or not Corridor_Output:
    Corridor_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\TravCorr_Reclass_Landmass_Inverse_%Name%" # provide a default value if unspecified

Island_Side_Reclassification_ = arcpy.GetParameterAsText(8)
if Island_Side_Reclassification_ == '#' or not Island_Side_Reclassification_:
    Island_Side_Reclassification_ = "2 3 1;3 4 2;4 5 3" # provide a default value if unspecified

Alexander_Extent_shp = arcpy.GetParameterAsText(9)
if Alexander_Extent_shp == '#' or not Alexander_Extent_shp:
    Alexander_Extent_shp = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Alexander_Extent.shp" # provide a default value if unspecified

Reclassification__2_ = arcpy.GetParameterAsText(10)
if Reclassification__2_ == '#' or not Reclassification__2_:
    Reclassification__2_ = "0 3 1;3 13 2;13 63 3" # provide a default value if unspecified

Reclassification = arcpy.GetParameterAsText(11)
if Reclassification == '#' or not Reclassification:
    Reclassification = "4 5 1;5 6 2;6 7 3;7 8 4;8 9 5;9 10 6;10 11 7" # provide a default value if unspecified

# Local variables:
Landmass_Inverse_35 = Input_GDB
Strait_Dist__Name_ = Landmass_Inverse_35
Strait_Reclass__Name_ = Strait_Dist__Name_
Island_Strait__Name_ = Strait_Reclass__Name_
Travel_Corridor__Name_ = Island_Strait__Name_
PCorridor_Viewshed__Name_ = Travel_Corridor__Name_
Output_direction_raster = Landmass_Inverse_35
```

```
86.Sinuosity_Line__Name_ = Landmass_Inverse_35
87.Sinuosity_Segment__Name_ = Sinuosity_Line__Name_
88.Shoreline__Name_ = Sinuosity_Segment__Name_
89.Shoreline__Name___2_ = Shoreline__Name_
90.Shoreline_Select__Name_ = Shoreline__Name___2_
91.Shoreline_Dist__Name_ = Shoreline_Select__Name_
92.Shoreline_Reclass__Name_ = Shoreline_Dist__Name_
93.Output_direction_raster__2_ = Shoreline_Select__Name_
94.In_Memory = Sinuosity_Line__Name_
95.Island_Distance__Name_ = Landmass_Inverse_35
96.Isldist_Reclass__Name_ = Island_Distance__Name_
97.Island_Sum__Name_ = Isldist_Reclass__Name_
98.Island_Reclass__Name_ = Island_Sum__Name_
99.Island_Direction__Name_ = Landmass_Inverse_35
100.Isldirc_Reclass__Name_ = Island_Direction__Name_
101.Vis_Buff__Name_ = Landmass_Inverse_35
102.Vis_Buff_Clip__Name_ = Vis_Buff__Name_
103.Vis_Buff_Clip_Line__Name_ = Vis_Buff_Clip__Name_
104.Vis_Buff_Clip_Points__Name_ = Vis_Buff_Clip_Line__Name_
105.Viewshed__Name_ = Vis_Buff_Clip_Points__Name_
106.Viewshed_Reclass__Name_ = Viewshed__Name_
107.Output_above_ground_level_raster = Vis_Buff_Clip_Points__Name_
108.In_Memory__2_ = Vis_Buff_Clip_Line__Name_
109.Alexander_30m_tif = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Alexander_30m.tif"
110.
111.# Process: Iterate Feature Classes
112.arcpy.IterateFeatureClasses_mb(Input_GDB, Wildcard, "POLYGON", "NOT_RECURSIVE")
113.
114.# Process: Euclidean Distance
115.arcpy.gp.EucDistance_sa(Landmass_Inverse_35, Strait_Dist__Name_, "", "30", Output_direction_raster)
116.
117.# Process: Polygon To Line
118.arcpy.PolygonToLine_management(Landmass_Inverse_35, Sinuosity_Line__Name_, "IDENTIFY_NEIGHBORS")
119.
120.# Process: Create Points on Lines
121.arcpy.CreatePointsLines_CreatePointsLines(Sinuosity_Line__Name_, "INTERVAL", "NO", "", Sinuosity_Segment_Distance, "NO", Sinuosity_Segment__Name_)

122.
123.# Process: Split Line at Point
124.arcpy.SplitLineAtPoint_management(Sinuosity_Line__Name_, Sinuosity_Segment__Name_, Shoreline__Name_, "")
125.
126.# Process: Calculate Sinuosity
127.arcpy.CalculateSinuosity_sample(Shoreline__Name_, "sinuosity")
128.
```

```python
# Process: Select
arcpy.Select_analysis(Shoreline__Name___2_, Shoreline_Select__Name_, Expression)

# Process: Euclidean Distance (2)
arcpy.gp.EucDistance_sa(Shoreline_Select__Name_, Shoreline_Dist__Name_, "", "30", Output_direction_raster__2_)

# Process: Multiple Ring Buffer
arcpy.MultipleRingBuffer_analysis(Landmass_Inverse_35, Vis_Buff__Name_, "5000", "Default", "distance", "ALL", "FULL")

# Process: Clip
arcpy.Clip_analysis(Vis_Buff__Name_, Alexander_Extent_shp, Vis_Buff_Clip__Name_, "")

# Process: Polygon To Line (2)
arcpy.PolygonToLine_management(Vis_Buff_Clip__Name_, Vis_Buff_Clip_Line__Name_, "IDENTIFY_NEIGHBORS")

# Process: Create Points on Lines (2)
arcpy.CreatePointsLines_CreatePointsLines(Vis_Buff_Clip_Line__Name_, "INTERVAL", "NO", "", "5000", "END", Vis_Buff_Clip_Points__Name_)

# Process: Viewshed
arcpy.gp.Viewshed_sa(Alexander_30m_tif, Vis_Buff_Clip_Points__Name_, Viewshed__Name_, "1", "FLAT_EARTH", "0.13", Output_above_ground_level_raster)


# Process: Reclassify (7)
arcpy.gp.Reclassify_sa(Viewshed__Name_, "Value", Reclassification__2_, Viewshed_Reclass__Name_, "DATA")

# Process: Reclassify
arcpy.gp.Reclassify_sa(Strait_Dist__Name_, "Value", Strait_Reclassification, Strait_Reclass__Name_, "DATA")

# Process: Euclidean Distance (3)
arcpy.gp.EucDistance_sa(Landmass_Inverse_35, Island_Distance__Name_, "", "30", Island_Direction__Name_)

# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(Island_Distance__Name_, "Value", "0 8508.3038330078125 1;8508.3038330078125 20760.261352539063 2;20760.261352539063 250000
3", Isldist_Reclass__Name_, "DATA")

# Process: Reclassify (5)
arcpy.Reclassify_3d(Island_Direction__Name_, "Value", "0 180 1;180 360 2", Isldirc_Reclass__Name_, "DATA")

# Process: Plus
arcpy.gp.Plus_sa(Isldist_Reclass__Name_, Isldirc_Reclass__Name_, Island_Sum__Name_)

# Process: Reclassify (3)
arcpy.gp.Reclassify_sa(Island_Sum__Name_, "Value", Island_Side_Reclassification_, Island_Reclass__Name_, "DATA")

```

```
# Process: Plus (2)
arcpy.gp.Plus_sa(Strait_Reclass__Name_, Island_Reclass__Name_, Island_Strait__Name_)

# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(Shoreline_Dist__Name_, "Value", Sinuosity_Reclassification_, Shoreline_Reclass__Name_, "DATA")

# Process: Plus (3)
arcpy.gp.Plus_sa(Island_Strait__Name_, Shoreline_Reclass__Name_, Travel_Corridor__Name_)

# Process: Plus (4)
arcpy.Plus_3d(Viewshed_Reclass__Name_, Travel_Corridor__Name_, PCorridor_Viewshed__Name_)

# Process: Reclassify (6)
arcpy.Reclassify_3d(PCorridor_Viewshed__Name_, "Value", Reclassification, Corridor_Output, "DATA")

```

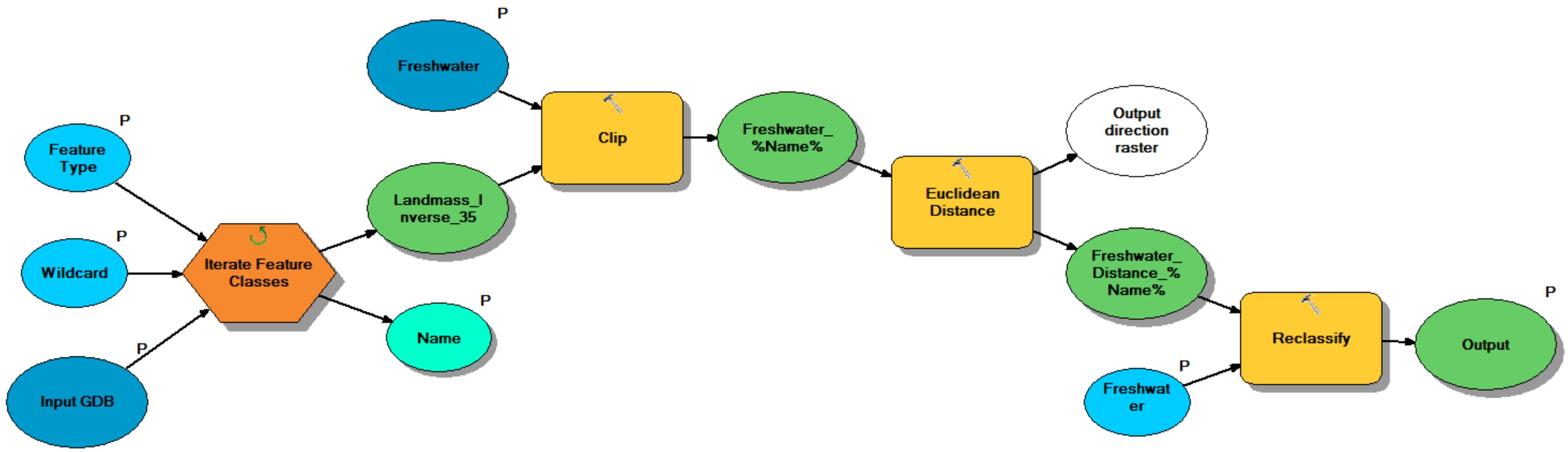
Travel Distance Model



```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Distance.py
# Created on: 2015-06-22 13:40:01.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Distance <Wildcard> <Input_GDB> <Feature_Type> <Name> <Travel_Distance_Reclassification> <Output> <Sum_Reclassification>
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

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

# Load required toolboxes
arcpy.ImportToolbox("Model Functions")

# Set Geoprocessing environments
arcpy.env.extent = "-14955650.3404565 7379657.14342709 -14755650.540356 7579657.14342709"

# Script arguments
Wildcard = arcpy.GetParameterAsText(0)
if Wildcard == '#' or not Wildcard:
    Wildcard = "Origin_*" # provide a default value if unspecified

Input_GDB = arcpy.GetParameterAsText(1)
if Input_GDB == '#' or not Input_GDB:
    Input_GDB = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Intermediate" # provide a default value if unspecified

Feature_Type = arcpy.GetParameterAsText(2)
if Feature_Type == '#' or not Feature_Type:
    Feature_Type = "POINT" # provide a default value if unspecified

Name = arcpy.GetParameterAsText(3)
if Name == '#' or not Name:
    Name = "Origin_9" # provide a default value if unspecified

Travel_Distance_Reclassification = arcpy.GetParameterAsText(4)
if Travel_Distance_Reclassification == '#' or not Travel_Distance_Reclassification:
    Travel_Distance_Reclassification = "0 5760 1;5760 250000 2" # provide a default value if unspecified

Output = arcpy.GetParameterAsText(5)
if Output == '#' or not Output:
```

```
    Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Distance_Reclass" # provide a default value if unspecified

Sum_Reclassification = arcpy.GetParameterAsText(6)
if Sum_Reclassification == '#' or not Sum_Reclassification:
    Sum_Reclassification = "36 1;37 2;38 3" # provide a default value if unspecified

# Local variables:
Origin_Merge = Input_GDB
Distance__Name_ = Origin_Merge
Distance_Output = Distance__Name_
Output_Values = Distance_Output
Travel_Distance = Output_Values
Output_direction_raster = Origin_Merge
Travel_Distance__2_ = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Travel_Distance"

# Process: Iterate Feature Classes
arcpy.IterateFeatureClasses_mb(Input_GDB, Wildcard, Feature_Type, "NOT_RECURSIVE")

# Process: Euclidean Distance
arcpy.gp.EucDistance_sa(Origin_Merge, Distance__Name_, "", "30", Output_direction_raster)

# Process: Reclassify
arcpy.gp.Reclassify_sa(Distance__Name_, "Value", Travel_Distance_Reclassification, Distance_Output, "DATA")

# Process: Collect Values
arcpy.CollectValues_mb("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Dist_Reclass_%Name%")

# Process: Cell Statistics
arcpy.gp.CellStatistics_sa(Output_Values, Travel_Distance, "SUM", "DATA")

# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(Travel_Distance, "Value", Sum_Reclassification, Output, "DATA")
```

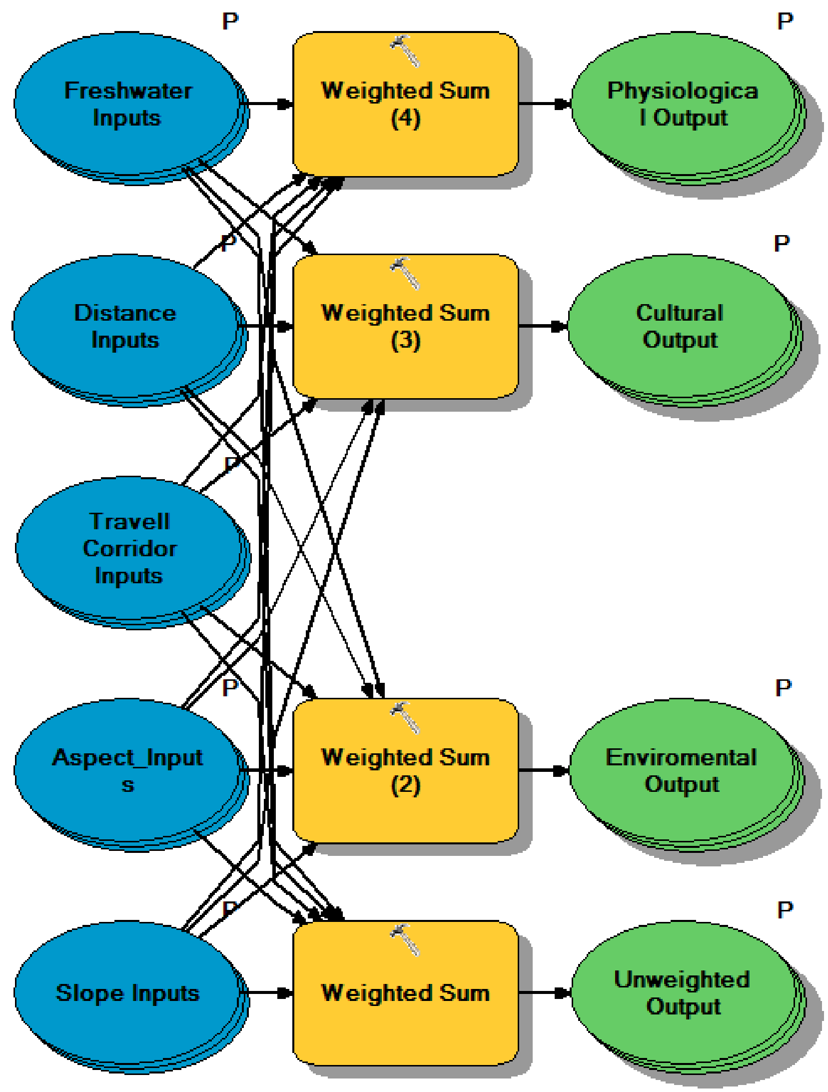
Freshwater Proximity Model



```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Freshwater.py
# Created on: 2015-06-22 13:40:48.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Freshwater <Name> <Feature_Type> <Input_GDB> <Wildcard> <Freshwater> <Output> <Freshwater_Distance_Reclassification>
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")
arcpy.CheckOutExtension("3D")

# Load required toolboxes
arcpy.ImportToolbox("Model Functions")

# Set Geoprocessing environments
arcpy.env.extent = "-14955650.3404565 7379657.14342709 -14755650.540356 7579657.14342709"

# Script arguments
Name = arcpy.GetParameterAsText(0)
if Name == '#' or not Name:
    Name = "Landmass_Inverse_150" # provide a default value if unspecified

Feature_Type = arcpy.GetParameterAsText(1)
if Feature_Type == '#' or not Feature_Type:
    Feature_Type = "POLYGON" # provide a default value if unspecified

Input_GDB = arcpy.GetParameterAsText(2)
if Input_GDB == '#' or not Input_GDB:
    Input_GDB = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb" # provide a default value if unspecified

Wildcard = arcpy.GetParameterAsText(3)
if Wildcard == '#' or not Wildcard:
    Wildcard = "Landmass_Inverse_*" # provide a default value if unspecified

Freshwater = arcpy.GetParameterAsText(4)
if Freshwater == '#' or not Freshwater:
    Freshwater = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Merge" # provide a default value if unspecified

```

```
Output = arcpy.GetParameterAsText(5)
if Output == '#' or not Output:
    Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Freshwater_Reclass_%Name%" # provide a default value if unspecified

Freshwater_Distance_Reclassification = arcpy.GetParameterAsText(6)
if Freshwater_Distance_Reclassification == '#' or not Freshwater_Distance_Reclassification:
    Freshwater_Distance_Reclassification = "0 200 1;200 250000 2" # provide a default value if unspecified

# Local variables:
Landmass_Inverse_35 = Input_GDB
Freshwater__Name_ = Landmass_Inverse_35
Freshwater_Distance__Name_ = Freshwater__Name_
Output_direction_raster = Freshwater__Name_

# Process: Iterate Feature Classes
arcpy.IterateFeatureClasses_mb(Input_GDB, Wildcard, Feature_Type, "NOT_RECURSIVE")

# Process: Clip
arcpy.Clip_analysis(Freshwater, Landmass_Inverse_35, Freshwater__Name_, "")

# Process: Euclidean Distance
arcpy.gp.EucDistance_sa(Freshwater__Name_, Freshwater_Distance__Name_, "", "30", Output_direction_raster)

# Process: Reclassify
arcpy.Reclassify_3d(Freshwater_Distance__Name_, "Value", Freshwater_Distance_Reclassification, Output, "NODATA")
```

Friction Surface Generation Model

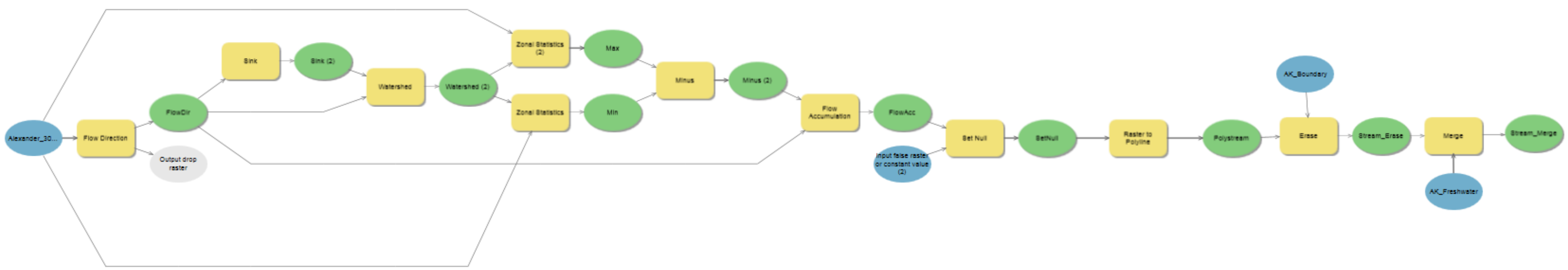


```python
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Friction_Surface.py
# Created on: 2015-06-22 13:41:31.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Friction_Surface <Slope_Inputs> <Aspect_Inputs> <Travell_Corridor_Inputs> <Distance_Inputs> <Freshwater_Inputs> <Enviromental_Output> <Cultural_Output> <Physiological_Output> <Unweighted_Output>
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

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

# Set Geoprocessing environments
arcpy.env.extent = "-14955650.3404565 7379657.14342709 -14755650.540356 7579657.14342709"

# Script arguments
Slope_Inputs = arcpy.GetParameterAsText(0)
if Slope_Inputs == '#' or not Slope_Inputs:
    Slope_Inputs = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Slope_Reclass_DEM_150" # provide a default value if unspecified

Aspect_Inputs = arcpy.GetParameterAsText(1)
if Aspect_Inputs == '#' or not Aspect_Inputs:
    Aspect_Inputs = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Aspect_Reclass_DEM_150" # provide a default value if unspecified

Travell_Corridor_Inputs = arcpy.GetParameterAsText(2)
if Travell_Corridor_Inputs == '#' or not Travell_Corridor_Inputs:
    Travell_Corridor_Inputs = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\TravCorr_Reclass_Landmass_Inverse_Landmass_Inverse_150" # provide a default value if unspecified

Distance_Inputs = arcpy.GetParameterAsText(3)
if Distance_Inputs == '#' or not Distance_Inputs:
    Distance_Inputs = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Distance_Reclass" # provide a default value if unspecified

Freshwater_Inputs = arcpy.GetParameterAsText(4)
if Freshwater_Inputs == '#' or not Freshwater_Inputs:
    Freshwater_Inputs = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Freshwater_Reclass_Landmass_Inverse_150" # provide a default value if unspecified
```

```python

Enviromental_Output = arcpy.GetParameterAsText(5)
if Enviromental_Output == '#' or not Enviromental_Output:
    Enviromental_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Friction_Surfaces\\Env_%i%" # provide a default value if unspecified

Cultural_Output = arcpy.GetParameterAsText(6)
if Cultural_Output == '#' or not Cultural_Output:
    Cultural_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Friction_Surfaces\\cult_%i%" # provide a default value if unspecified

Physiological_Output = arcpy.GetParameterAsText(7)
if Physiological_Output == '#' or not Physiological_Output:
    Physiological_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Friction_Surfaces\\Phy_%i%" # provide a default value if unspecified

Unweighted_Output = arcpy.GetParameterAsText(8)
if Unweighted_Output == '#' or not Unweighted_Output:
    Unweighted_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Friction_Surfaces\\Unw_%i%" # provide a default value if unspecified

# Local variables:

# Process: Weighted Sum (2)
arcpy.gp.WeightedSum_sa("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Slope_Reclass_DEM_150 Value 0.25;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Aspect_Reclass_DEM_150 Value 0.25;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\TravCorr_Reclass_Landmass_Inverse_Landmass_Inverse_150 Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Distance_Reclass Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Freshwater_Reclass_Landmass_Inverse_150 Value 0.25", Enviromental_Output)

# Process: Weighted Sum (3)
arcpy.gp.WeightedSum_sa("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Slope_Reclass_DEM_150 Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Aspect_Reclass_DEM_150 Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Freshwater_Reclass_Landmass_Inverse_150 Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Distance_Reclass Value 0.25;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\TravCorr_Reclass_Landmass_Inverse_Landmass_Inverse_150 Value 0.5", Cultural_Output)

# Process: Weighted Sum (4)
arcpy.gp.WeightedSum_sa("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Slope_Reclass_DEM_150 Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Aspect_Reclass_DEM_150 Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\TravCorr_Reclass_Landmass_Inverse_Landmass_Inverse_150 Value 0.125;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Distance_Reclass Value 0.5;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Freshwater_Reclass_Landmass_Inverse_150 Value 0.125", Physiological_Output)

# Process: Weighted Sum
```

```
arcpy.gp.WeightedSum_sa("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Slope_Reclass_DEM_150 Value 0.2;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Aspect_Reclass_DEM_150 Value 0.2;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\TravCorr_Reclass_Landmass_Inverse_Landmass_Inverse_150 Value 0.2;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Freshwater_Reclass_Landmass_Inverse_150 Value 0.2;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Distance_Reclass Value 0.2", Unweighted_Output)
```

Drowned Landscape Hydrology Model

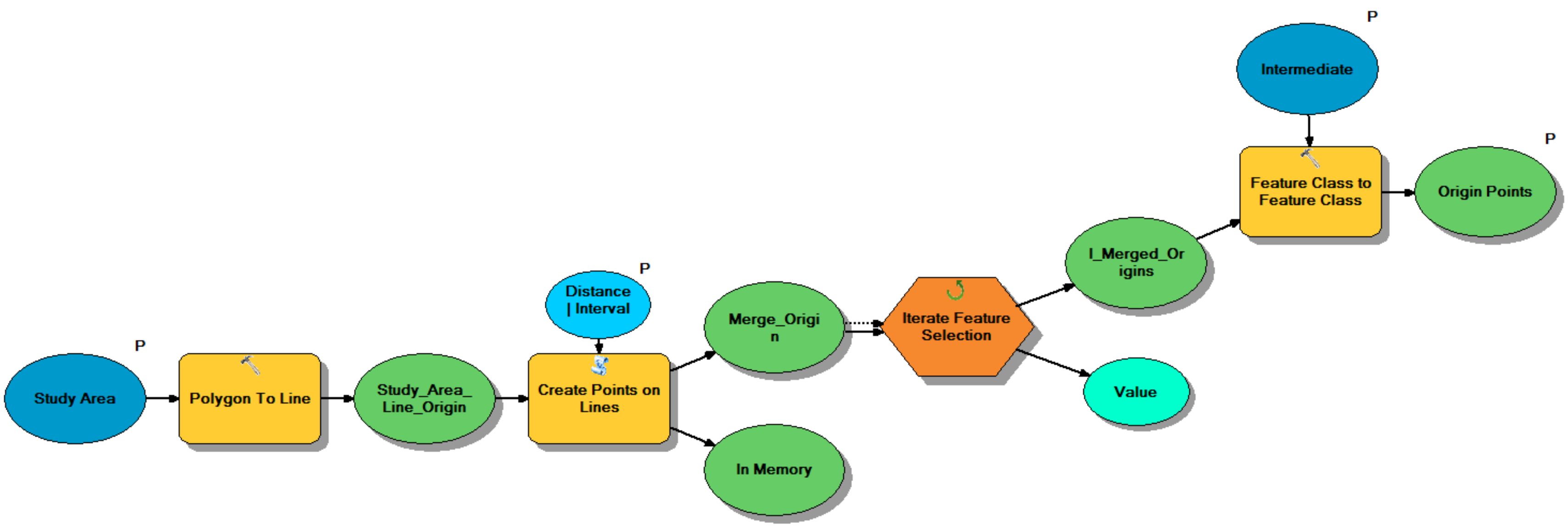


```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Hydrology.py
# Created on: 2015-06-22 14:16:14.00000
#   (generated by ArcGIS/ModelBuilder)
# Description:
# Model
# ---------------------------------------------------------------------------

# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy


# Local variables:
Input_false_raster_or_constant_value__2_ = "1"
AK_Freshwater = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater"
Alexander_30m_tif = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Alexander_30m.tif"
AK_Boundary = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\AK_Boundary"
FlowDir = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\FlowDir"
Output_drop_raster = ""
Sink__2_ = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Sink"
Watershed__2_ = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Watershed"
Min = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Min"
Max = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Max"
Minus__2_ = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Minus"
FlowAcc = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\FlowAcc"
SetNull = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\SetNull"
Polystream = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Polystream"
Stream_Erase = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase"
Stream_Merge = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Merge"

# Process: Flow Direction
arcpy.gp.FlowDirection_sa(Alexander_30m_tif, FlowDir, "NORMAL", Output_drop_raster)

# Process: Sink
arcpy.gp.Sink_sa(FlowDir, Sink__2_)

# Process: Watershed
arcpy.gp.Watershed_sa(FlowDir, Sink__2_, Watershed__2_, "VALUE")
```

```
# Process: Zonal Statistics (2)
arcpy.gp.ZonalStatistics_sa(Watershed__2_, "VALUE", Alexander_30m_tif, Max, "MAXIMUM", "DATA")

# Process: Zonal Statistics
arcpy.gp.ZonalStatistics_sa(Watershed__2_, "VALUE", Alexander_30m_tif, Min, "MINIMUM", "DATA")

# Process: Minus
arcpy.gp.Minus_sa(Max, Min, Minus__2_)

# Process: Flow Accumulation
arcpy.gp.FlowAccumulation_sa(FlowDir, FlowAcc, Minus__2_, "FLOAT")

# Process: Set Null
arcpy.gp.SetNull_sa(FlowAcc, Input_false_raster_or_constant_value__2_, SetNull, "VALUE <= 20000")

# Process: Raster to Polyline
arcpy.RasterToPolyline_conversion(SetNull, Polystream, "ZERO", "0", "SIMPLIFY", "Value")

# Process: Erase
arcpy.Erase_analysis(Polystream, AK_Boundary, Stream_Erase, "")

# Process: Merge
arcpy.Merge_management("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase;C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater", Stream_Merge, "Shape_Length \"Shape_Length\" true false true 0 Double 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase,Shape_Length,-1,-1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater,Shape_Length,-1,-1;ARCID \"ARCID\" true true false 0 Long 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase,ARCID,-1,-1;FROM_NOD \"FROM_NOD\" true true false 0 Long 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase,FROM_NOD,-1,-1;TO_NOD \"TO_NOD\" true true false 0 Long 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase,TO_NOD,-1,-1;GRID_CODE \"GRID_CODE\" true true false 0 Long 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase,GRID_CODE,-1,-1;Shape_length_1 \"Shape_length\" true true false 0 Double 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Stream_Modeling\\Stream_Modeling.gdb\\Stream_Erase,Shape_length,-1,-1;NAME \"NAME\" true true false 40 Text 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater,NAME,0,40;WATERTYPE \"WATERTYPE\" true true false 1 Text 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater,WATERTYPE,0,1;SOURCE \"SOURCE\" true true false 12 Text 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater,SOURCE,0,12;SCALE \"SCALE\" true true false 8 Double 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater,SCALE,-1,-1;SOURCEDATE \"SOURCEDATE\" true true false 8 Text 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\AK_Freshwater,SOURCEDATE,0,8;DISPLAY \"DISPLAY\" true true false 1 Text 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.
```

```
gdb\\AK_Freshwater,DISPLAY,0,1;MI_LABEL \"MI_LABEL\" true true false 40 Text 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\
Model\\Model.gdb\\AK_Freshwater,MI_LABEL,0,40;RFRSHDT \"RFRSHDT\" true true false 8 Date 0 0,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions
\\Alexander\\Model\\Model.gdb\\AK_Freshwater,RFRSHDT,-1,-1")
```

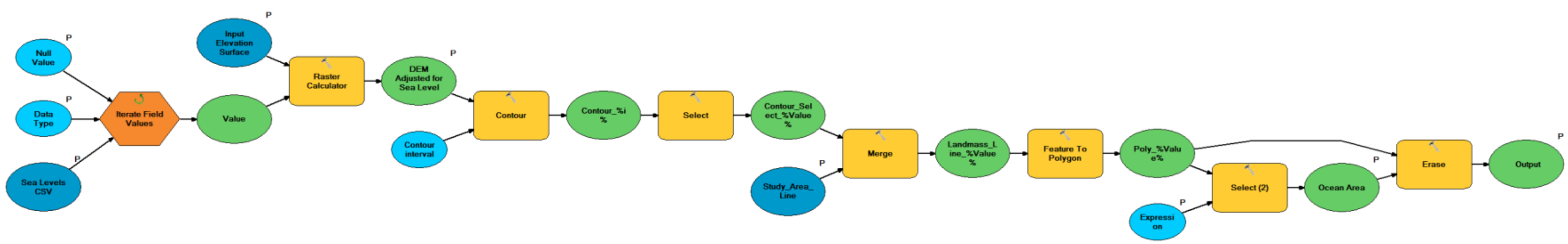
Origin Point Creation Model



```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Origin.py
# Created on: 2015-06-22 13:42:23.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Origin <Study_Area> <Origin_Points> <Distance___Interval___Percentage_Value> <Model_gdb> <Intermediate>
# Description:
# ---------------------------------------------------------------------------

# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy

# Load required toolboxes
arcpy.ImportToolbox("Model Functions")
arcpy.ImportToolbox("C:/Users/Rgustas/Dropbox/Thesis/Data/Subregions/Alexander/Model/CreatePointsLines.tbx")

# Set Geoprocessing environments
arcpy.env.snapRaster = ""
arcpy.env.extent = "-14955650.3404565 7379657.14342709 -14755650.540356 7579657.14342709"

# Script arguments
Study_Area = arcpy.GetParameterAsText(0)
if Study_Area == '#' or not Study_Area:
    Study_Area = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Alexander_Extent.shp" # provide a default value if unspecified

Origin_Points = arcpy.GetParameterAsText(1)
if Origin_Points == '#' or not Origin_Points:
    Origin_Points = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Intermediate\\Origin_%Value%.shp" # provide a default value if unspecified

Distance___Interval___Percentage_Value = arcpy.GetParameterAsText(2)
if Distance___Interval___Percentage_Value == '#' or not Distance___Interval___Percentage_Value:
    Distance___Interval___Percentage_Value = "34558" # provide a default value if unspecified

Model_gdb = arcpy.GetParameterAsText(3)
if Model_gdb == '#' or not Model_gdb:
    Model_gdb = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb" # provide a default value if unspecified

Intermediate = arcpy.GetParameterAsText(4)
if Intermediate == '#' or not Intermediate:
```

```
    Intermediate = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Intermediate" # provide a default value if unspecified

# Local variables:
Study_Area_Line_Origin = Study_Area
Merge_Origin = Study_Area_Line_Origin
I_Merged_Origins = Merge_Origin
Value = Merge_Origin
In_Memory = Study_Area_Line_Origin

# Process: Polygon To Line
arcpy.PolygonToLine_management(Study_Area, Study_Area_Line_Origin, "IDENTIFY_NEIGHBORS")

# Process: Create Points on Lines
arcpy.CreatePointsLines_CreatePointsLines(Study_Area_Line_Origin, "INTERVAL", "NO", "", Distance___Interval___Percentage_Value, "END", Merge_Origin)

# Process: Iterate Feature Selection
arcpy.IterateFeatureSelection_mb(Merge_Origin, "", "false")

# Process: Feature Class to Feature Class
arcpy.FeatureClassToFeatureClass_conversion(I_Merged_Origins, Intermediate, "Origin_%Value%.shp", "", "", "")
```

Landmass Recreation Model

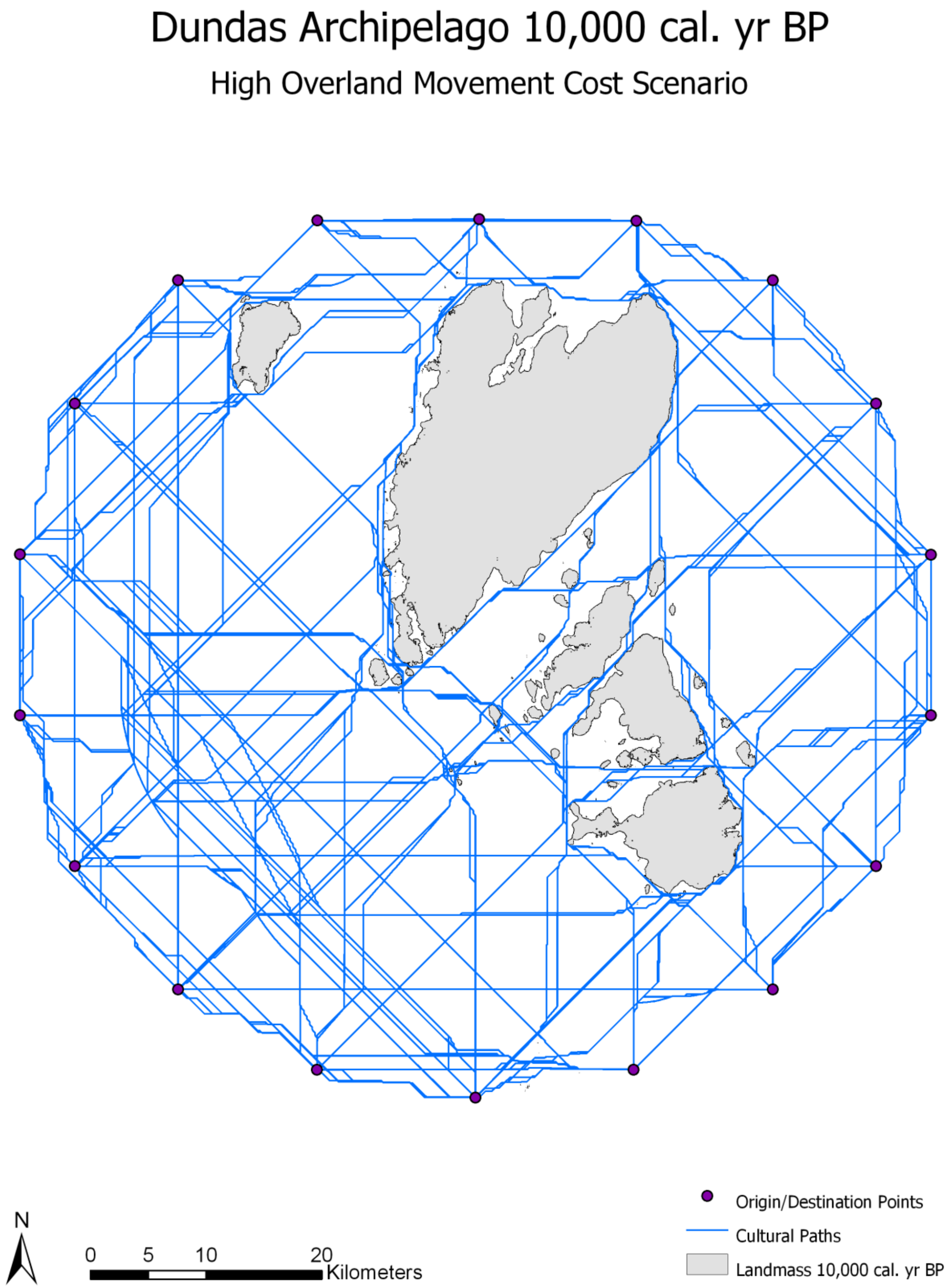


```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Alexander_Plaeolandmass.py
# Created on: 2015-06-22 13:43:40.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Alexander_Plaeolandmass <Sea_Levels_CSV> <Null_Value> <Input_Elevation_Surface> <v_Output> <Ocean_Area> <DEM_Adjusted_for_Sea_Level_Change> <Expression> <Study_Area_Line> <Data_Type>
# Description:
# ---------------------------------------------------------------------------

# Set the necessary product code
# import arcinfo


# Import arcpy module
import arcpy

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

# Load required toolboxes
arcpy.ImportToolbox("Model Functions")

# Set Geoprocessing environments
arcpy.env.snapRaster = ""
arcpy.env.extent = "-14741645.4461 6760651.5945 -14541645.4461 6960651.5945"

# Script arguments
Sea_Levels_CSV = arcpy.GetParameterAsText(0)
if Sea_Levels_CSV == '#' or not Sea_Levels_CSV:
    Sea_Levels_CSV = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\SeaLevel.csv" # provide a default value if unspecified

Null_Value = arcpy.GetParameterAsText(1)
if Null_Value == '#' or not Null_Value:
    Null_Value = "-1" # provide a default value if unspecified

Input_Elevation_Surface = arcpy.GetParameterAsText(2)
if Input_Elevation_Surface == '#' or not Input_Elevation_Surface:
    Input_Elevation_Surface = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Alexander_30m" # provide a default value if unspecified

v_Output = arcpy.GetParameterAsText(3)
if v_Output == '#' or not v_Output:
```

```
    v_Output = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Landmass_Inverse_%Value%" # provide a default value if unspecified

Ocean_Area = arcpy.GetParameterAsText(4)
if Ocean_Area == '#' or not Ocean_Area:
    Ocean_Area = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Landmass_Select_%Value%" # provide a default value if unspecified

DEM_Adjusted_for_Sea_Level_Change = arcpy.GetParameterAsText(5)
if DEM_Adjusted_for_Sea_Level_Change == '#' or not DEM_Adjusted_for_Sea_Level_Change:
    DEM_Adjusted_for_Sea_Level_Change = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\DEM_%Value%" # provide a default value if unspecified

Expression = arcpy.GetParameterAsText(6)
if Expression == '#' or not Expression:
    Expression = "\"Shape_Area\" > 4319702682" # provide a default value if unspecified

Study_Area_Line = arcpy.GetParameterAsText(7)
if Study_Area_Line == '#' or not Study_Area_Line:
    Study_Area_Line = "C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line" # provide a default value if unspecified

Data_Type = arcpy.GetParameterAsText(8)
if Data_Type == '#' or not Data_Type:
    Data_Type = "Double" # provide a default value if unspecified

# Local variables:
Value = Sea_Levels_CSV
Contour__i_ = DEM_Adjusted_for_Sea_Level_Change
Contour_Select__Value_ = Contour__i_
Landmass_Line__Value_ = Contour_Select__Value_
Poly__Value_ = Landmass_Line__Value_
Contour_interval = "1"

# Process: Iterate Field Values
arcpy.IterateFieldValues_mb(Sea_Levels_CSV, "Field1", Data_Type, "false", "false", Null_Value)

# Process: Raster Calculator
arcpy.gp.RasterCalculator_sa("\"%Input Elevation Surface%\" >= float(%Value%)", DEM_Adjusted_for_Sea_Level_Change)

# Process: Contour
arcpy.gp.Contour_sa(DEM_Adjusted_for_Sea_Level_Change, Contour__i_, Contour_interval, "0", "1")

# Process: Select
```

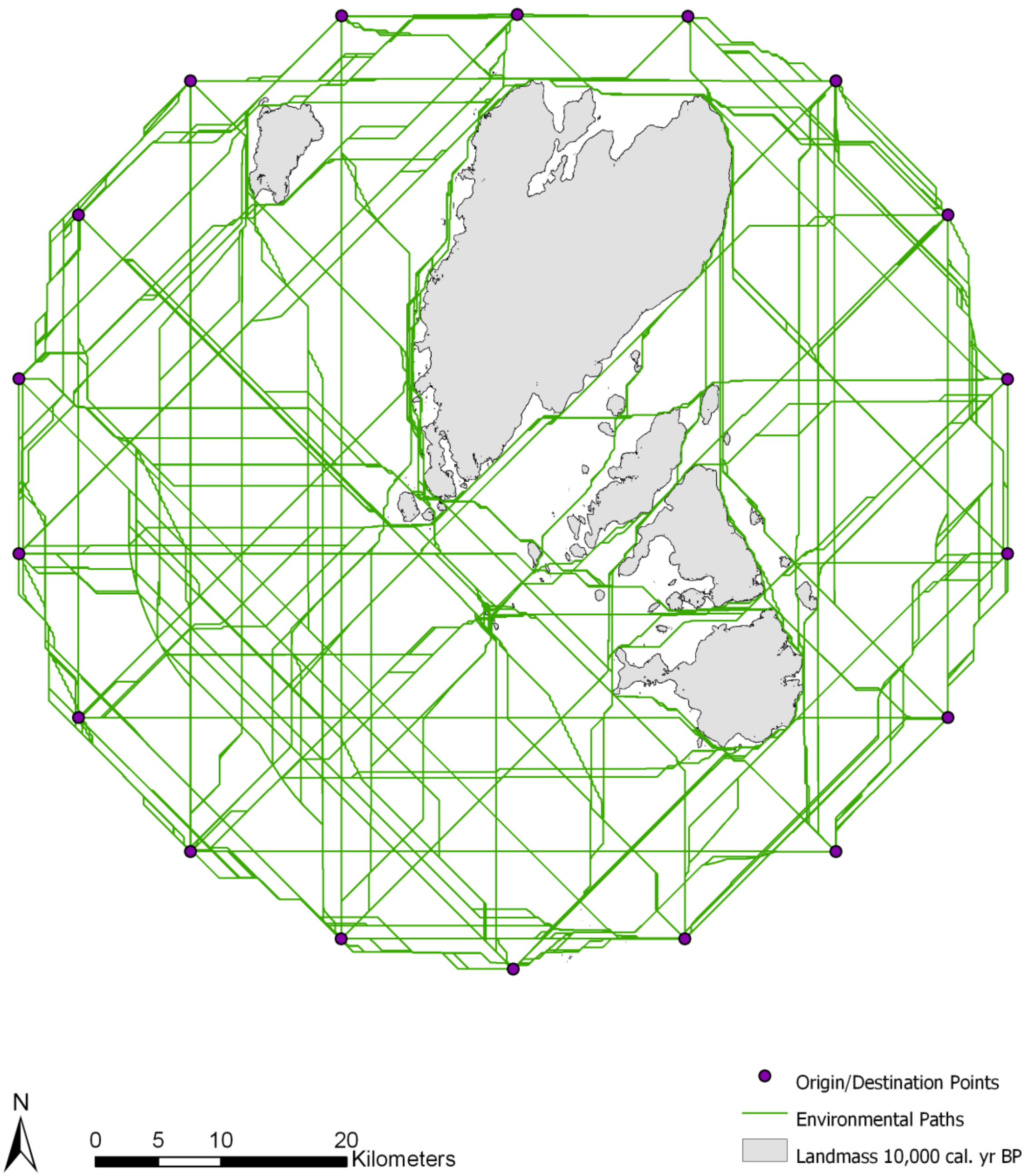
```
arcpy.Select_analysis(Contour__i_, Contour_Select__Value_, "Contour = %Value%")

# Process: Merge
arcpy.Merge_management("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Contour_Select_%Value%;C:\\Users\\Rgustas\\Drop
box\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line", Landmass_Line__Value_, "LEFT_FID \"LEFT_FID\" true true false 4 Long 0 0 ,First
,#,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Study_Area_Line,LEFT_FID,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,LEFT_FID,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,LEFT_FID,-1,-
1;RIGHT_FID \"RIGHT_FID\" true true false 4 Long 0 0 ,First,#,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Study_Area_Line,RIGHT_FID,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,RIGHT_FID,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,RIGHT_FID,-1,-
1;Shape_Length \"Shape_Length\" false true true 8 Double 0 0 ,First,#,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Study_Area_Line,Shape_Length,-1,-
1,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Contour_Select_%Value%,Shape_Length,-1,-
1,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Contour_Select_%Value%,Shape_Length,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,Shape_Length,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,Shape_Length,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Contour_Select_%Value%,Shape_Length,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,Shape_Length,-1,-
1;Id \"Id\" true true false 4 Long 0 0 ,First,#,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Contour_Select_%Value%,Id,-1,-
1,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Contour_Select_%Value%,Id,-1,-
1;Contour \"Contour\" true true false 8 Double 0 0 ,First,#,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Contour_Select_%Value%,Contour,-1,-
1,D:\\R_Gustas\\Dundas\\Model\\Model.gdb\\Contour_Select_%Value%,Contour,-1,-
1,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Contour_Select_%Value%,CONTOUR,-1,-
1;FID_Study_Area \"FID_Study_Area\" true true false 4 Long 0 0 ,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study
_Area_Line,FID_Study_Area,-1,-
1;XCoord \"XCoord\" true true false 8 Double 0 0 ,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,XC
oord,-1,-
1;YCoord \"YCoord\" true true false 8 Double 0 0 ,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,YC
oord,-1,-
1;BUFF_DIST \"BUFF_DIST\" true true false 8 Double 0 0 ,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area
_Line,BUFF_DIST,-1,-
1;ORIG_FID \"ORIG_FID\" true true false 4 Long 0 0 ,First,#,C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Study_Area_Line,
ORIG_FID,-1,-1")

# Process: Feature To Polygon
arcpy.FeatureToPolygon_management("C:\\Users\\Rgustas\\Dropbox\\Thesis\\Data\\Subregions\\Alexander\\Model\\Model.gdb\\Landmass_Line_%Value%", Poly__Val
ue_, "", "ATTRIBUTES", "")

# Process: Select (2)
arcpy.Select_analysis(Poly__Value_, Ocean_Area, Expression)

# Process: Erase
arcpy.Erase_analysis(Poly__Value_, Ocean_Area, v_Output, ""
```

Appendix E: Paths By Study Area -- High Overland Movement Cost Scenario



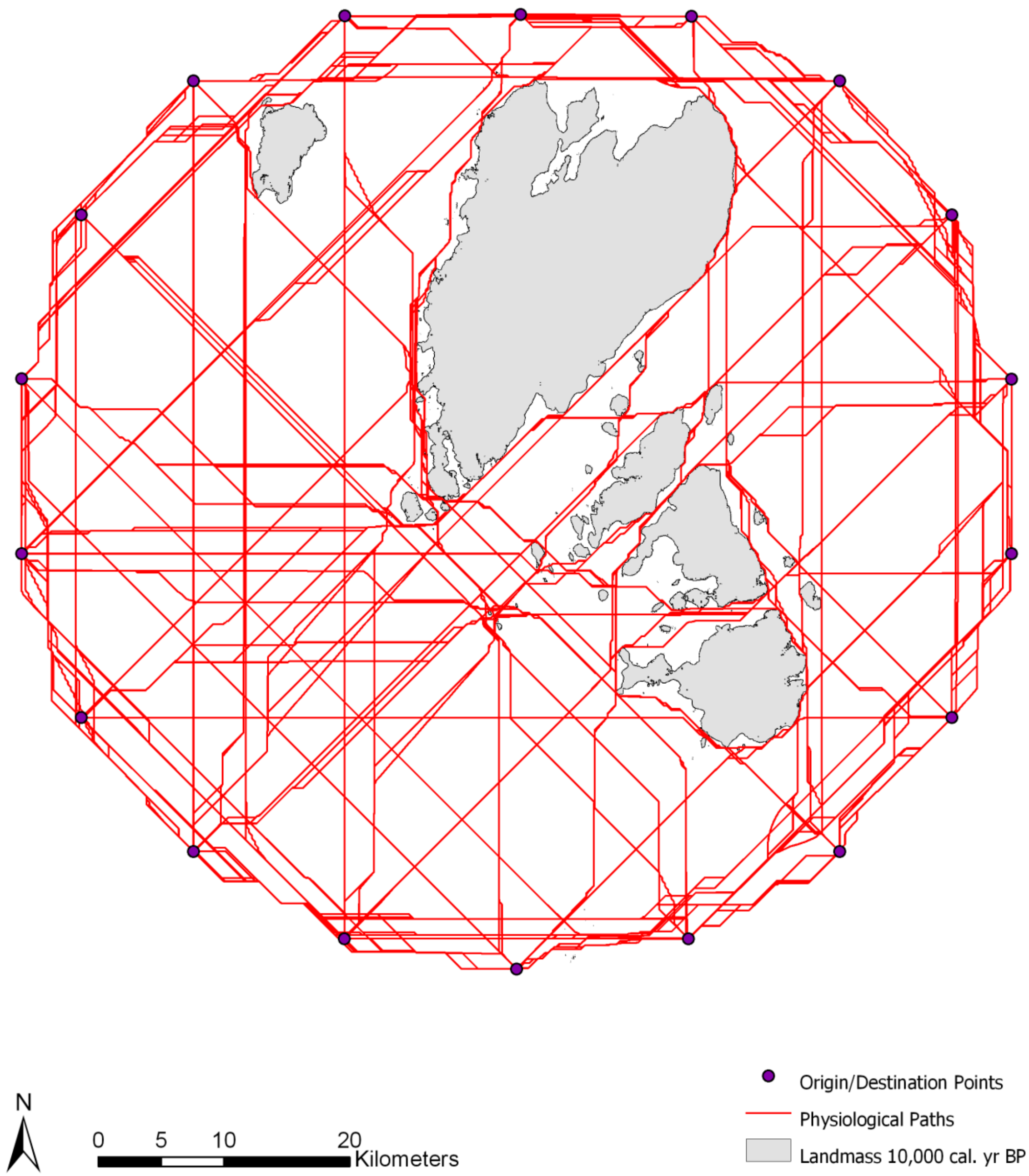
Dundas Archipelago 10,000 cal. yr BP

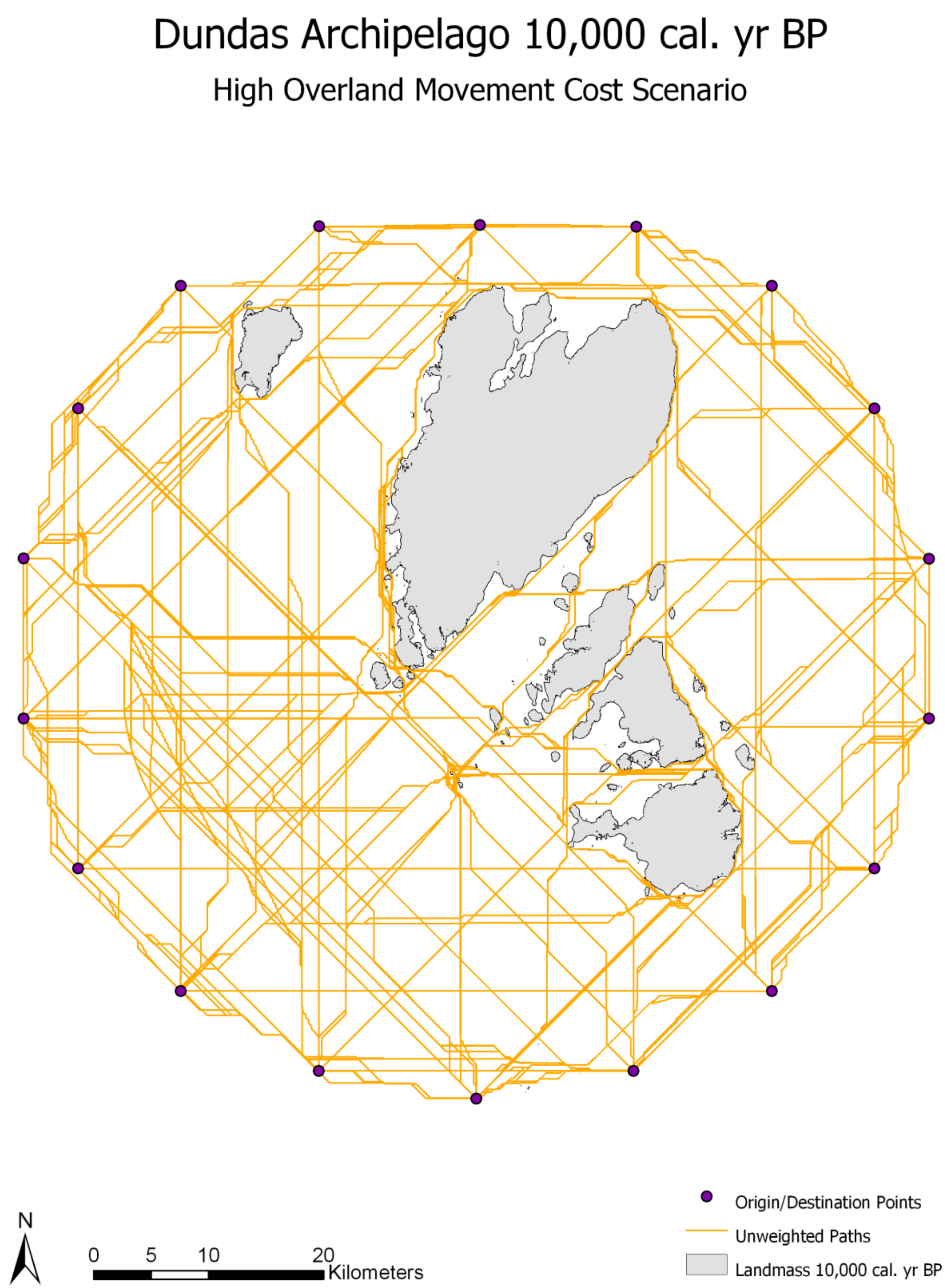
High Overland Movement Cost Scenario



Dundas Archipelago 10,000 cal. yr BP

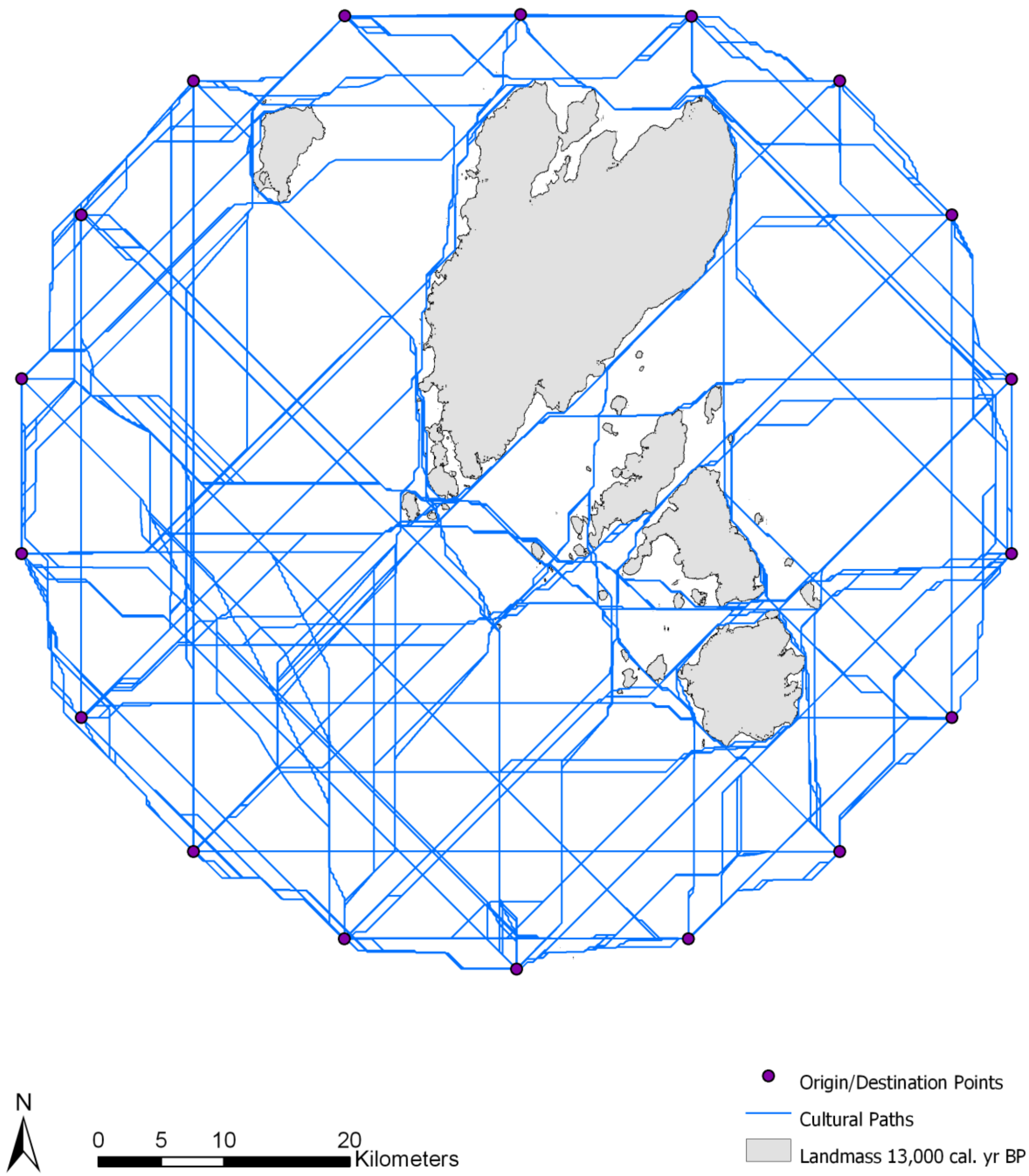
High Overland Movement Cost Scenario

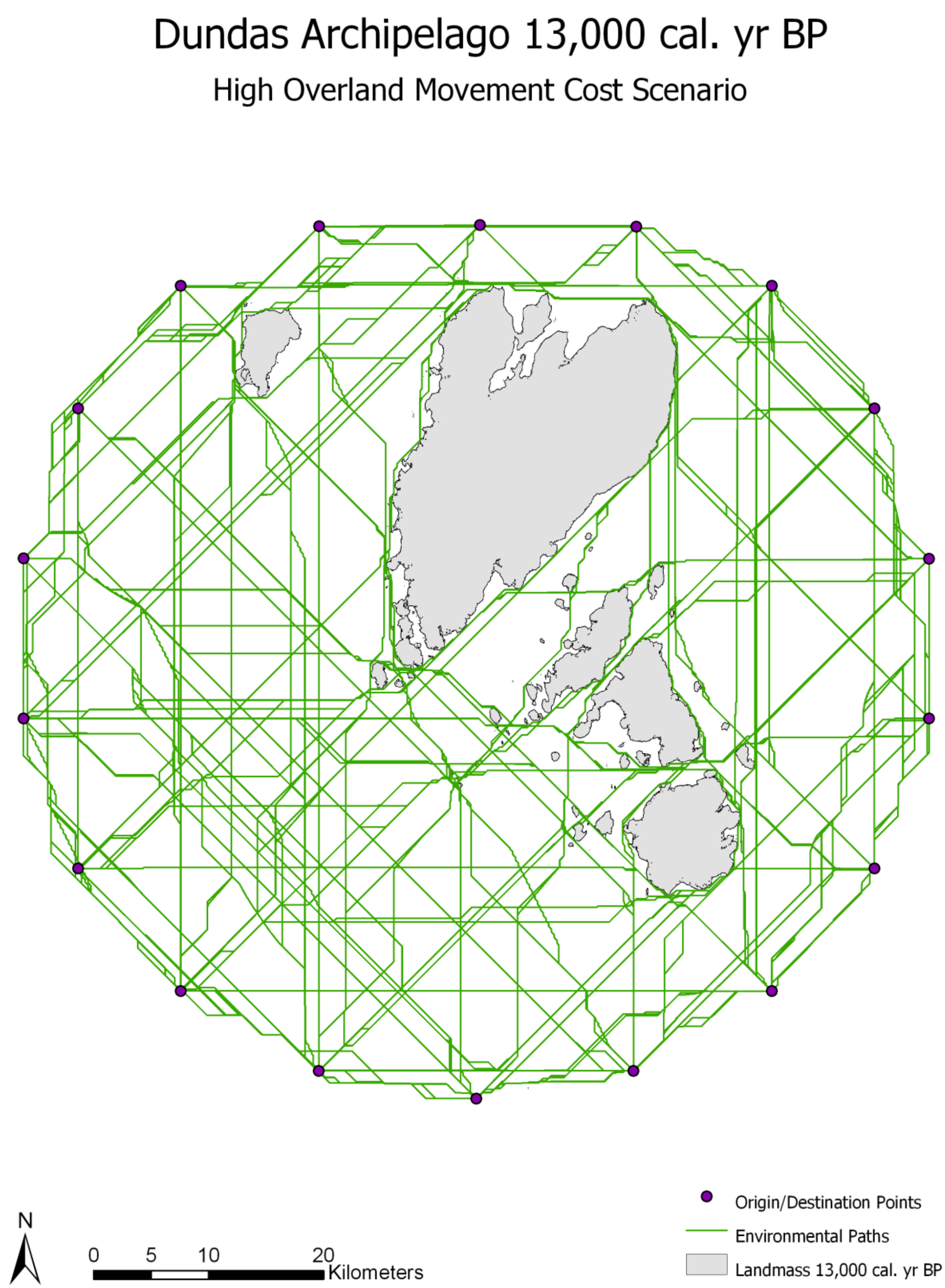



Dundas Archipelago 10,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Unweighted Paths
Landmass 10,000 cal. yr BP

Dundas Archipelago 13,000 cal. yr BP

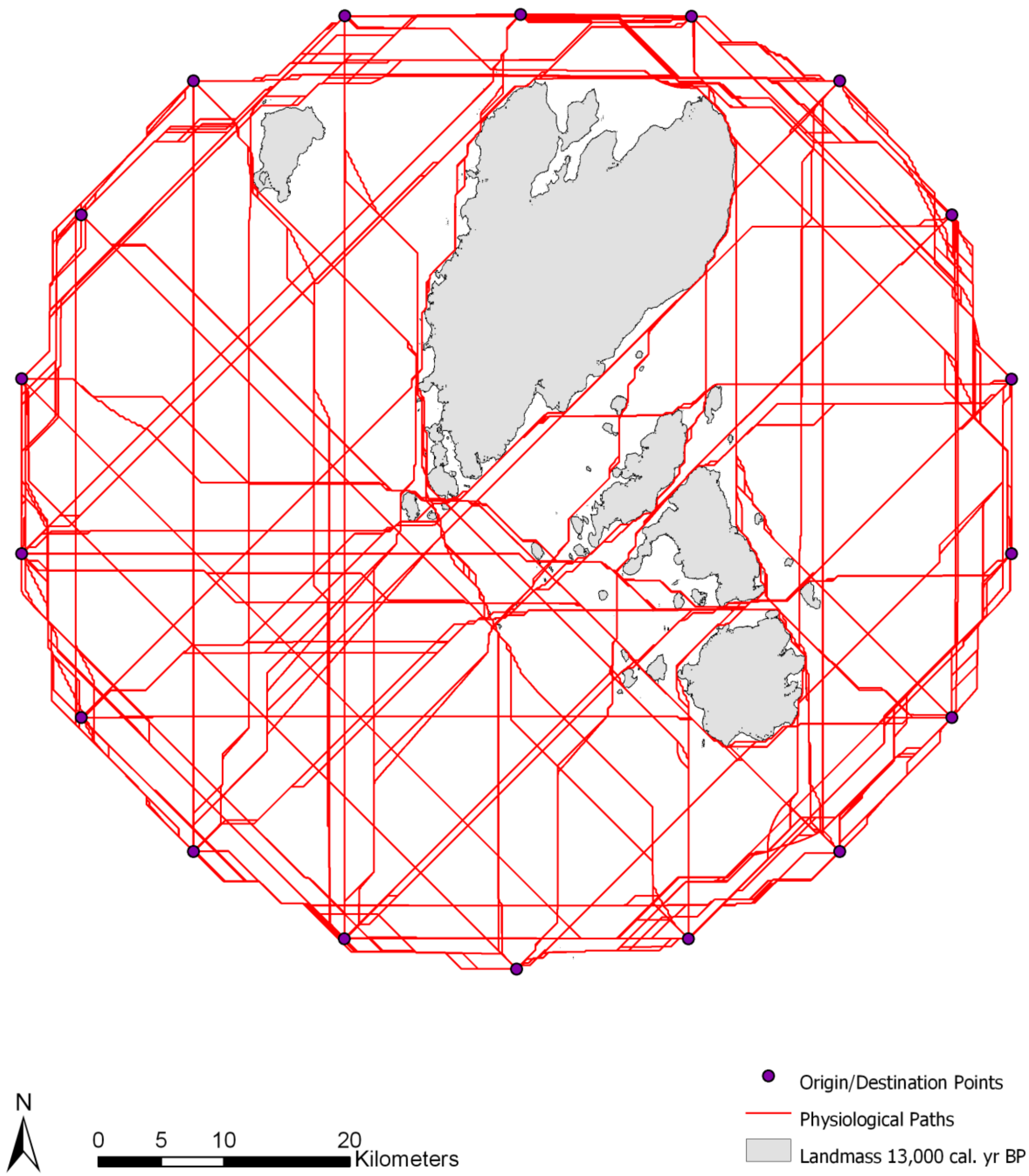
High Overland Movement Cost Scenario

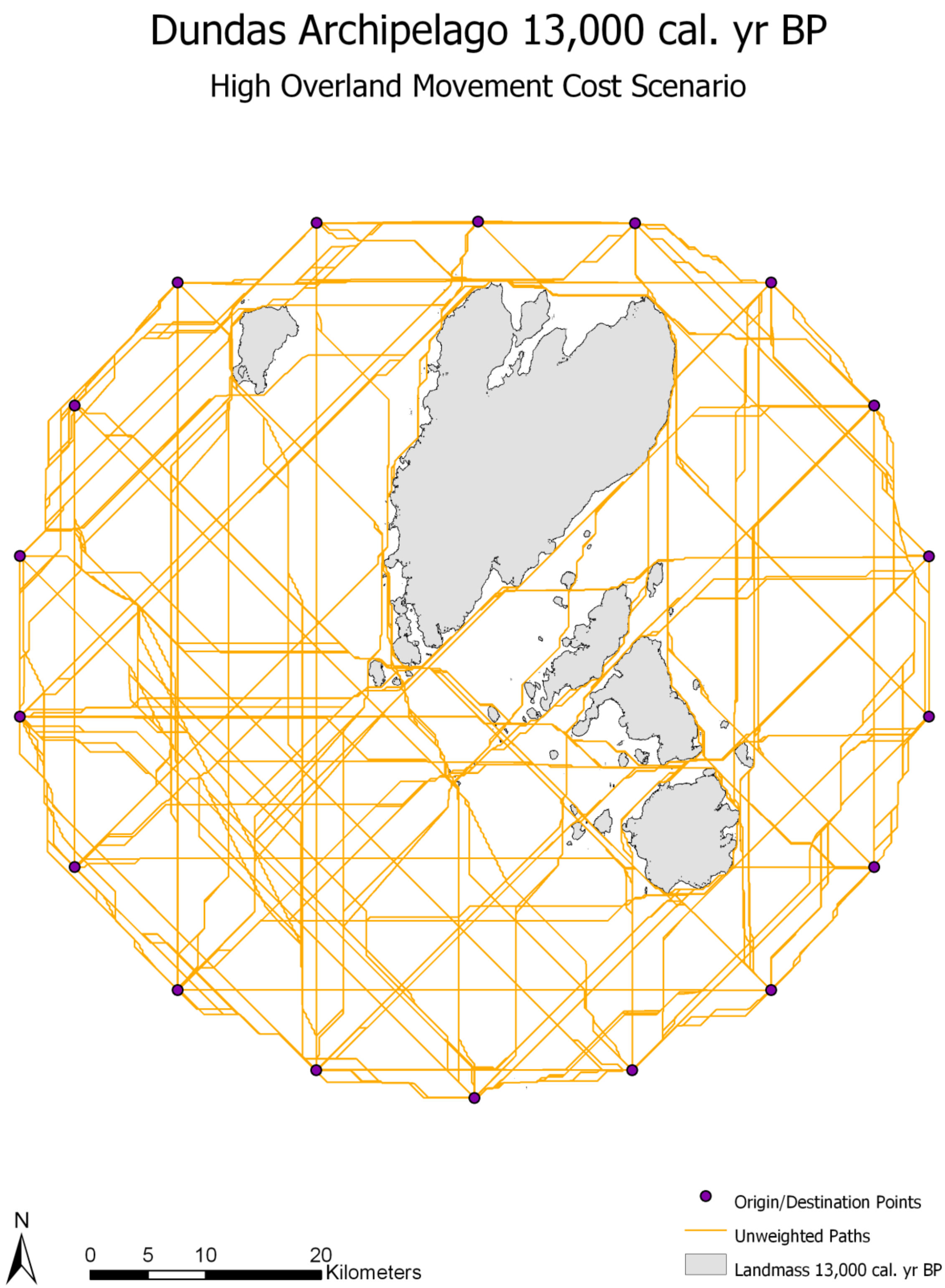



Dundas Archipelago 13,000 cal. yr BP
High Overland Movement Cost Scenario
N
0 5 10 20
Kilometers
Origin/Destination Points
Environmental Paths
Landmass 13,000 cal. yr BP

Dundas Archipelago 13,000 cal. yr BP

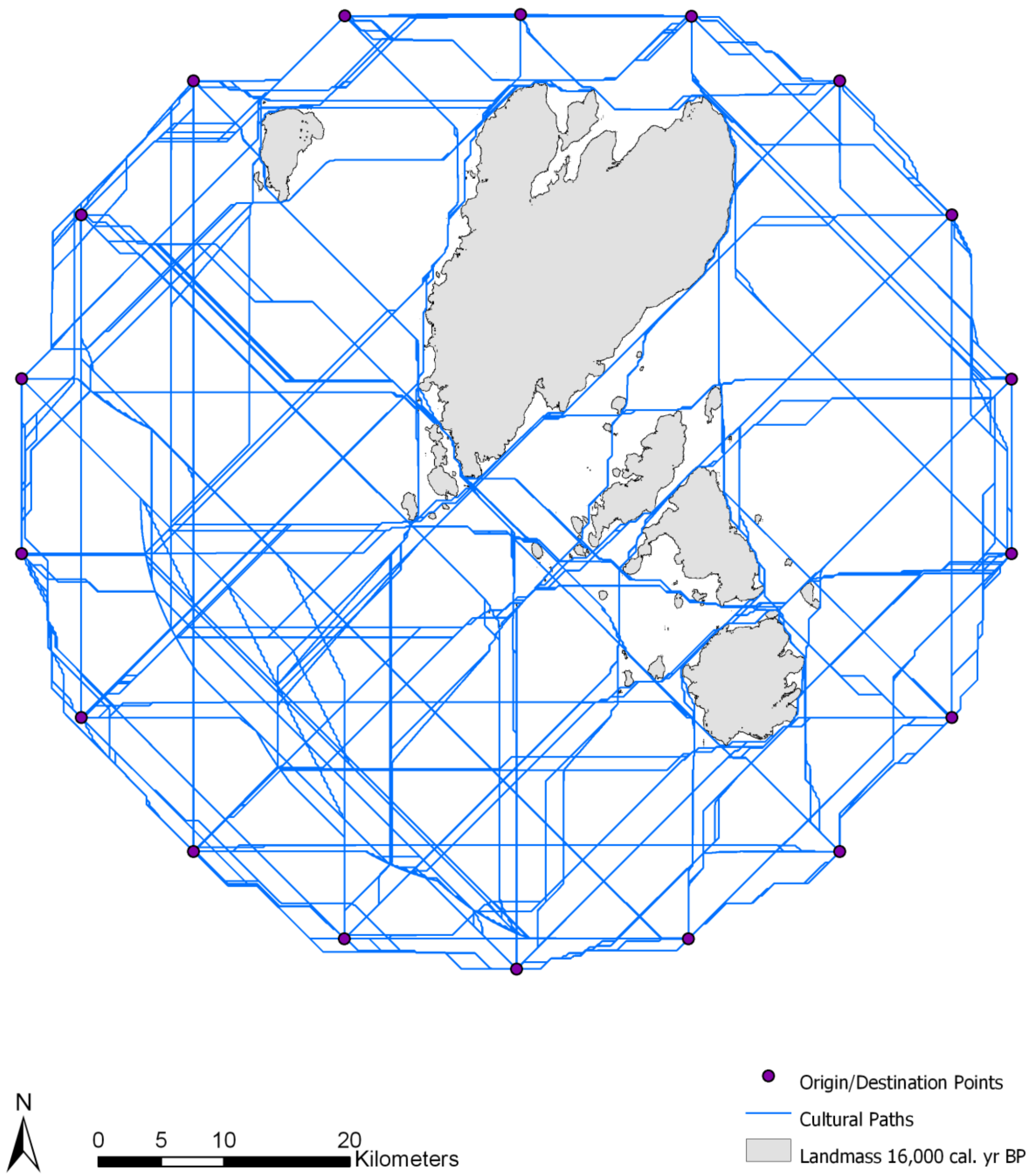
High Overland Movement Cost Scenario




Dundas Archipelago 13,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Unweighted Paths
Landmass 13,000 cal. yr BP

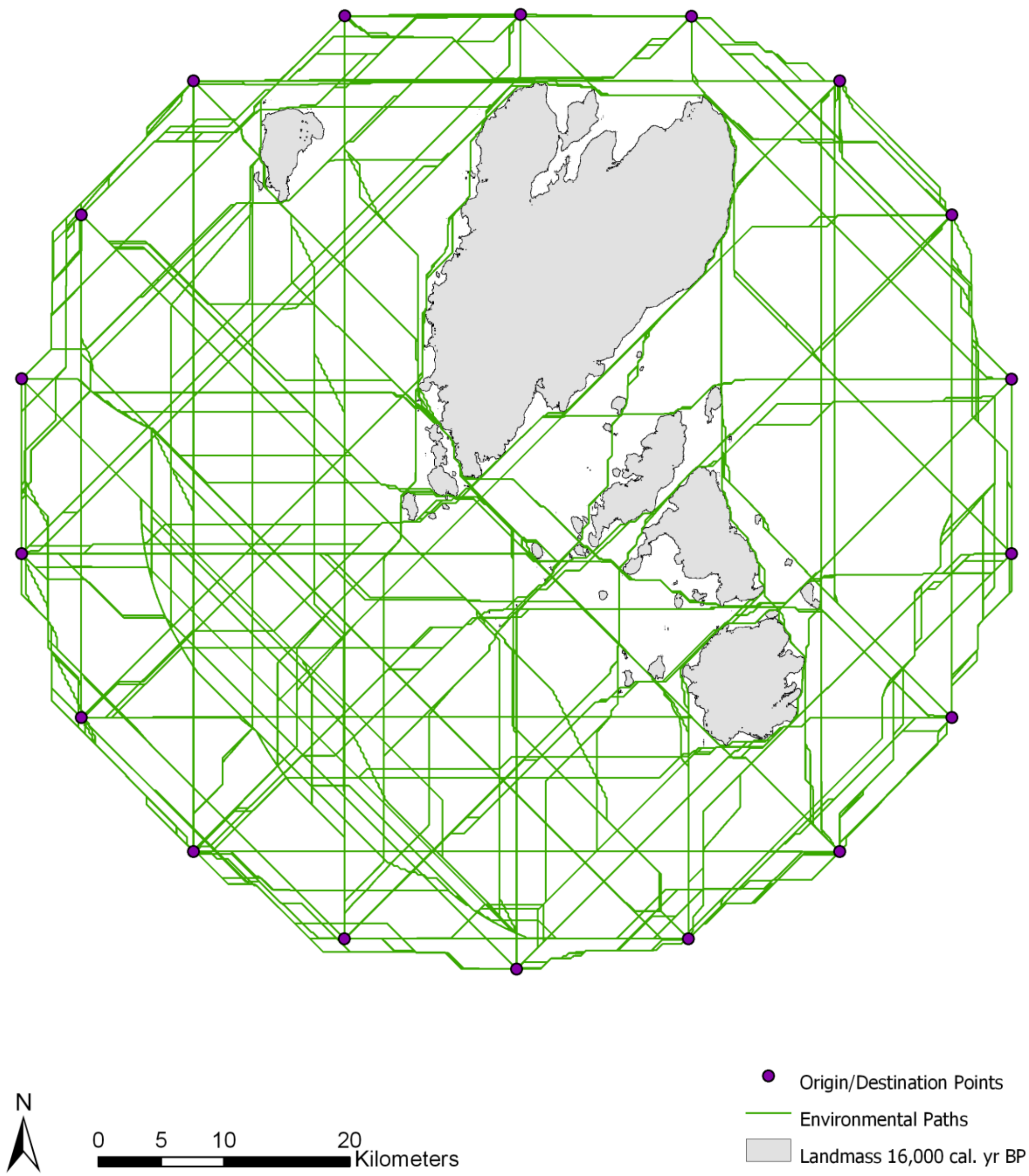
Dundas Archipelago 16,000 cal. yr BP

High Overland Movement Cost Scenario



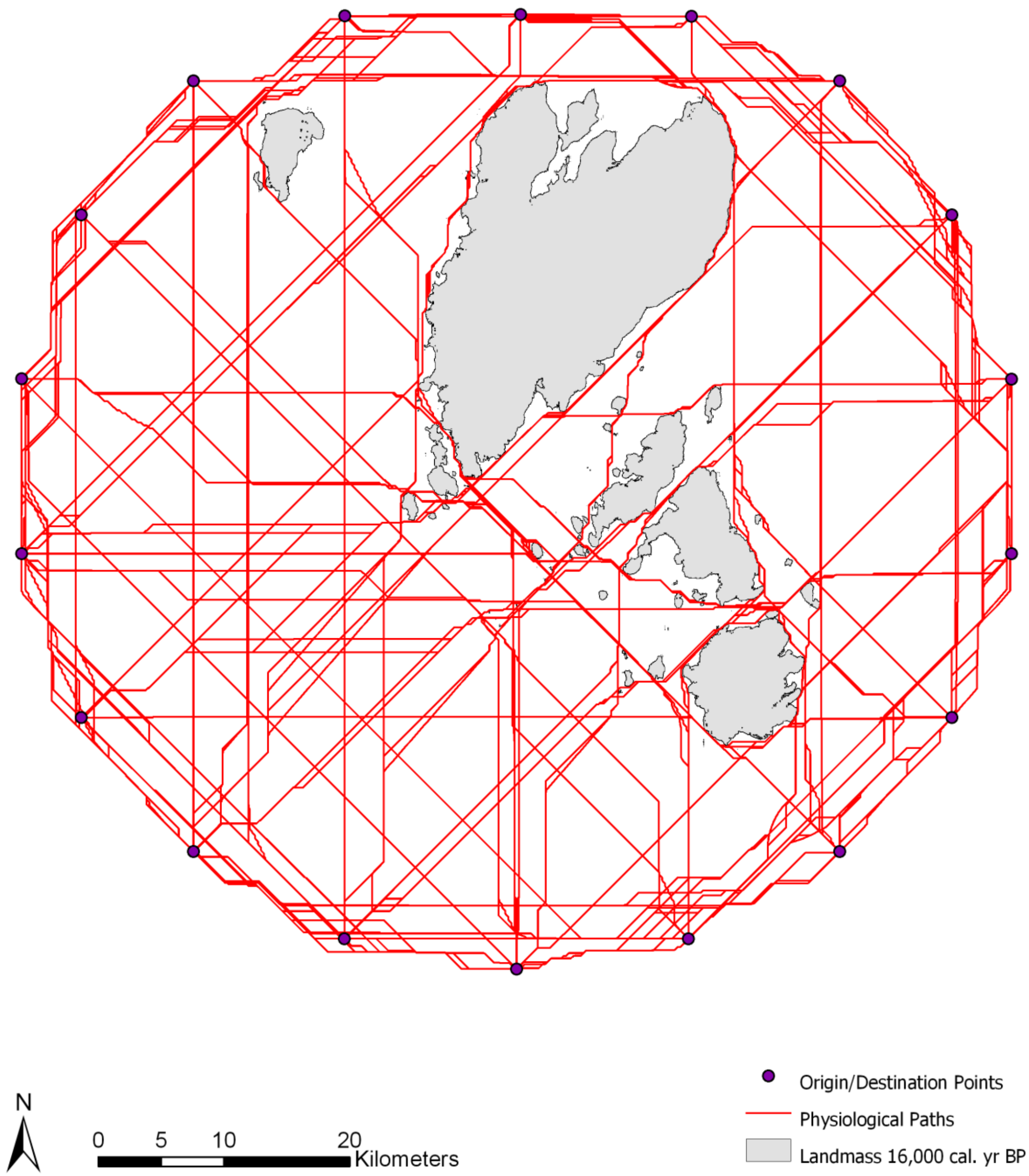
Dundas Archipelago 16,000 cal. yr BP

High Overland Movement Cost Scenario



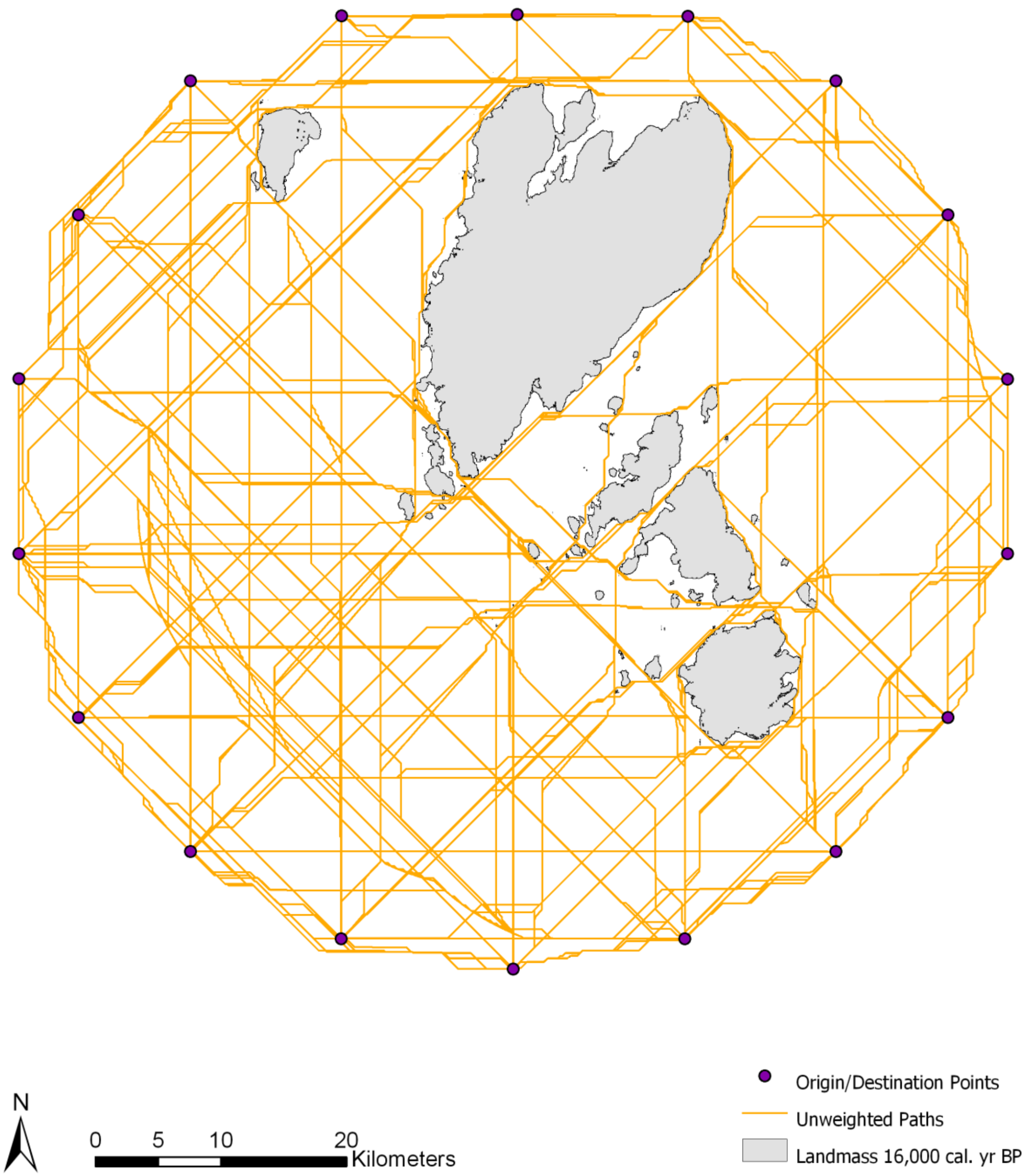
Dundas Archipelago 16,000 cal. yr BP

High Overland Movement Cost Scenario



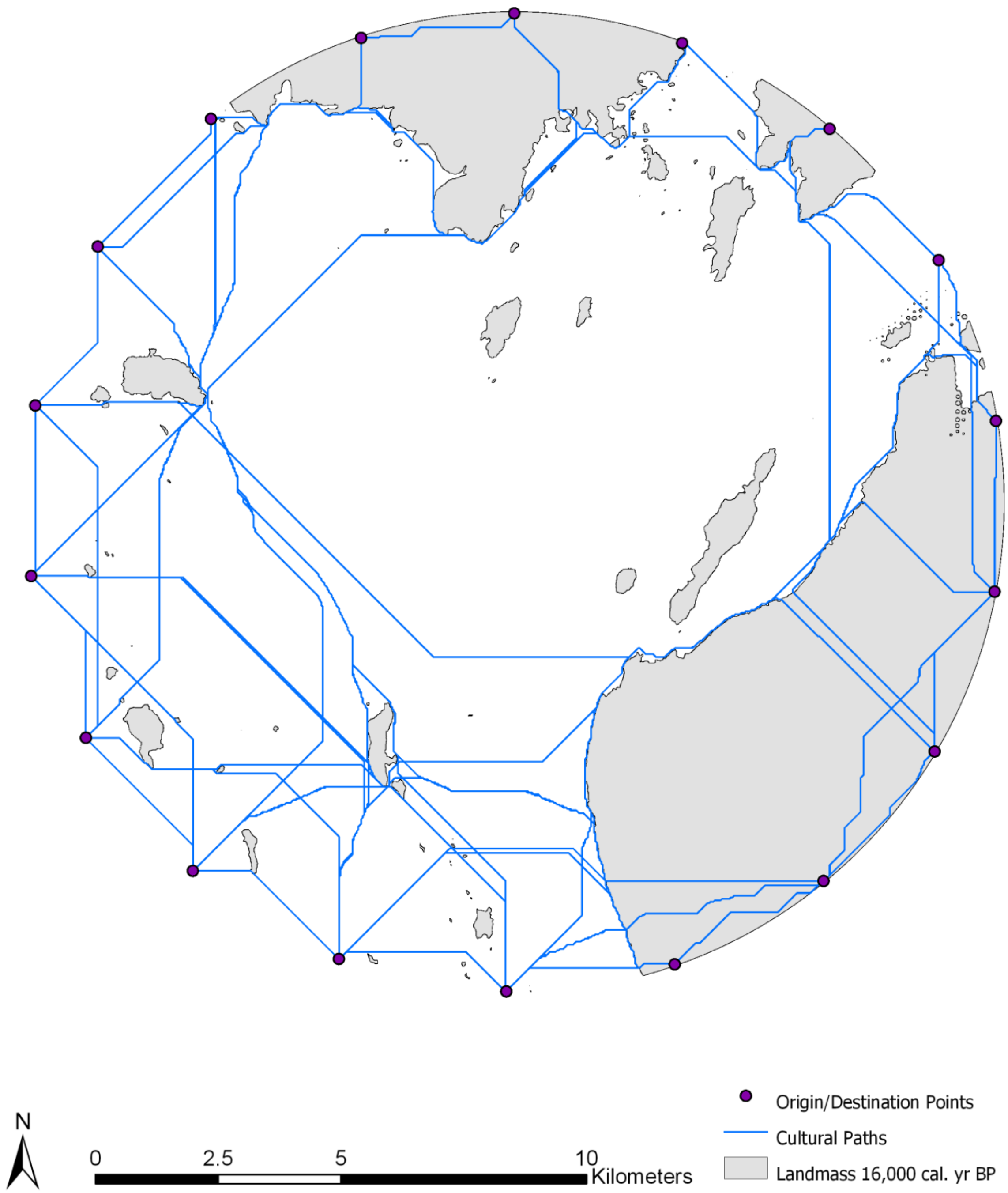
Dundas Archipelago 16,000 cal. yr BP

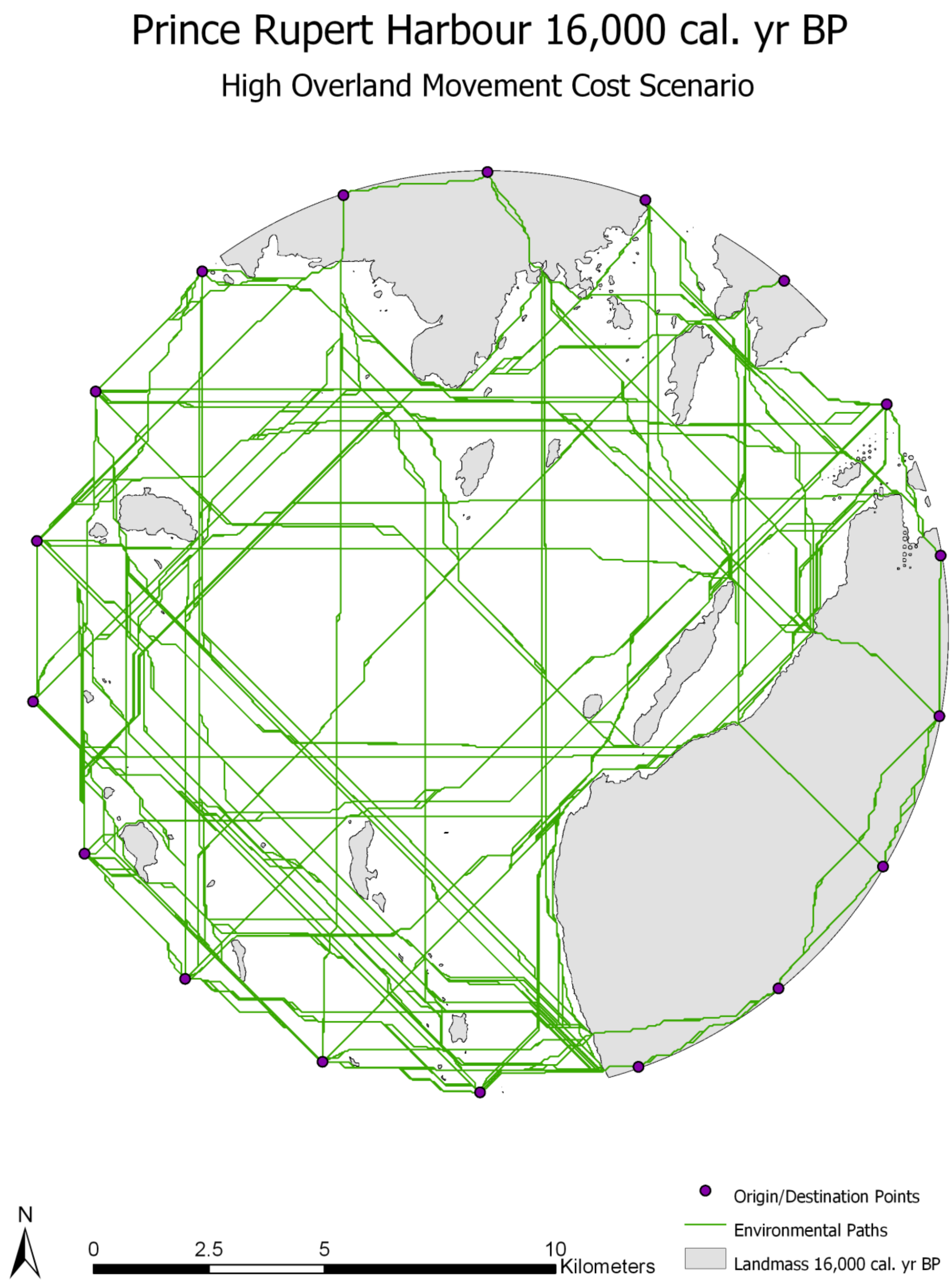
High Overland Movement Cost Scenario

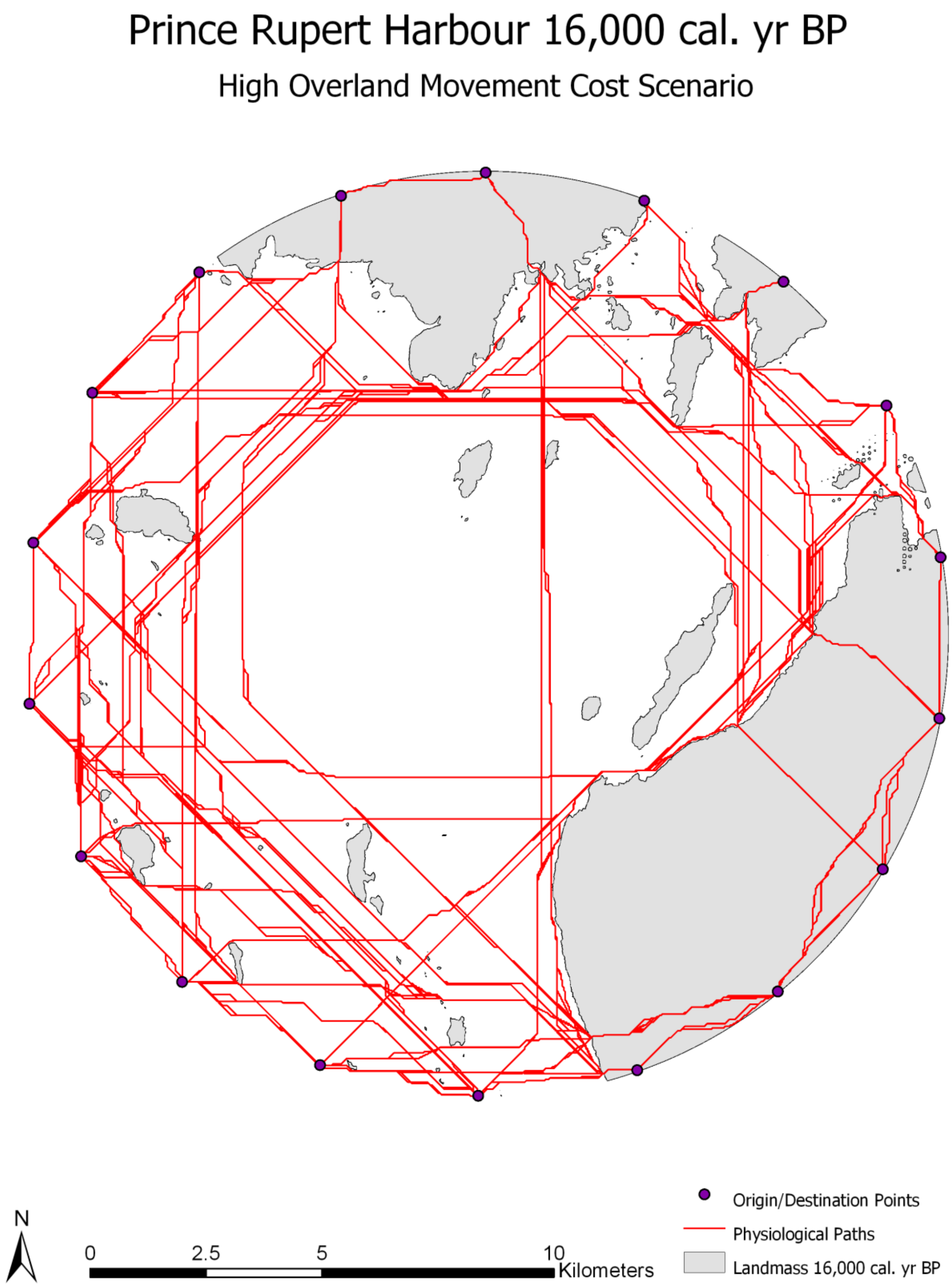


Prince Rupert Harbour 16,000 cal. yr BP

High Overland Movement Cost Scenario

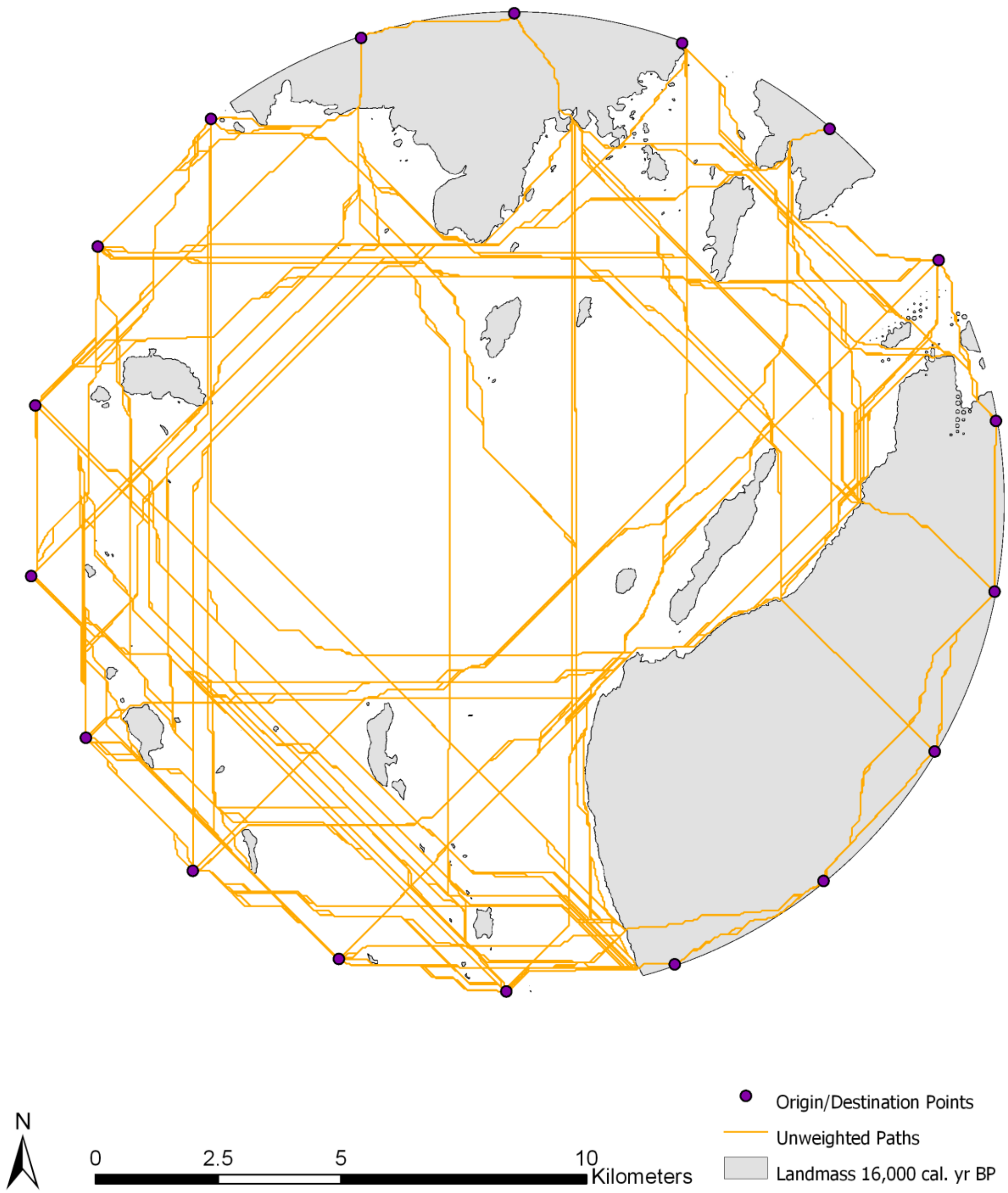



Prince Rupert Harbour 16,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Environmental Paths
Landmass 16,000 cal. yr BP
N
0
2.5
5
10
Kilometers


Prince Rupert Harbour 16,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
2.5
5
10
Kilometers
Origin/Destination Points
Physiological Paths
Landmass 16,000 cal. yr BP

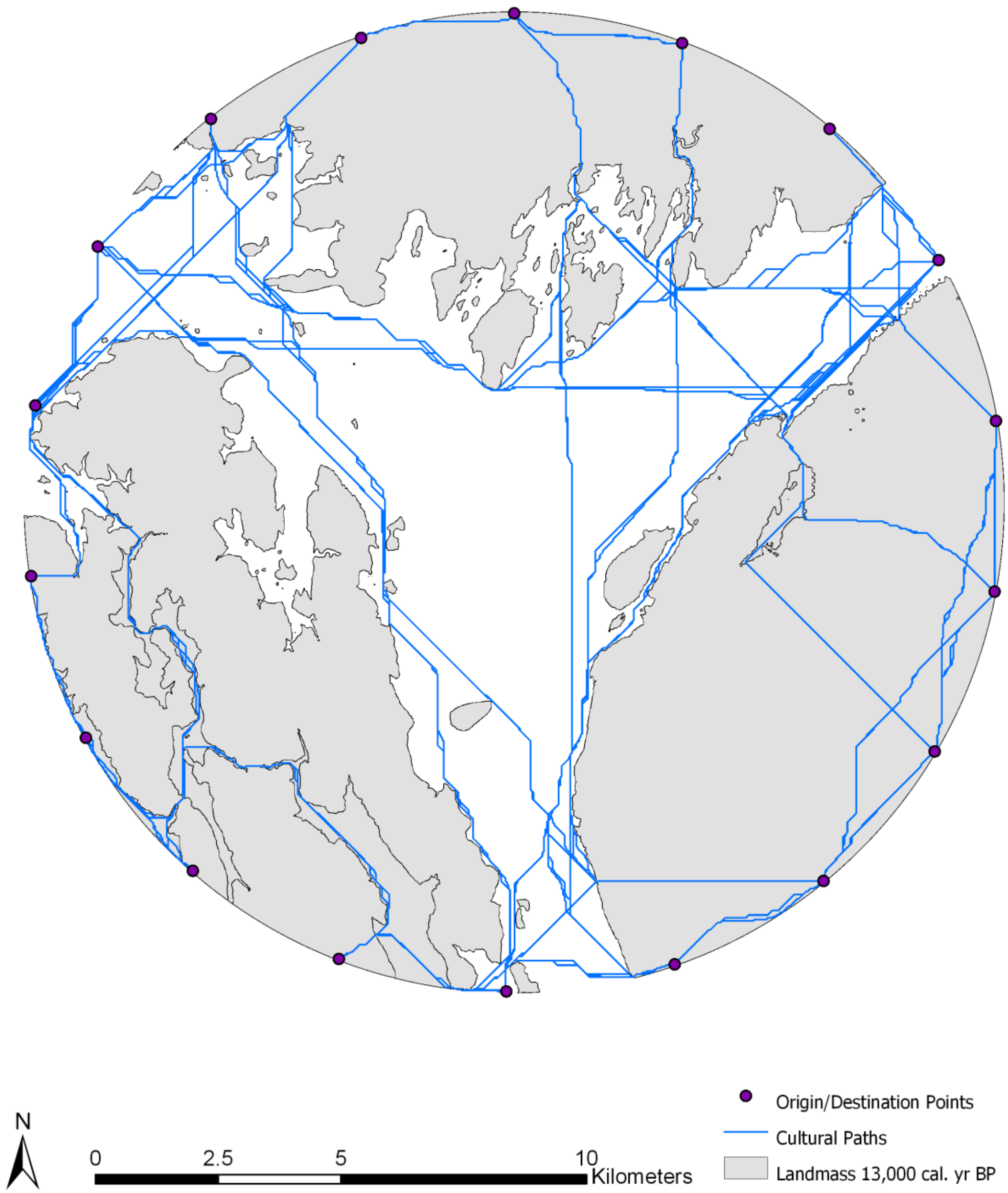
Prince Rupert Harbour 16,000 cal. yr BP

High Overland Movement Cost Scenario



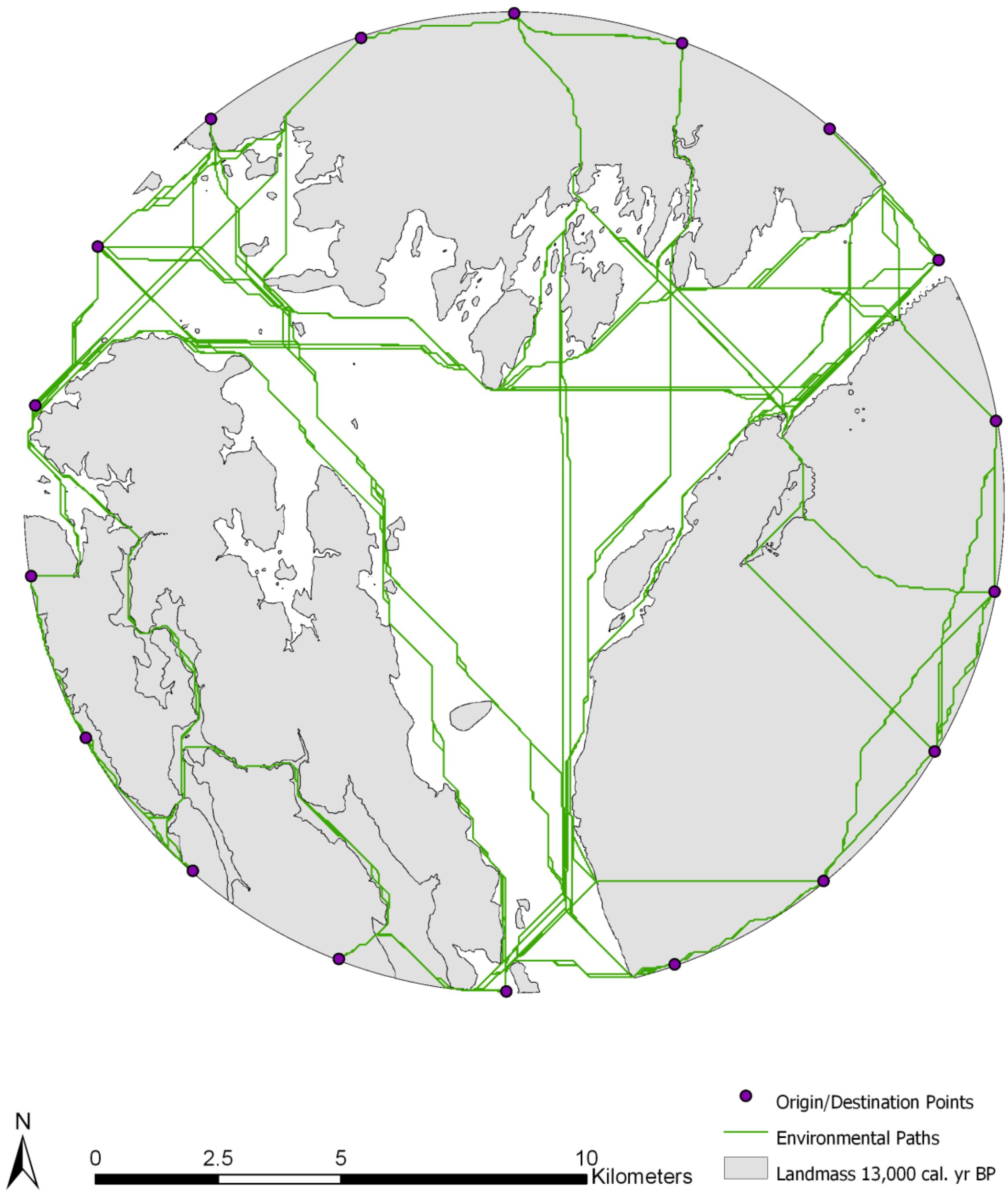
Prince Rupert Harbour 13,000 cal. yr BP

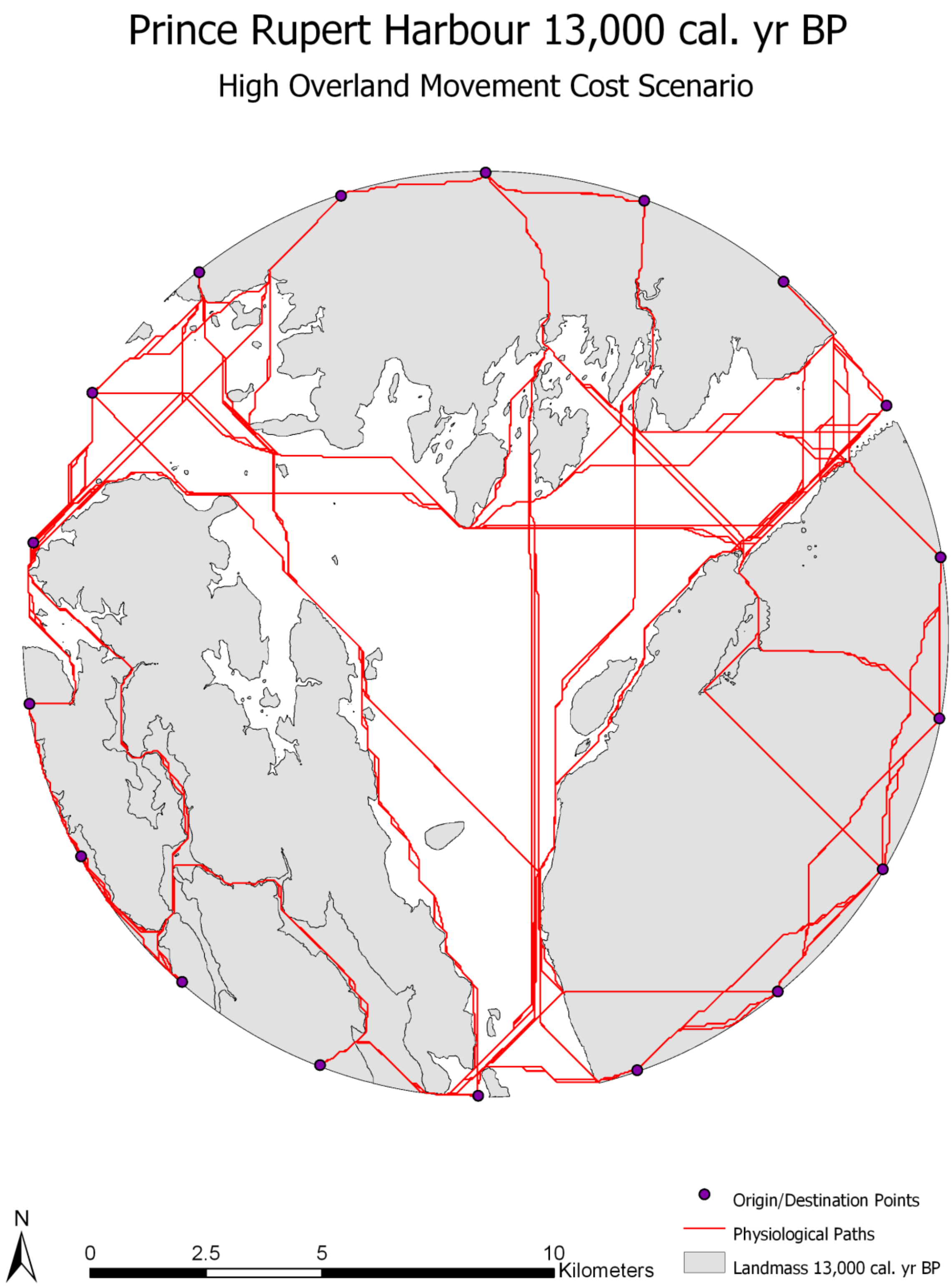
High Overland Movement Cost Scenario



Prince Rupert Harbour 13,000 cal. yr BP

High Overland Movement Cost Scenario

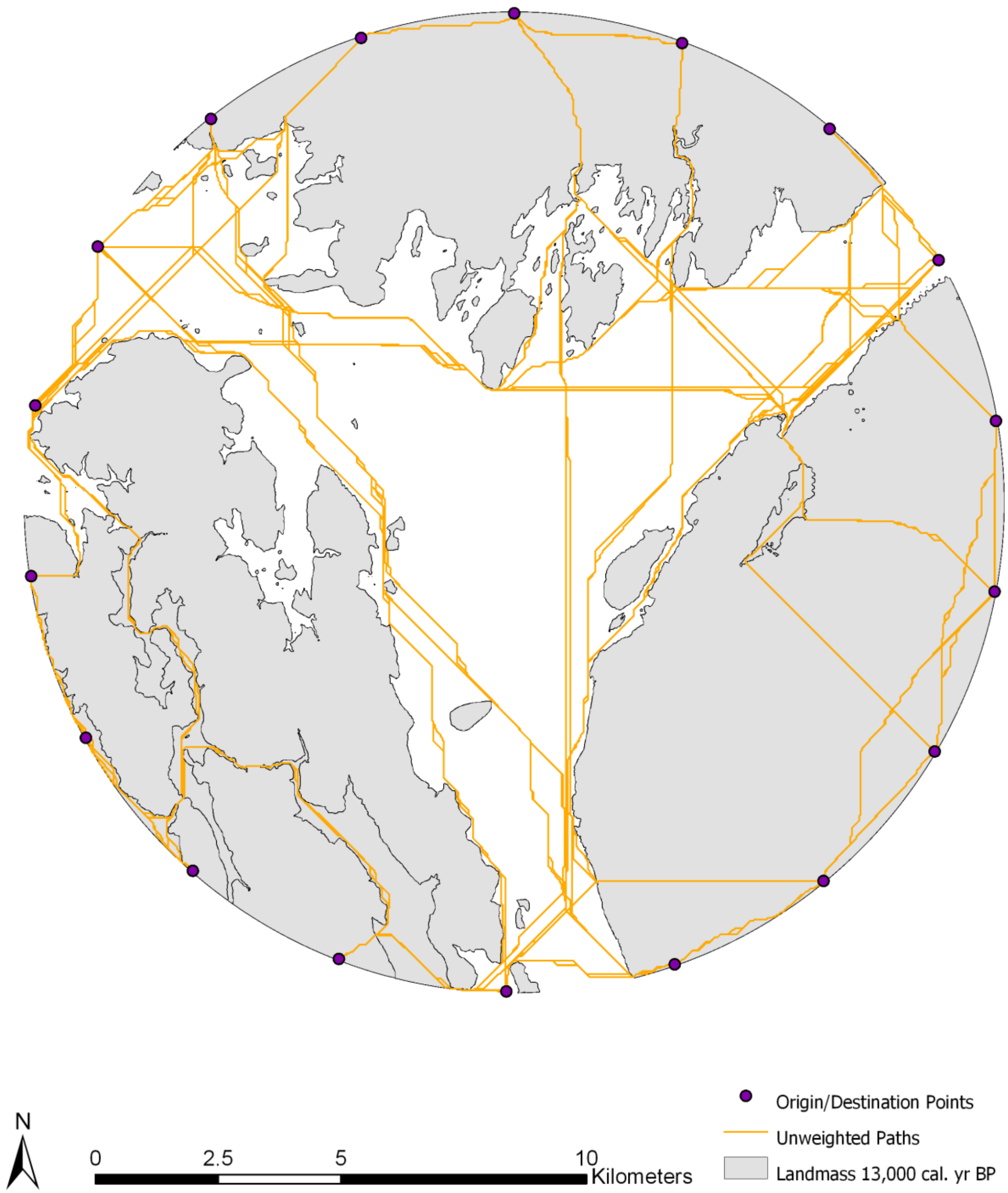




Prince Rupert Harbour 13,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
2.5
5
10
Kilometers
Origin/Destination Points
Physiological Paths
Landmass 13,000 cal. yr BP

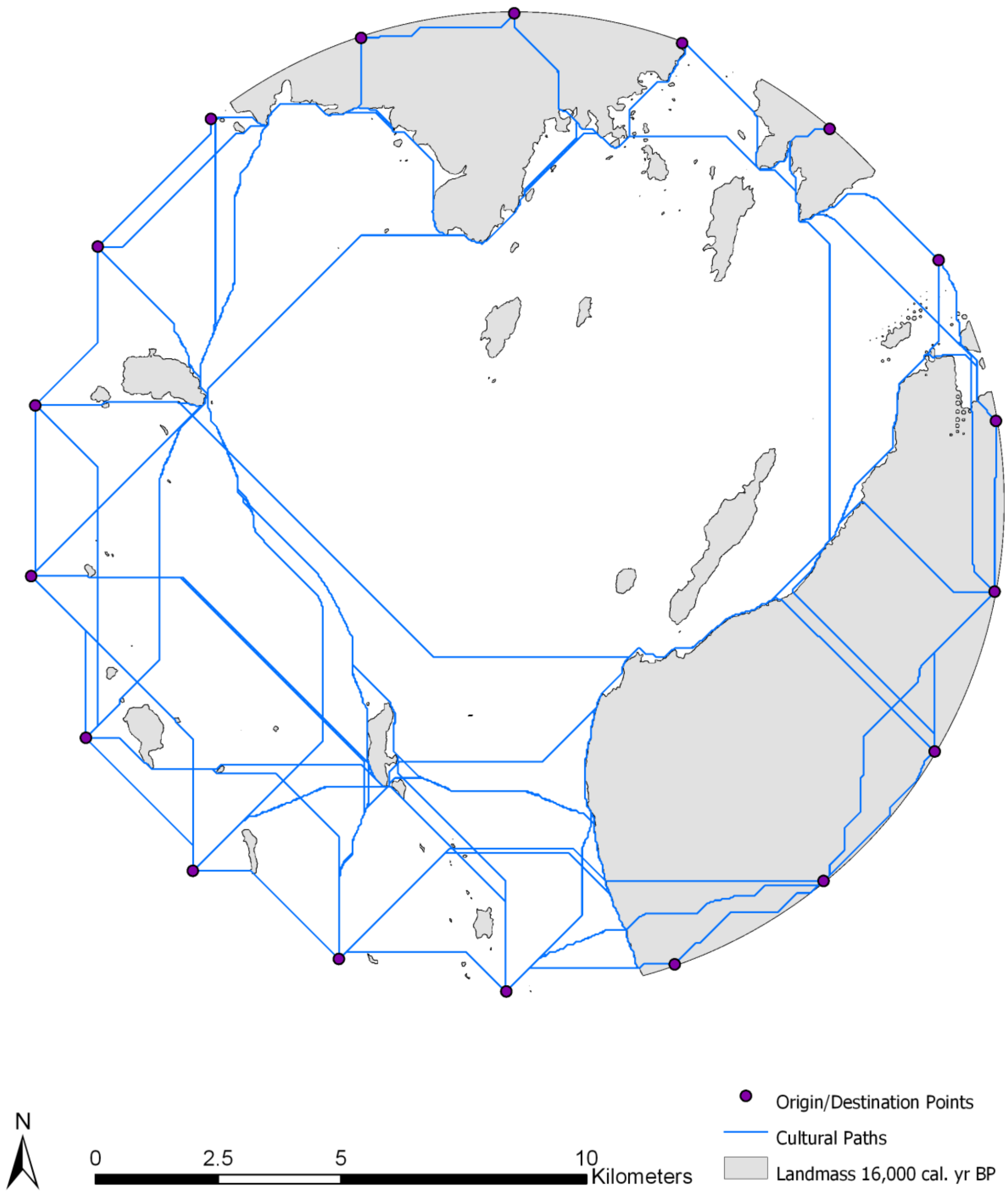
Prince Rupert Harbour 13,000 cal. yr BP

High Overland Movement Cost Scenario



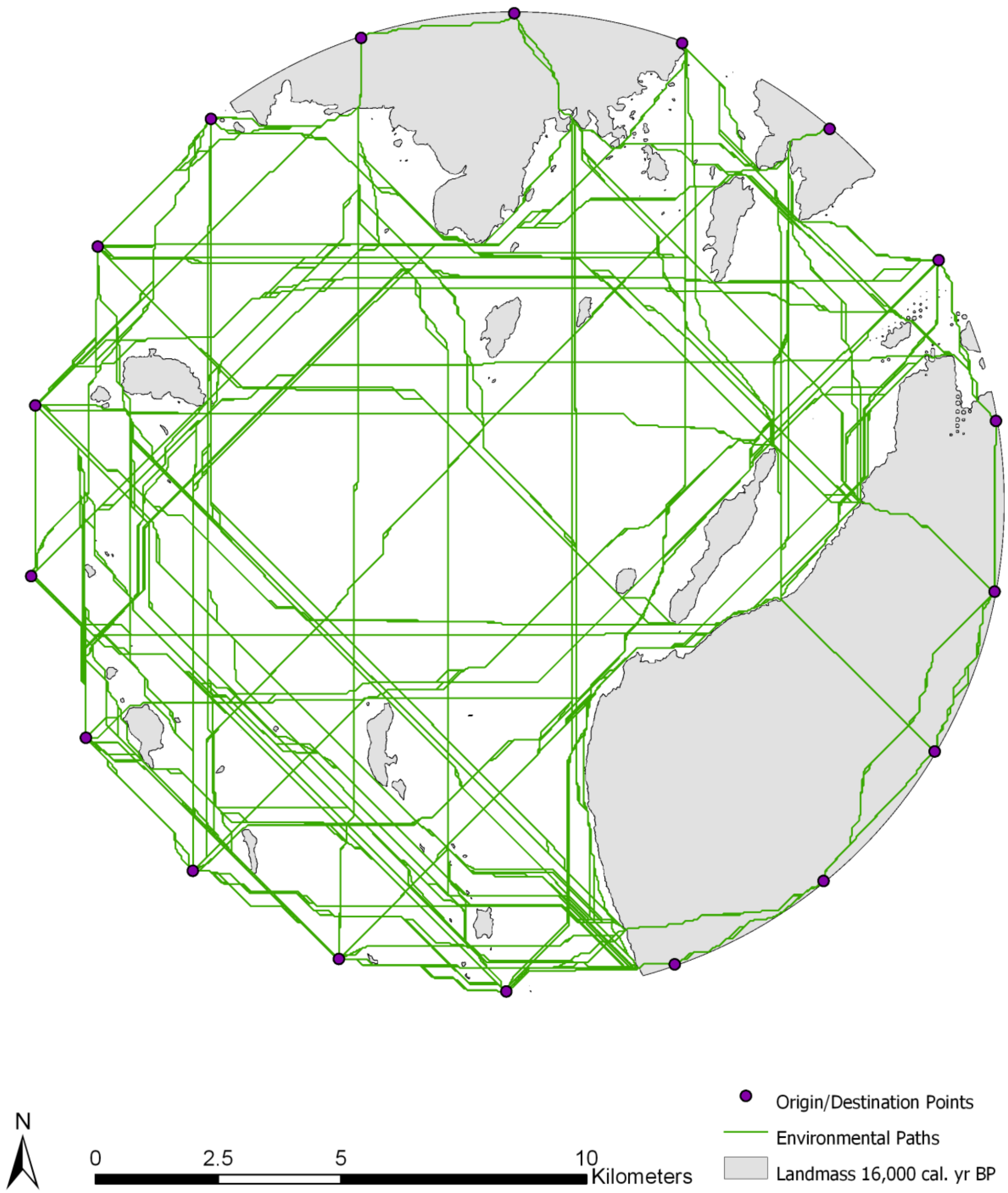
Prince Rupert Harbour 16,000 cal. yr BP

High Overland Movement Cost Scenario



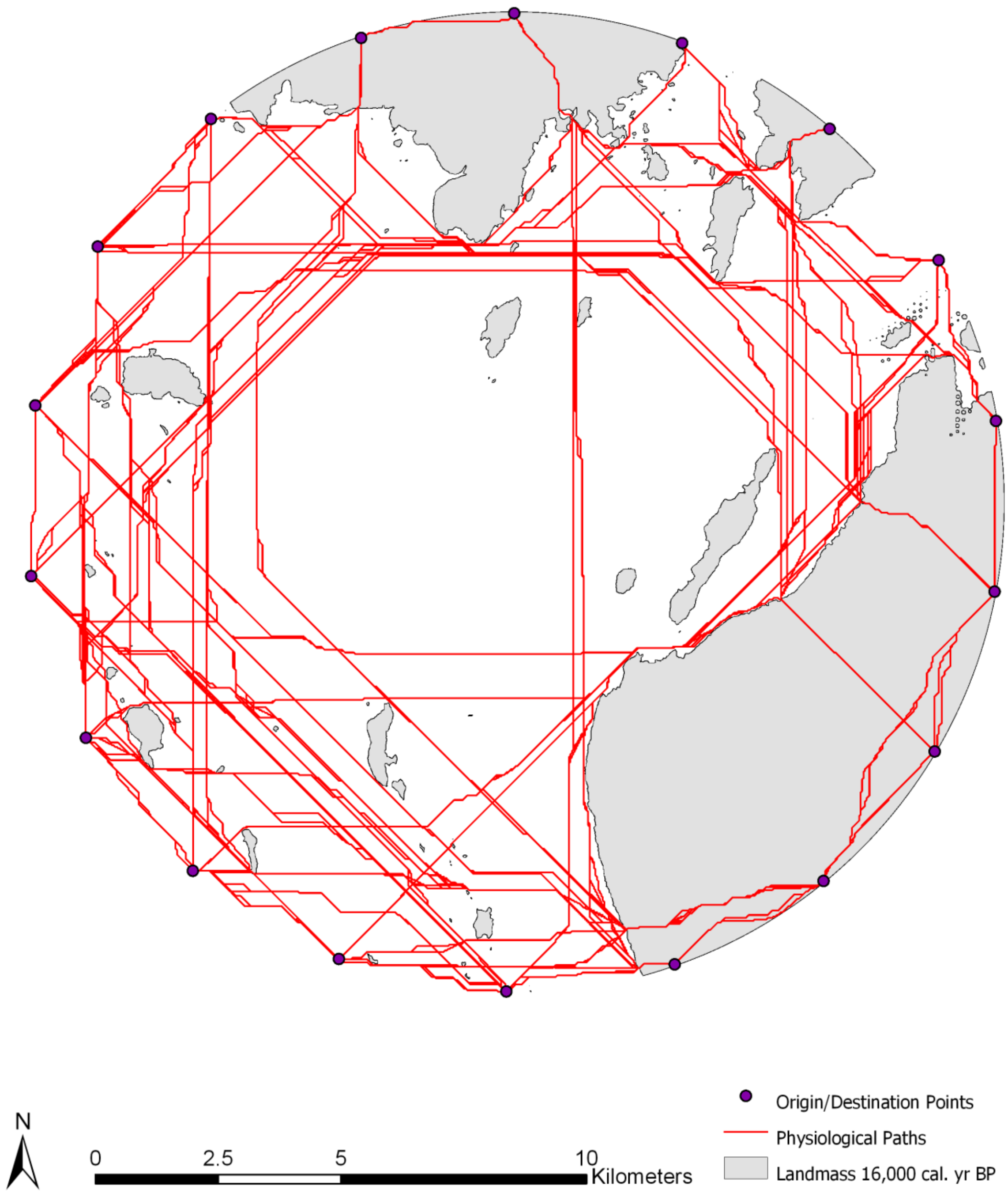
Prince Rupert Harbour 16,000 cal. yr BP

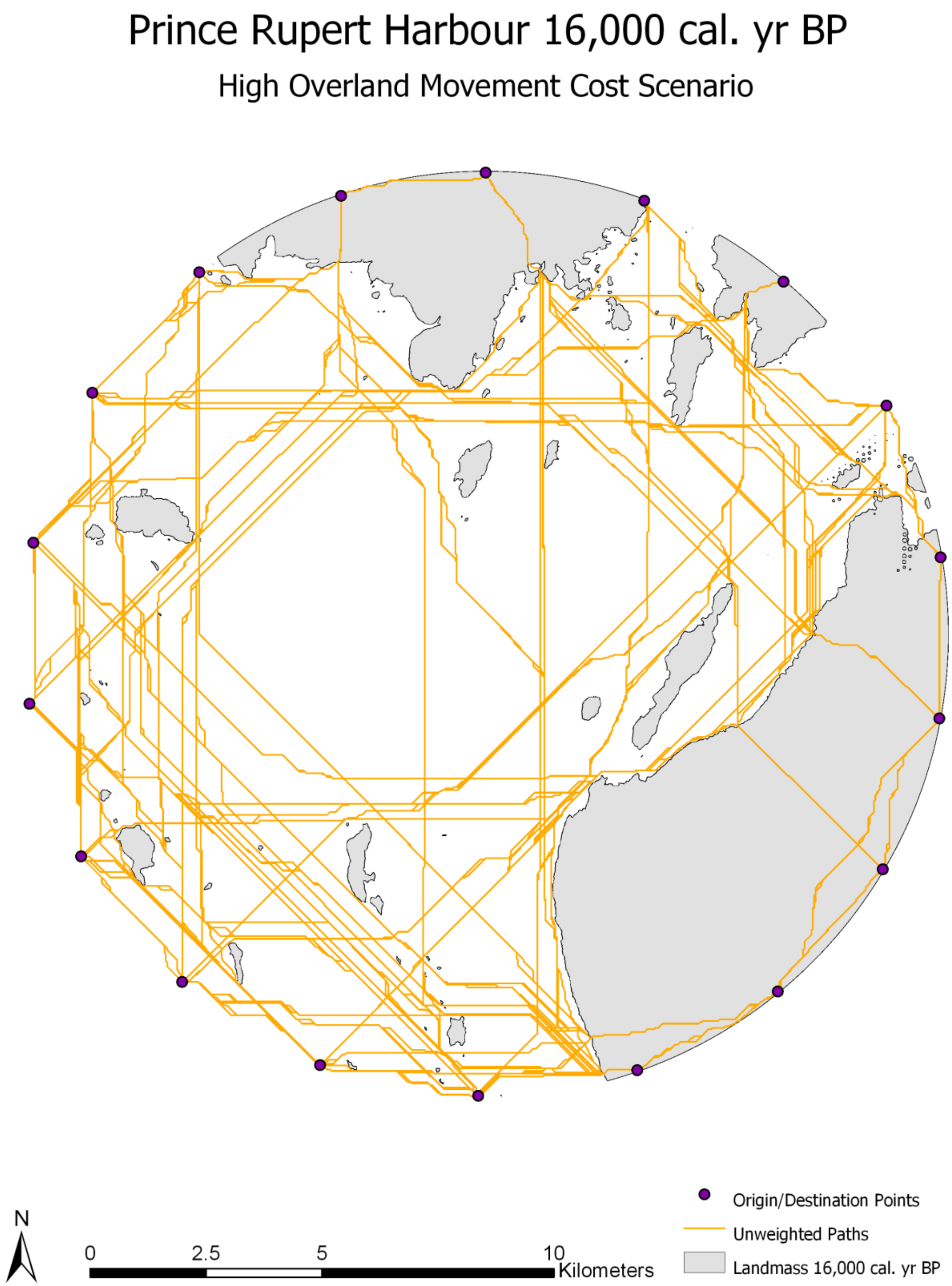
High Overland Movement Cost Scenario

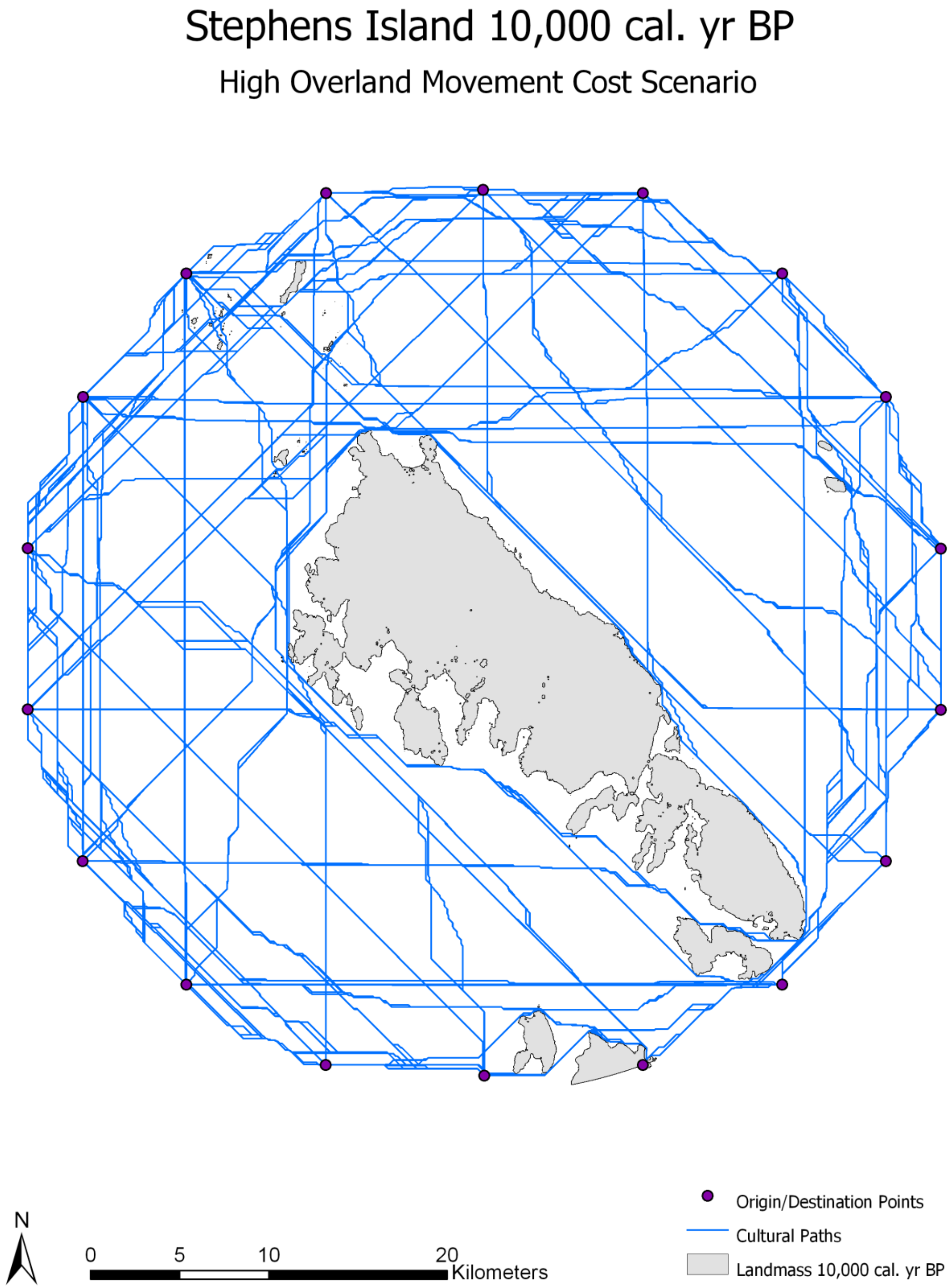


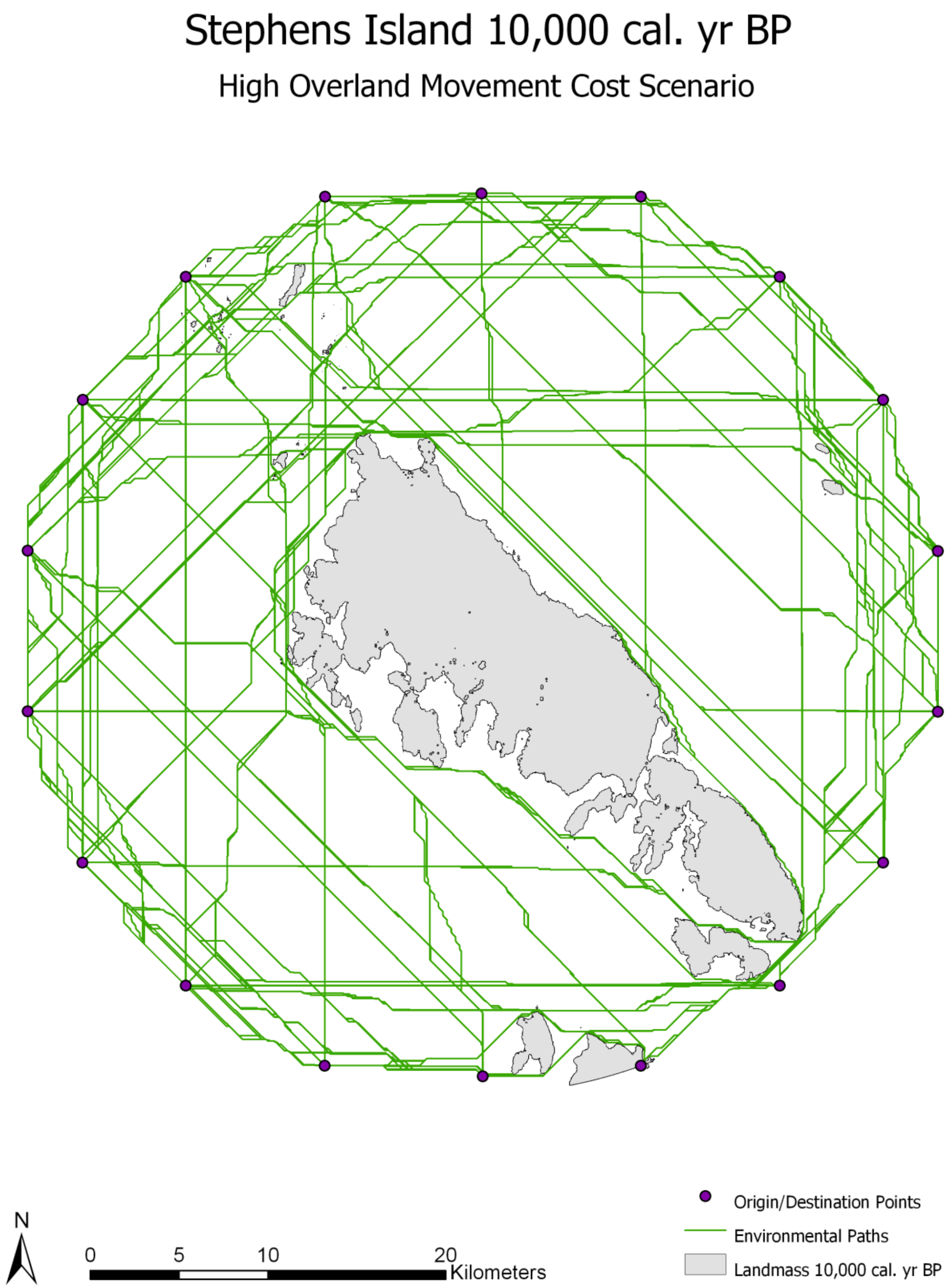
Prince Rupert Harbour 16,000 cal. yr BP

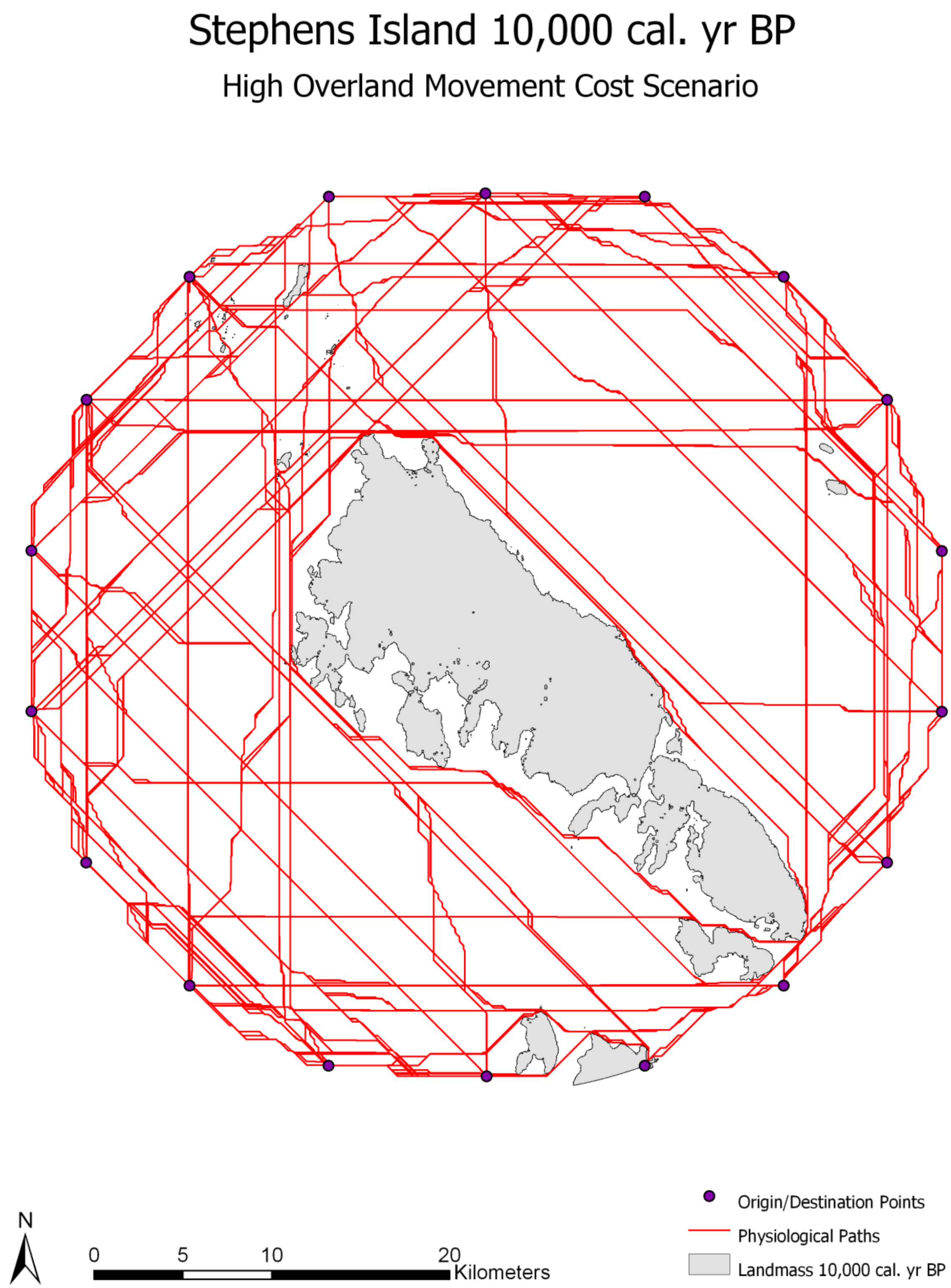
High Overland Movement Cost Scenario

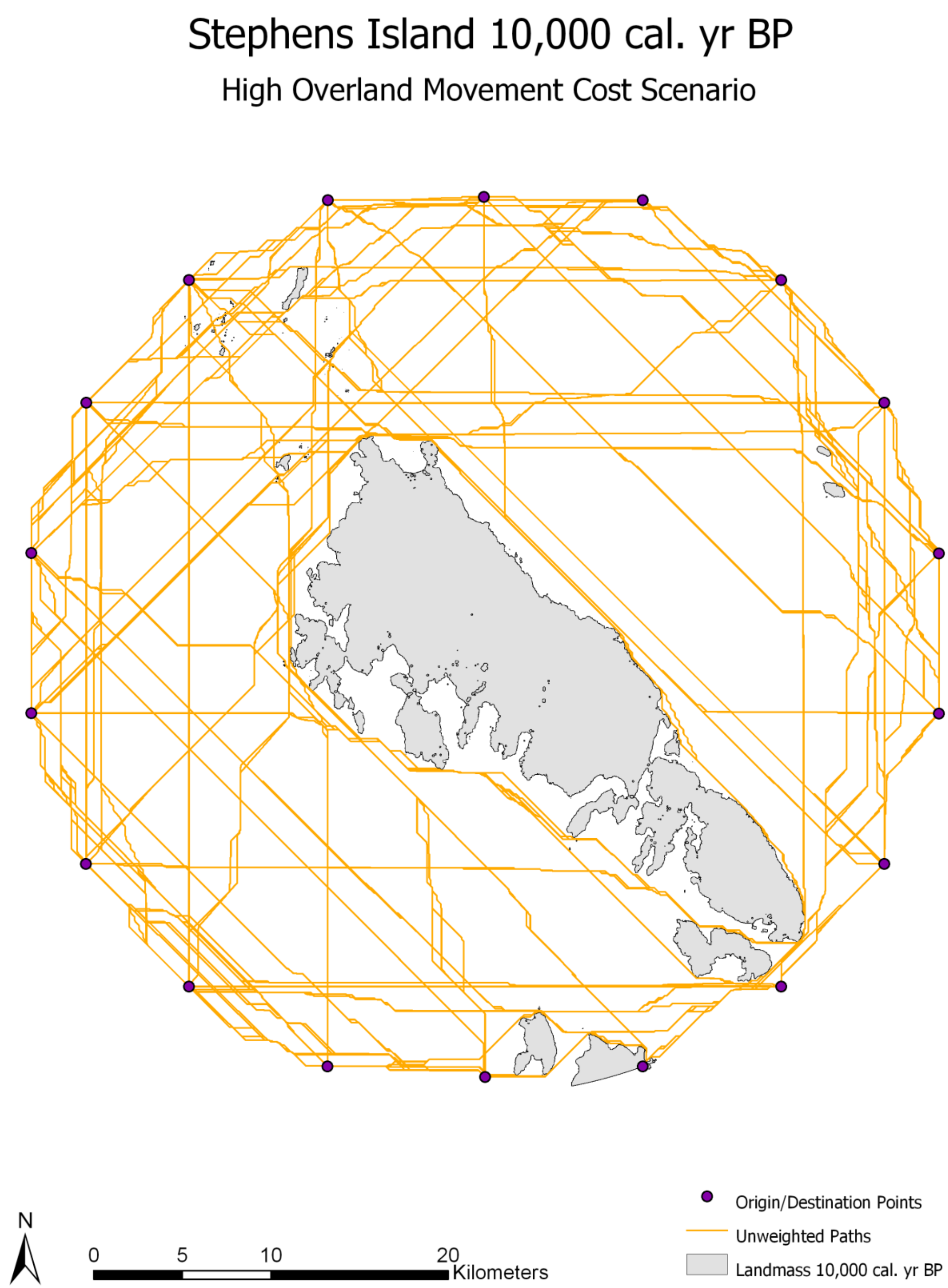



Prince Rupert Harbour 16,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Unweighted Paths
Landmass 16,000 cal. yr BP
N
0
2.5
5
10
Kilometers


Stephens Island 10,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Cultural Paths
Landmass 10,000 cal. yr BP

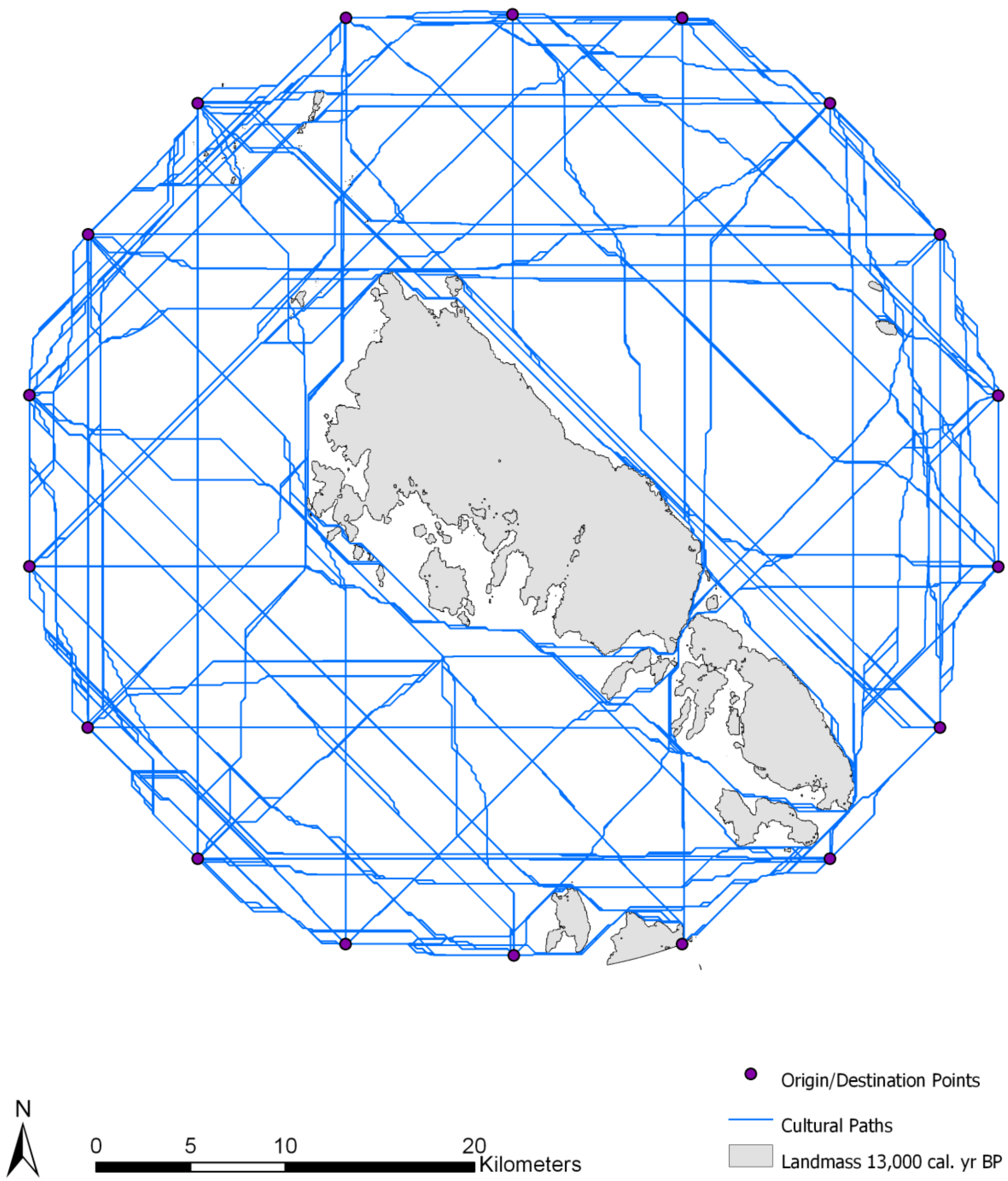

Stephens Island 10,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Environmental Paths
Landmass 10,000 cal. yr BP


Stephens Island 10,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Physiological Paths
Landmass 10,000 cal. yr BP


Stephens Island 10,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Unweighted Paths
Landmass 10,000 cal. yr BP

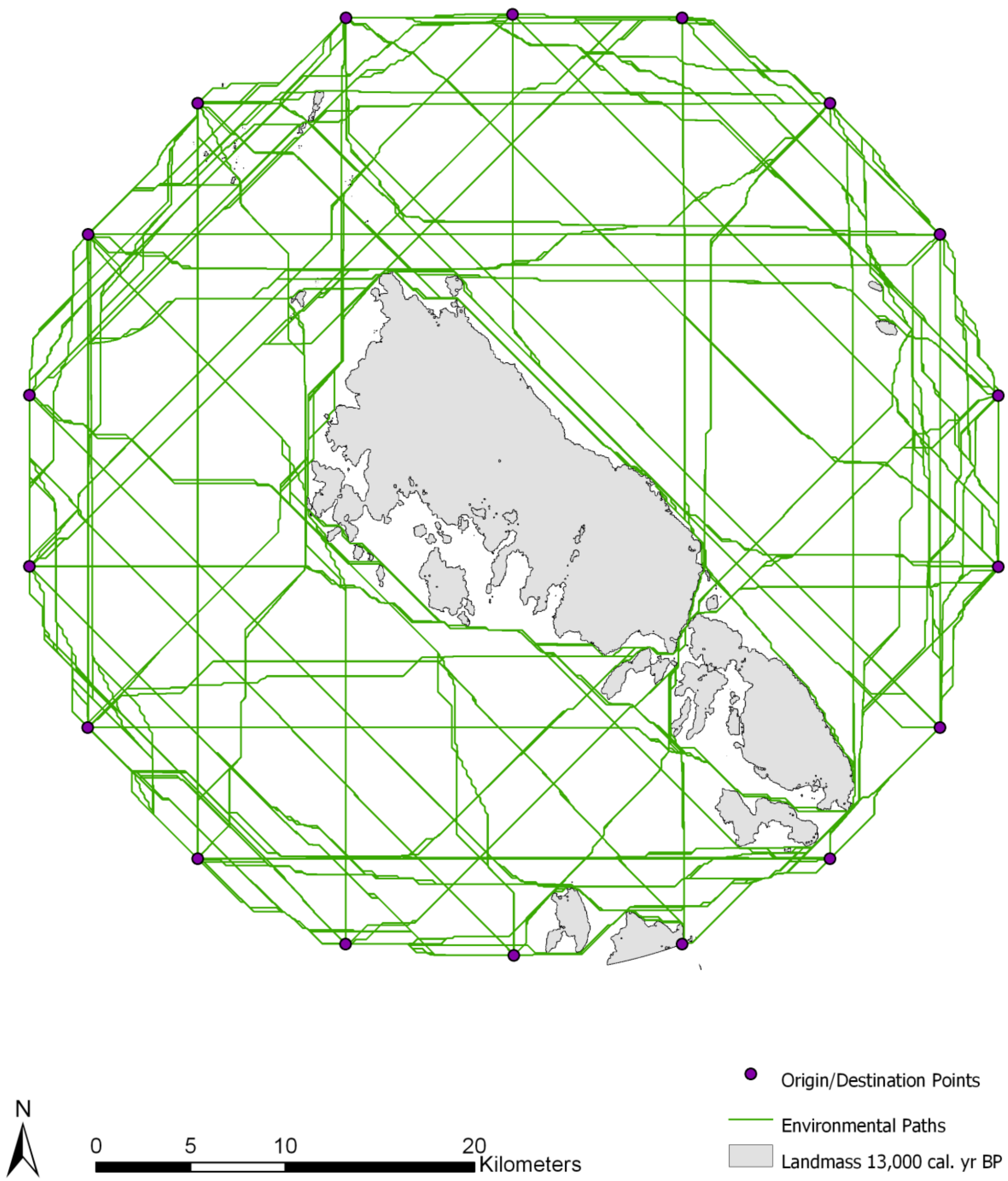
Stephens Island 13,000 cal. yr BP

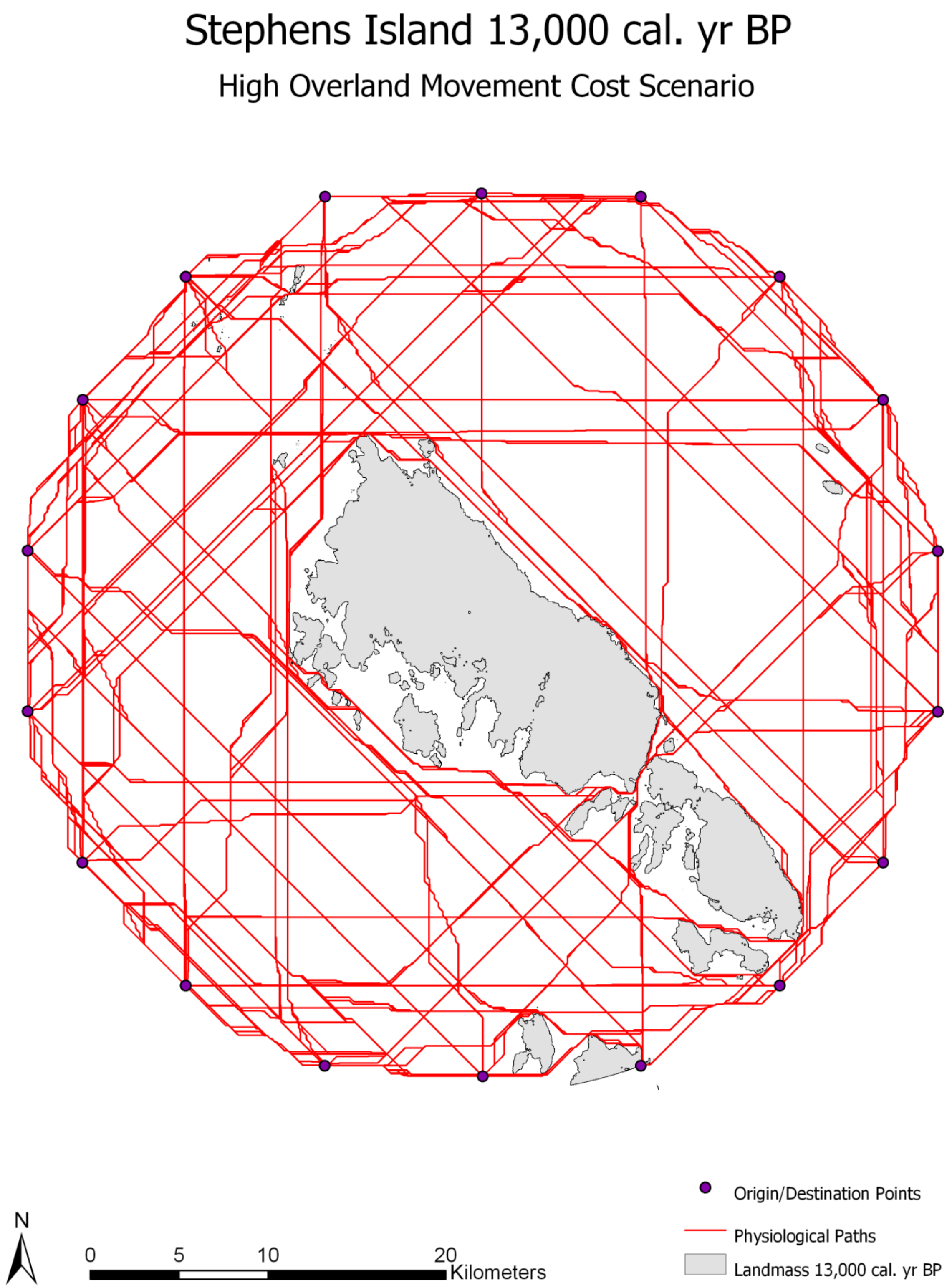
High Overland Movement Cost Scenario



Stephens Island 13,000 cal. yr BP

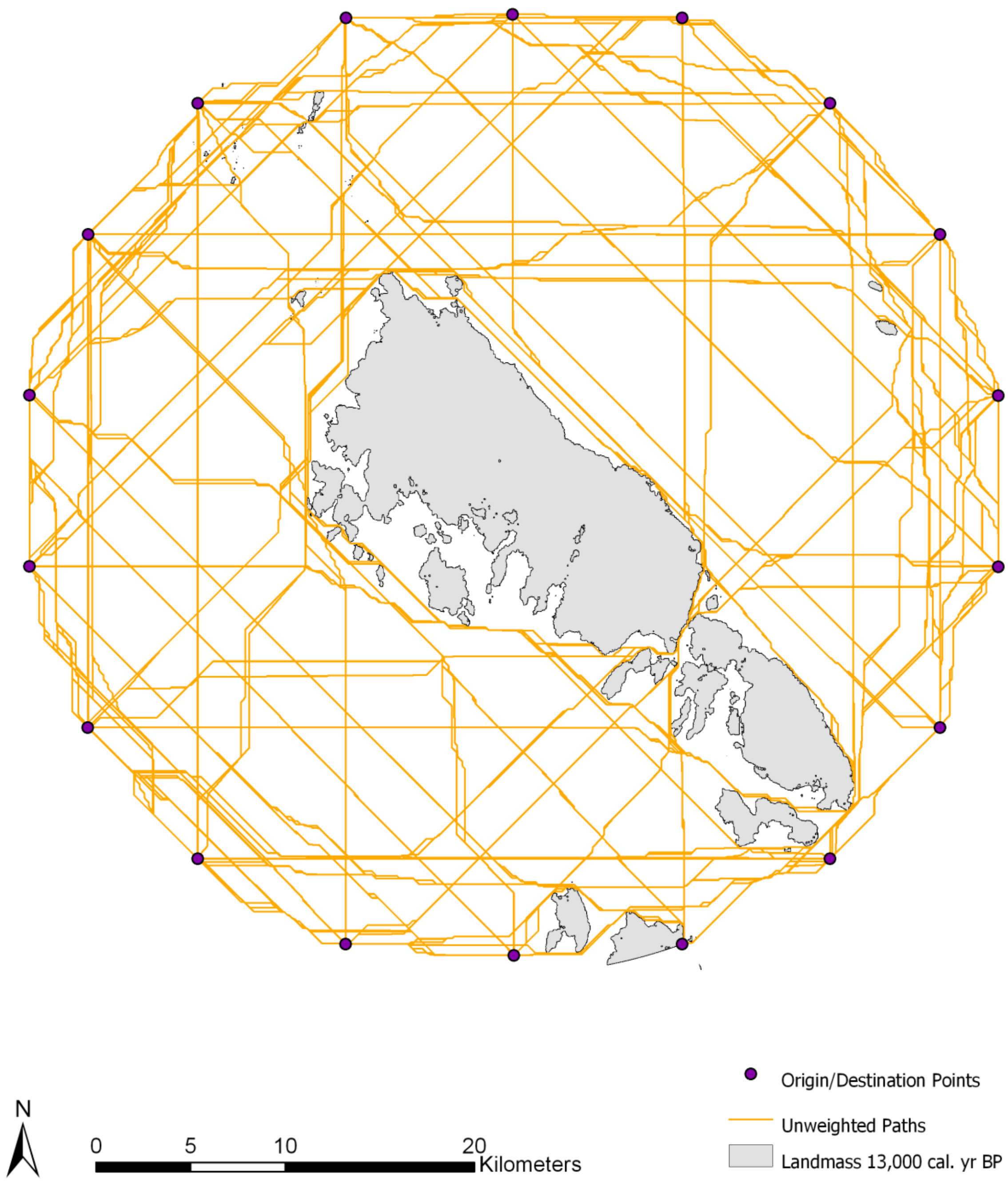
High Overland Movement Cost Scenario

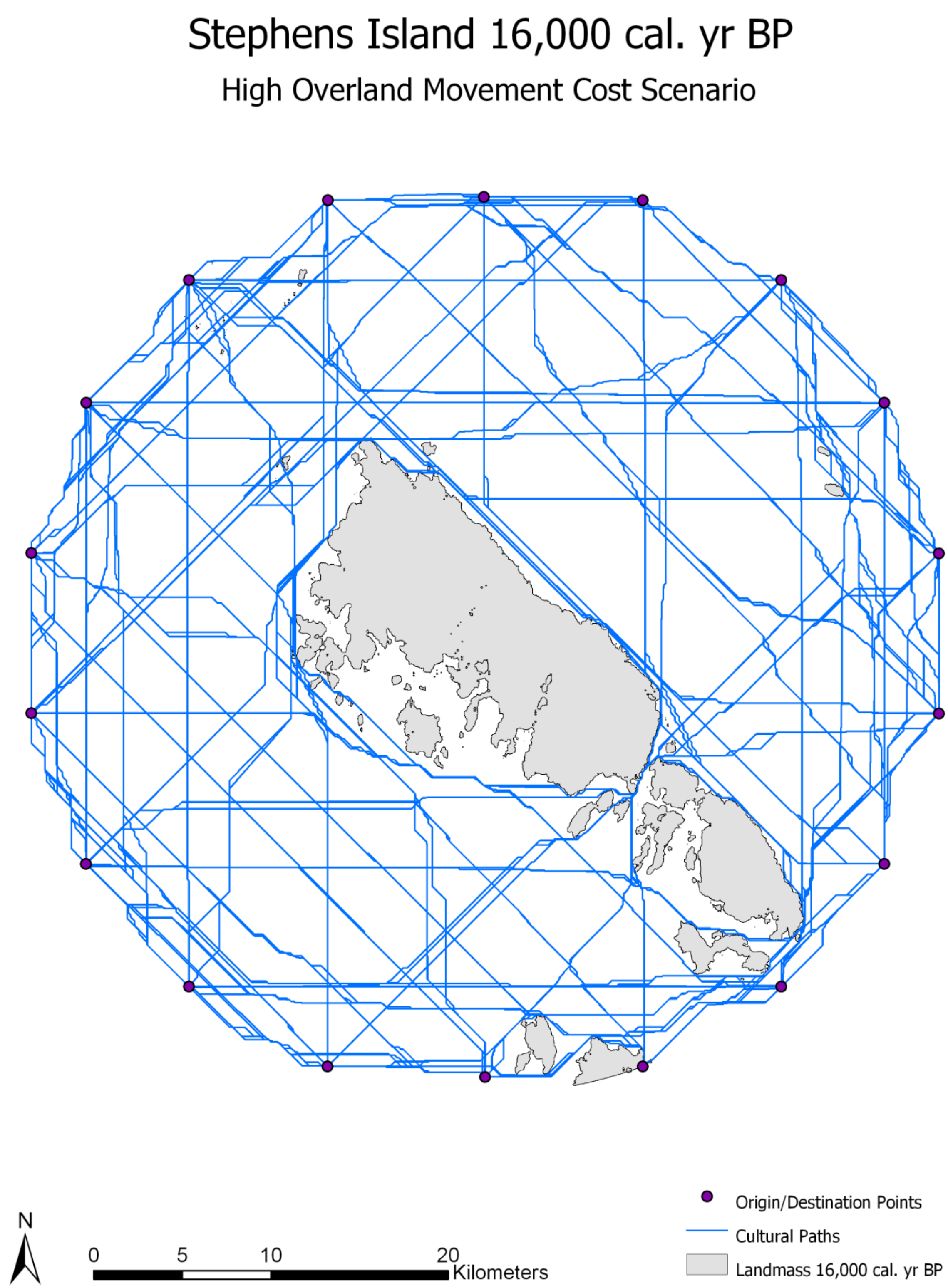


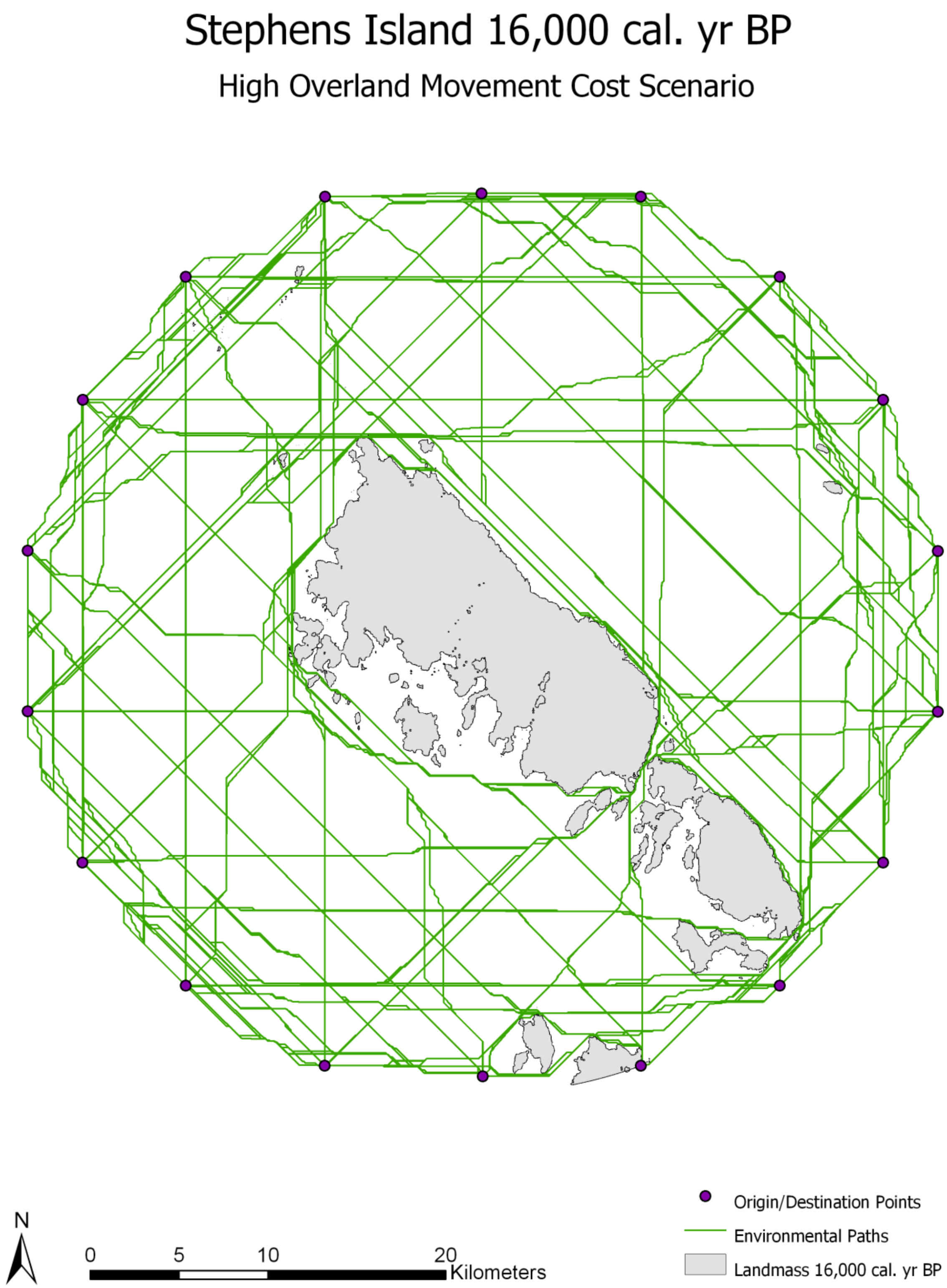

Stephens Island 13,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Physiological Paths
Landmass 13,000 cal. yr BP

Stephens Island 13,000 cal. yr BP

High Overland Movement Cost Scenario

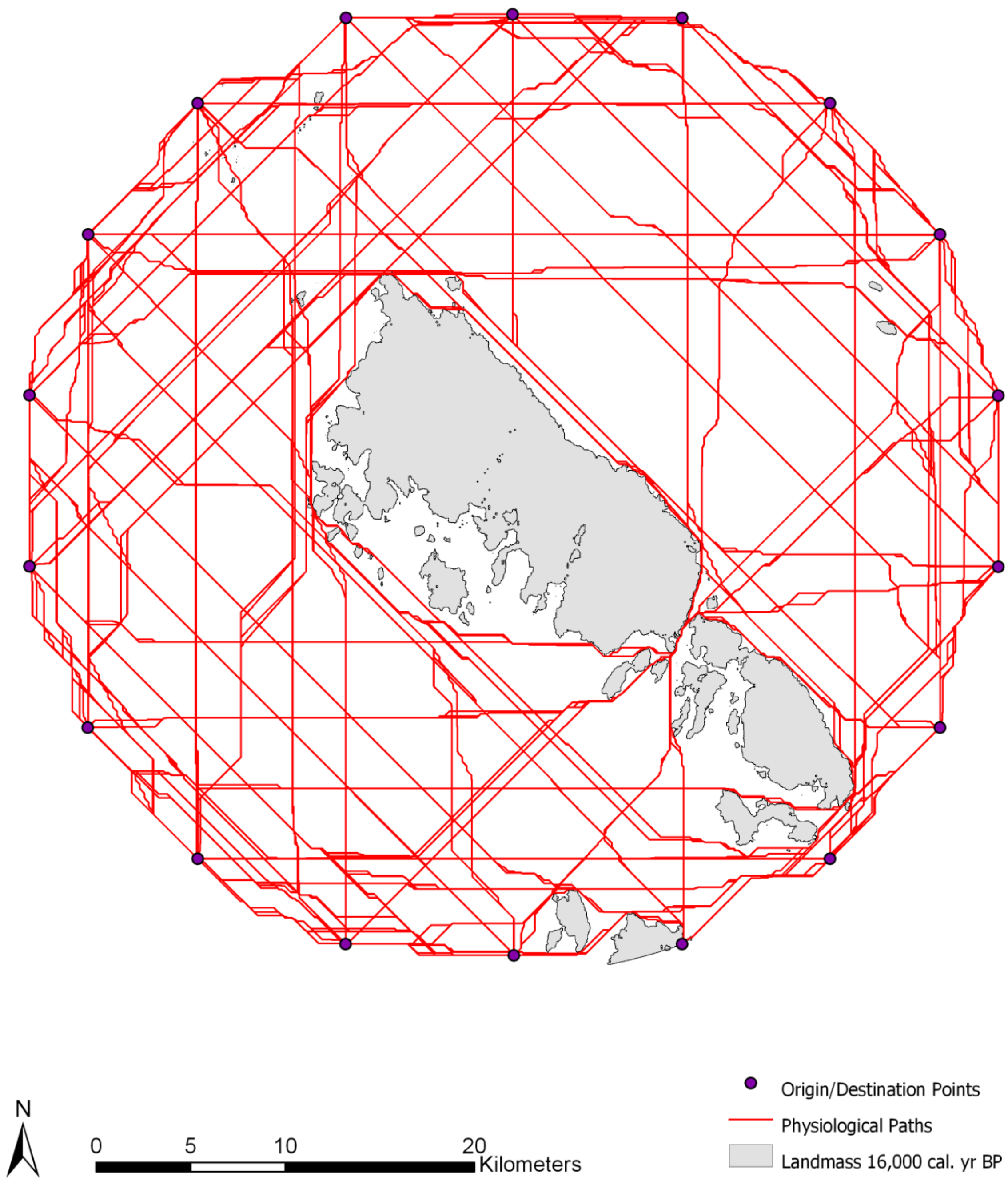


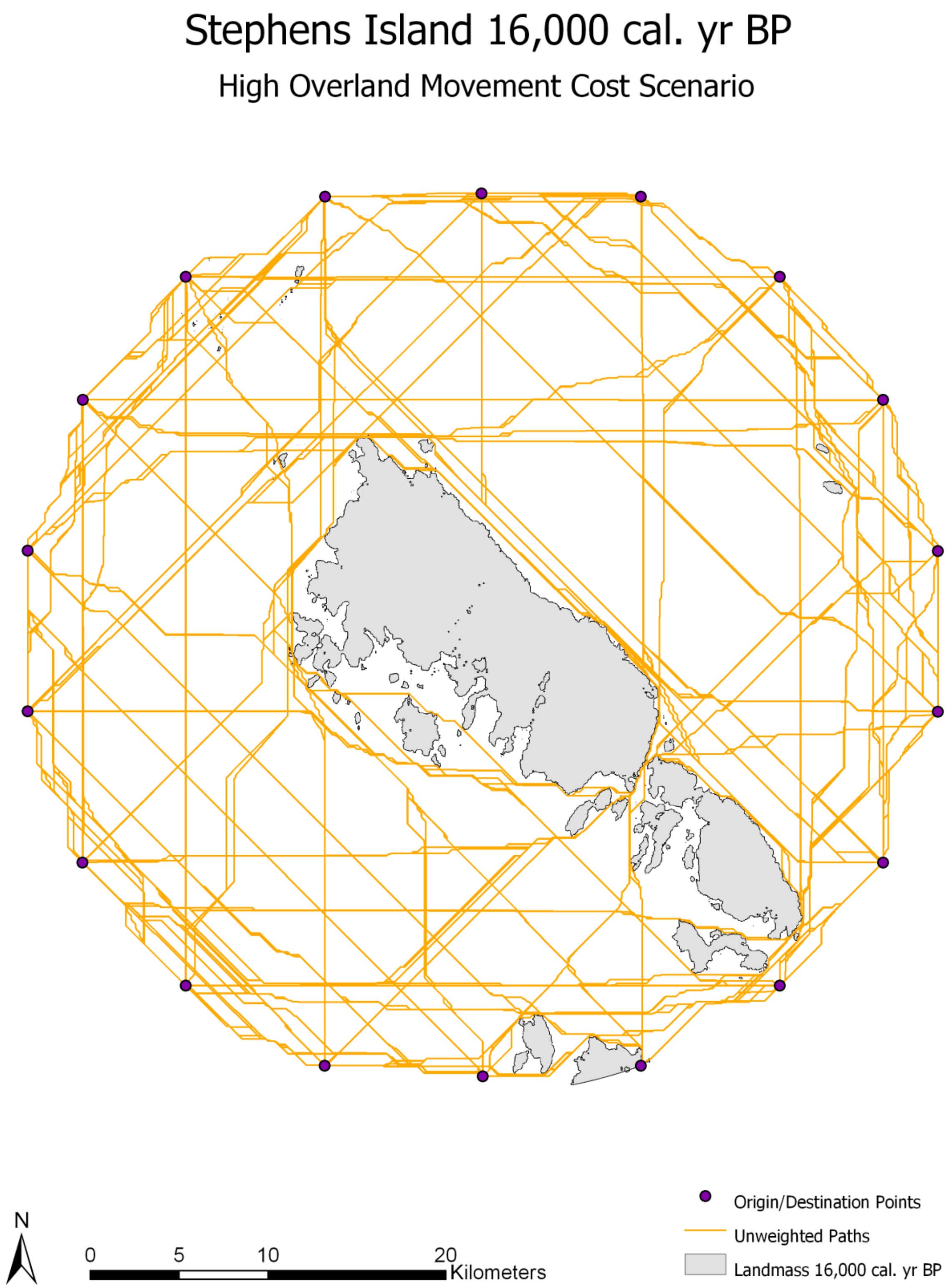

Stephens Island 16,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Cultural Paths
Landmass 16,000 cal. yr BP


Stephens Island 16,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Environmental Paths
Landmass 16,000 cal. yr BP

Stephens Island 16,000 cal. yr BP

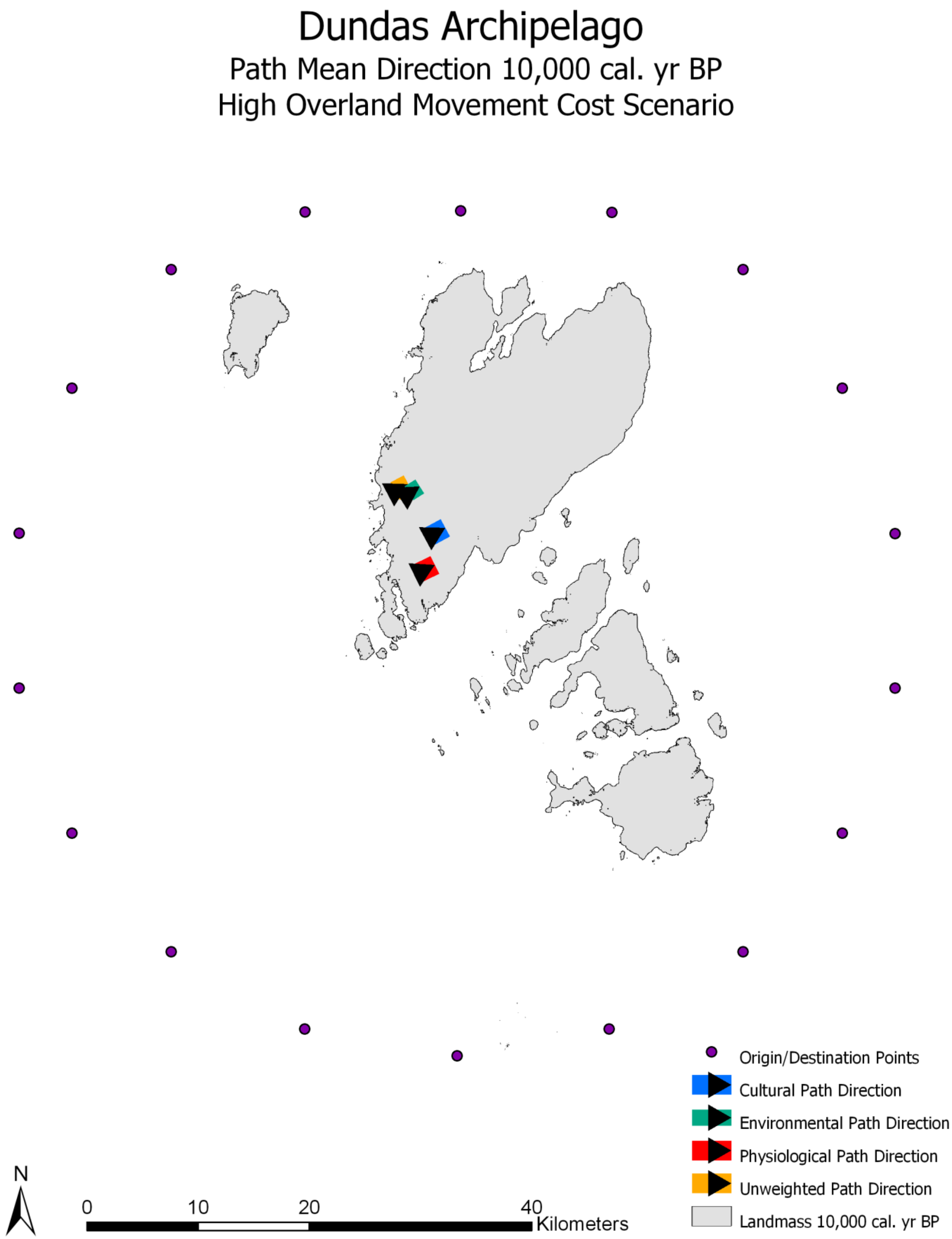
High Overland Movement Cost Scenario

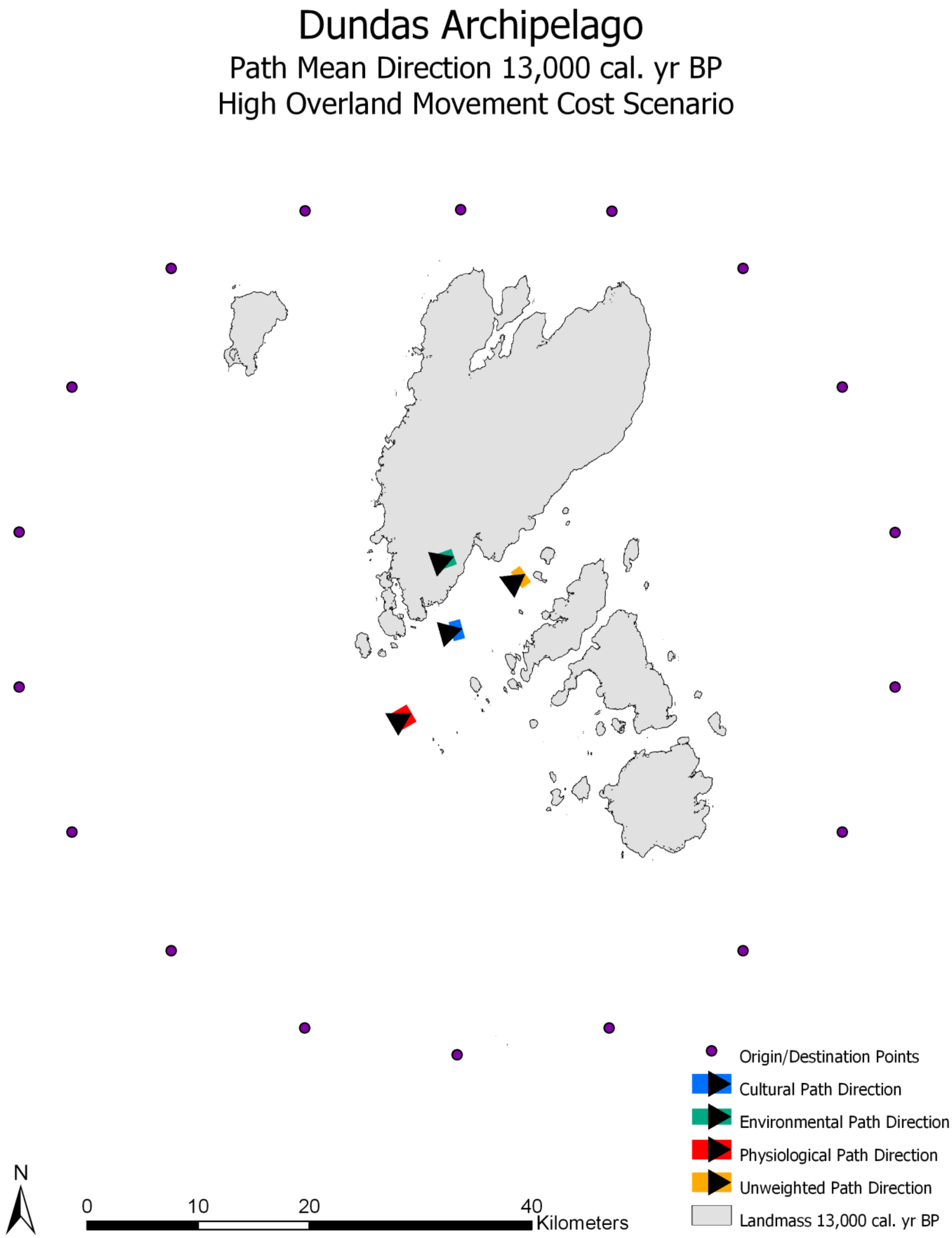


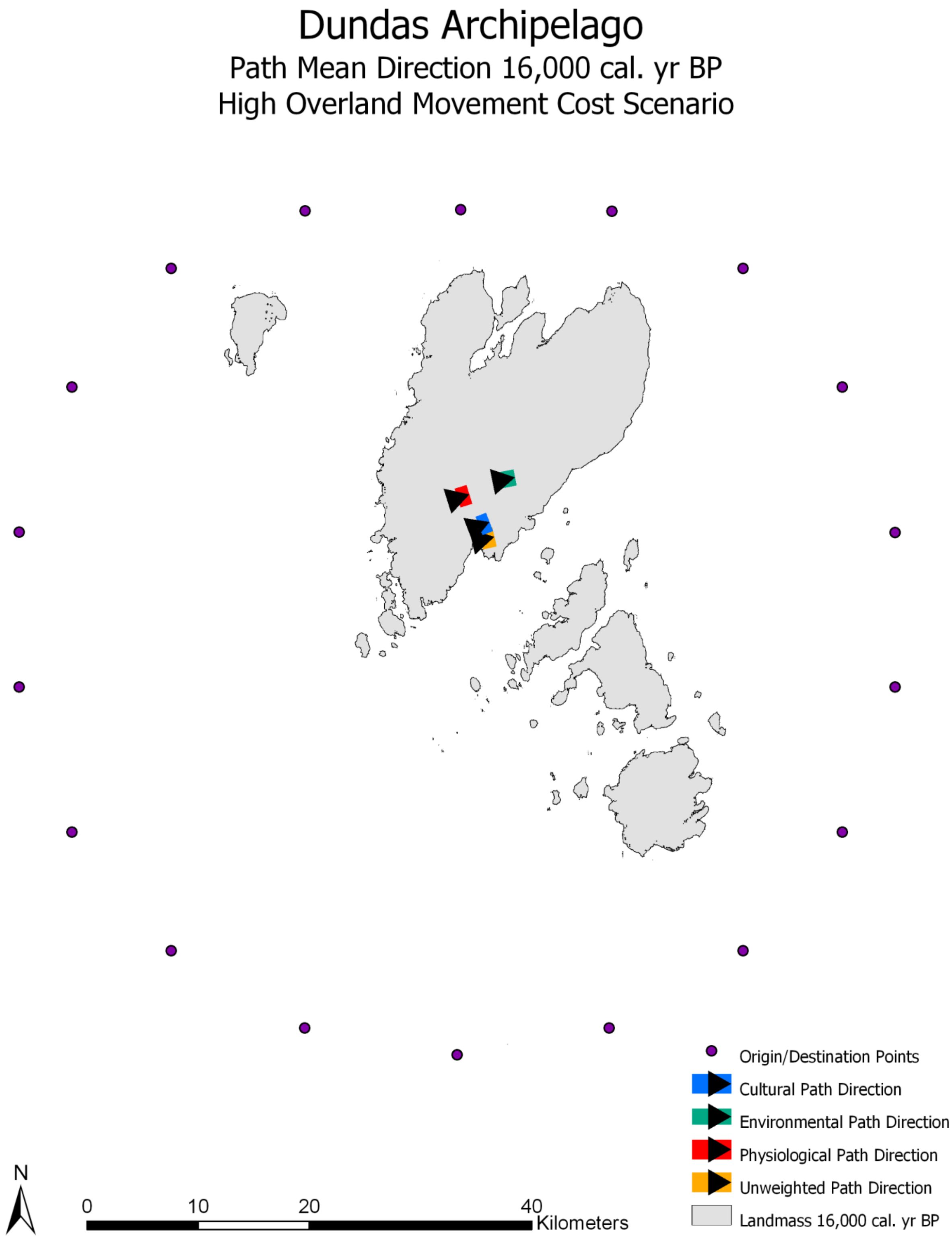


Stephens Island 16,000 cal. yr BP
High Overland Movement Cost Scenario
N
0
5
10
20
Kilometers
Origin/Destination Points
Unweighted Paths
Landmass 16,000 cal. yr BP

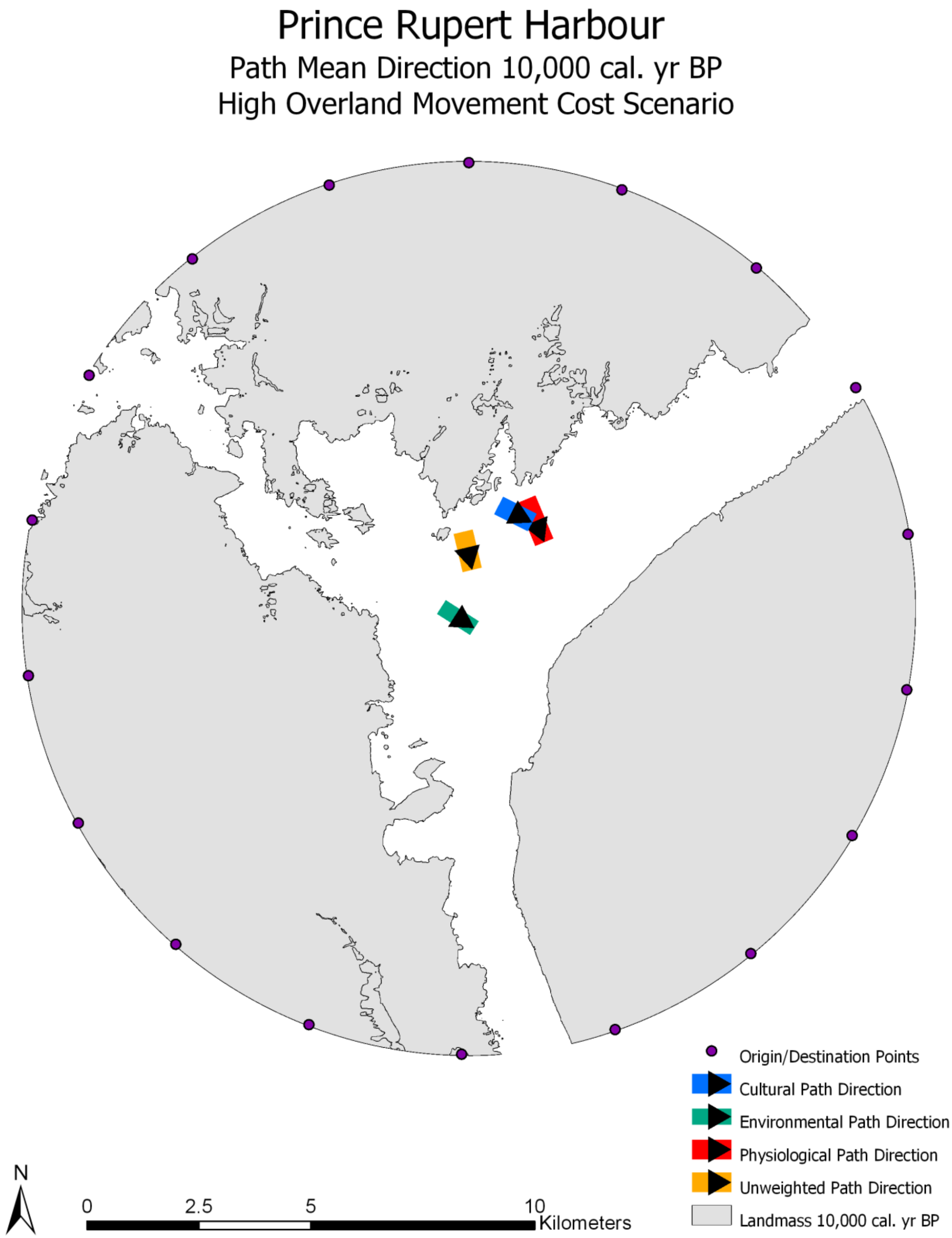
Appendix F: Mean Path Direction -- High Overland Movement Cost Scenario



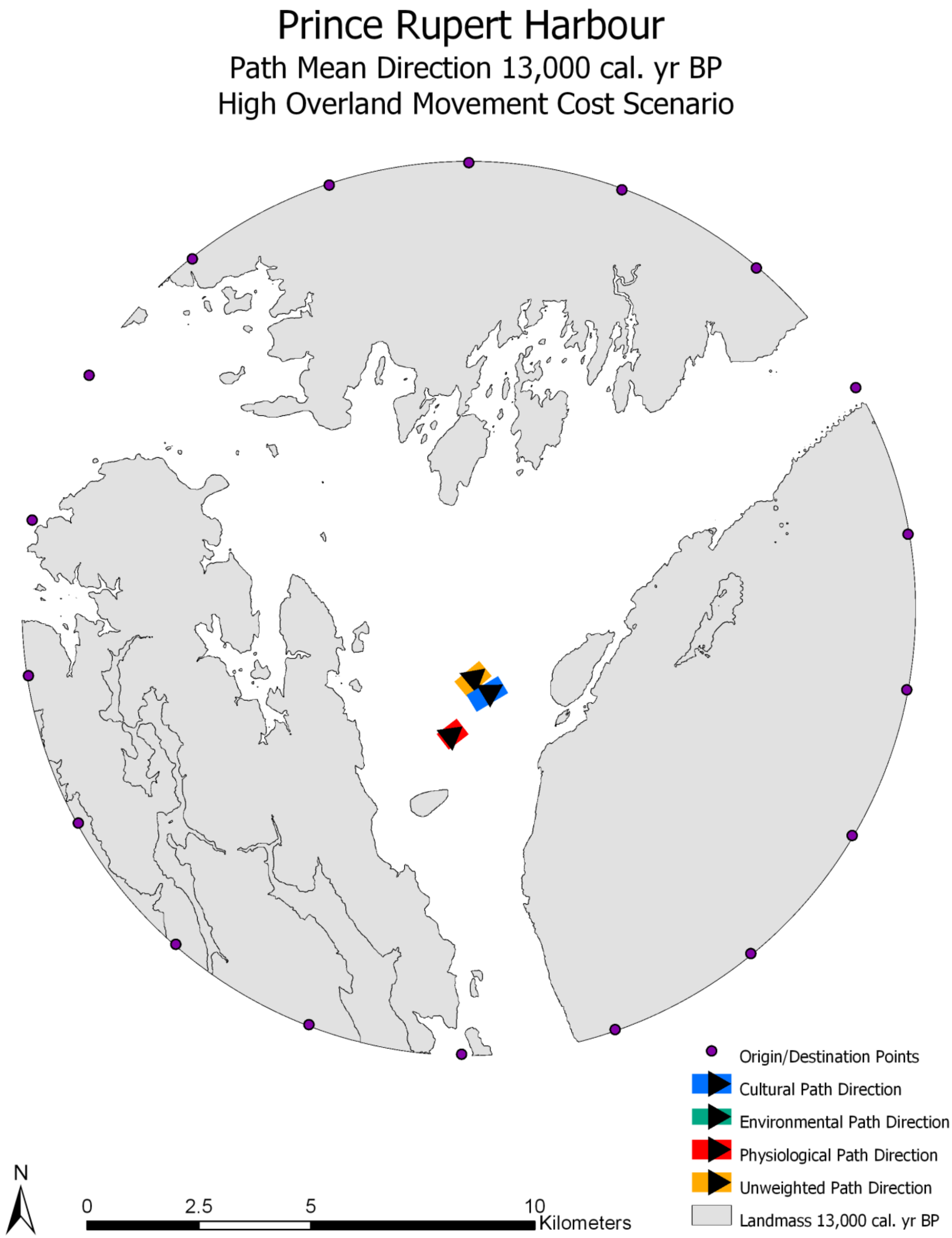

Dundas Archipelago
Path Mean Direction 13,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 13,000 cal. yr BP
N
0
10
20
40
Kilometers



Dundas Archipelago
Path Mean Direction 16,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 16,000 cal. yr BP
N
0
10
20
40
Kilometers

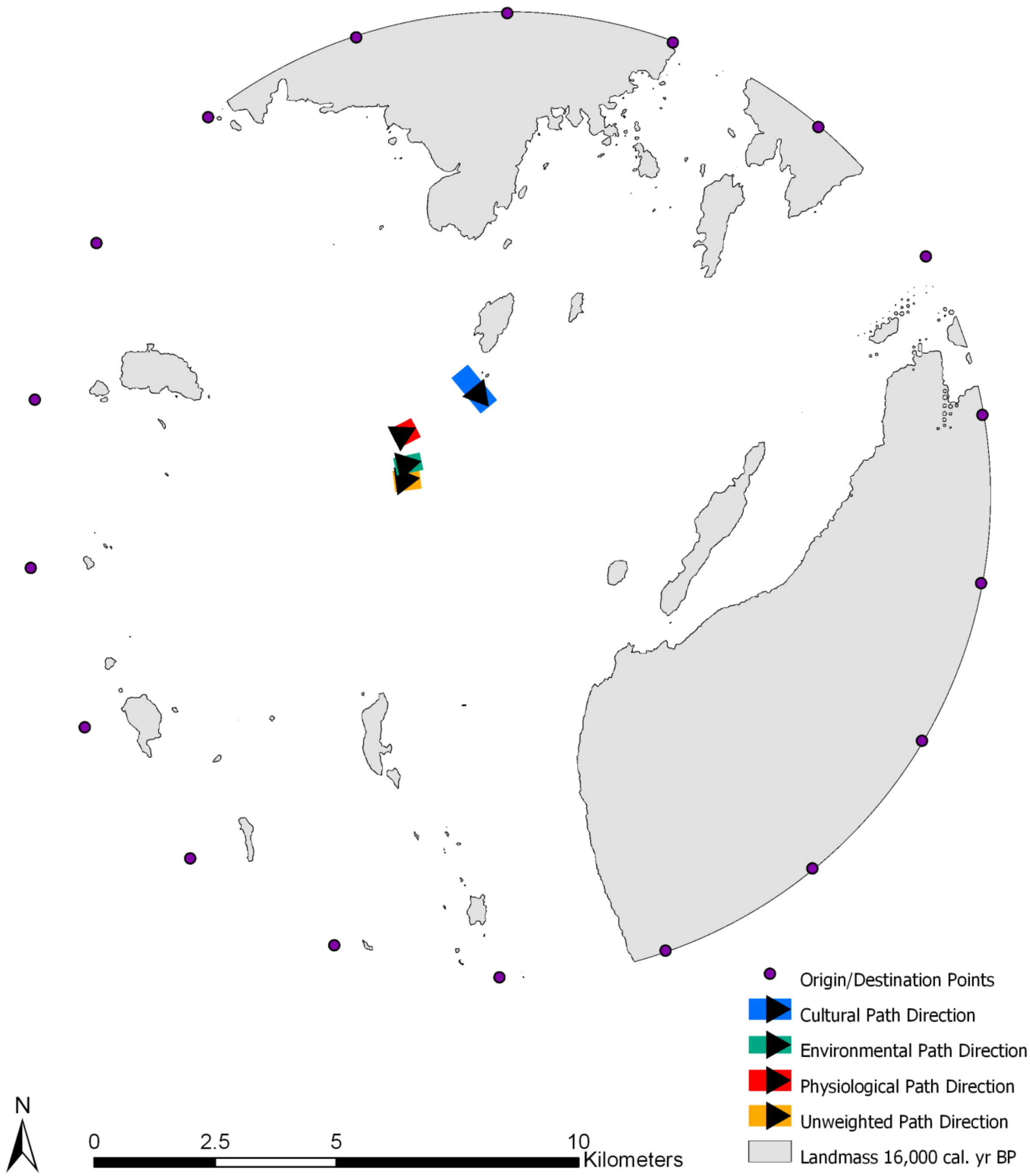


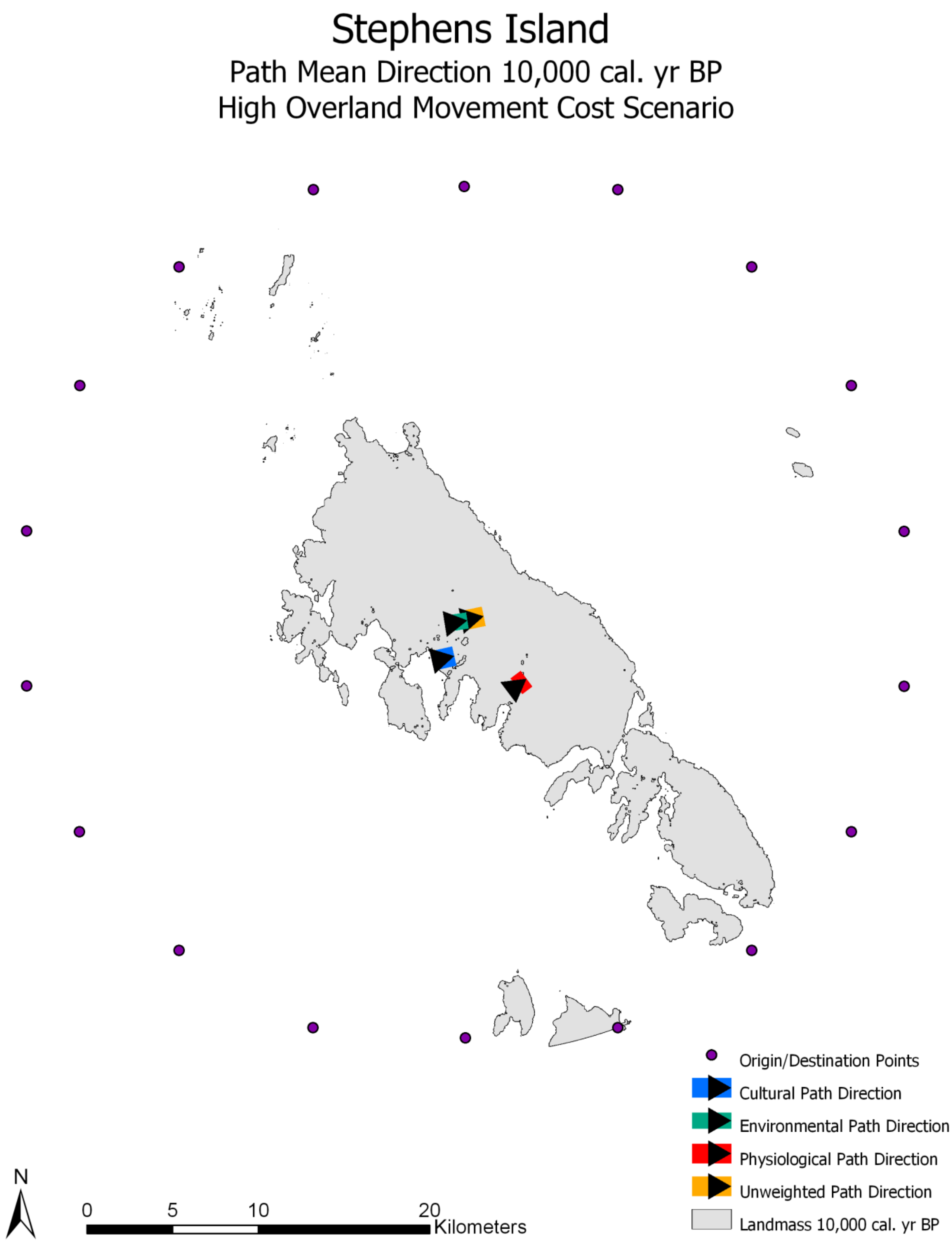
Prince Rupert Harbour
Path Mean Direction 10,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 10,000 cal. yr BP
N
0
2.5
5
10
Kilometers


Prince Rupert Harbour
Path Mean Direction 13,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 13,000 cal. yr BP
N
0
2.5
5
10
Kilometers

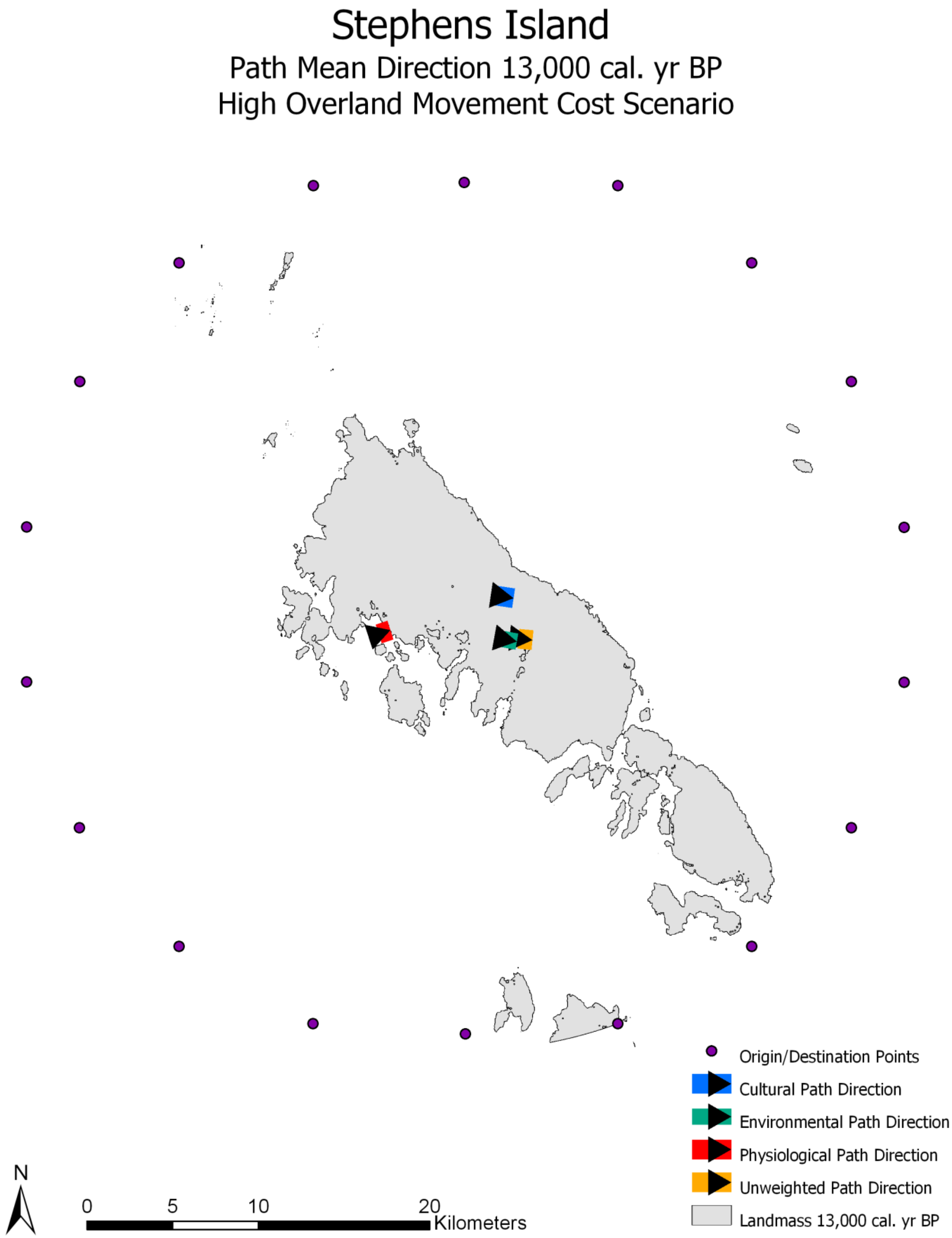
Prince Rupert Harbour

Path Mean Direction 16,000 cal. yr BP
High Overland Movement Cost Scenario





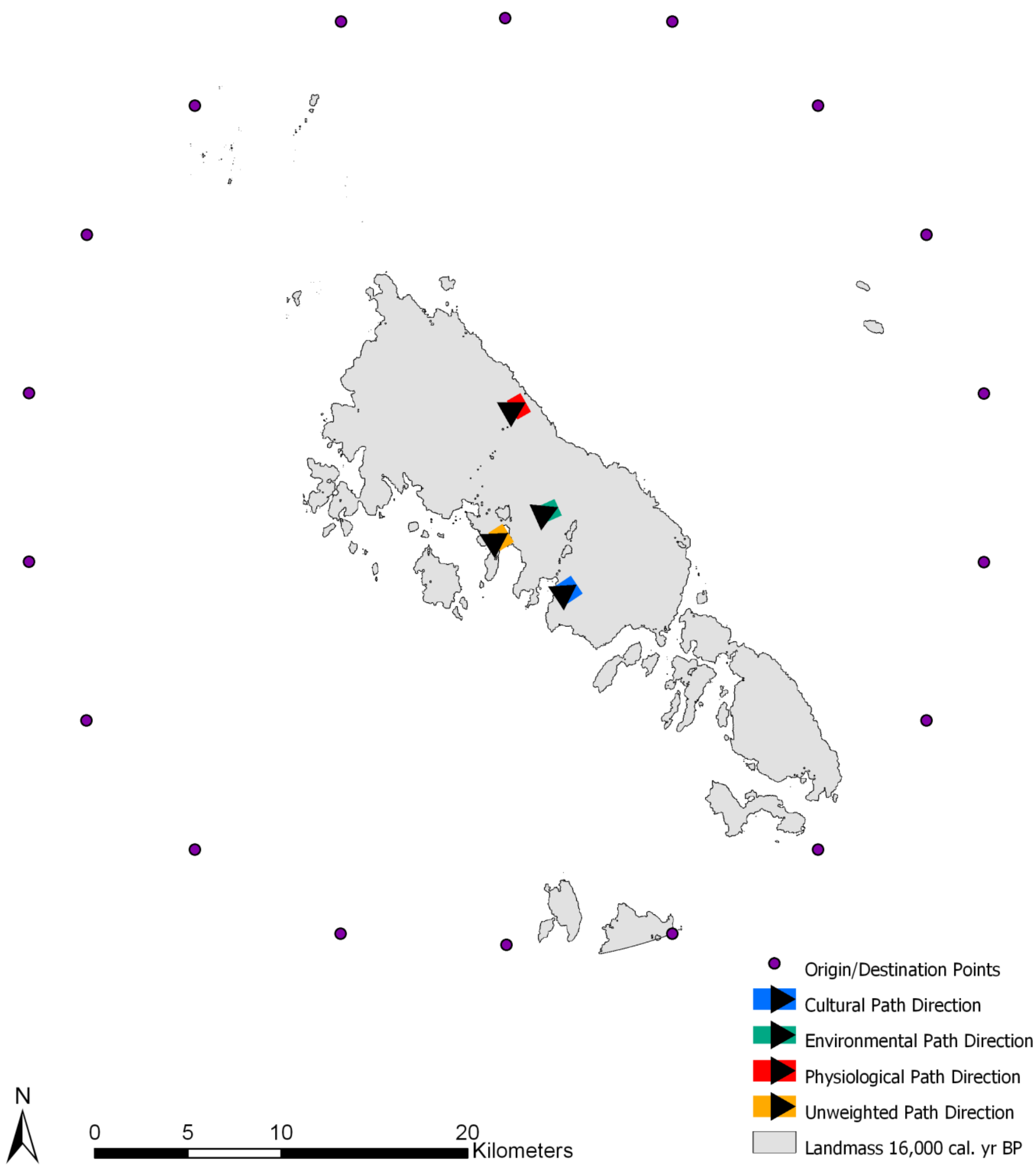
Stephens Island
Path Mean Direction 10,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 10,000 cal. yr BP
N
0
5
10
20
Kilometers



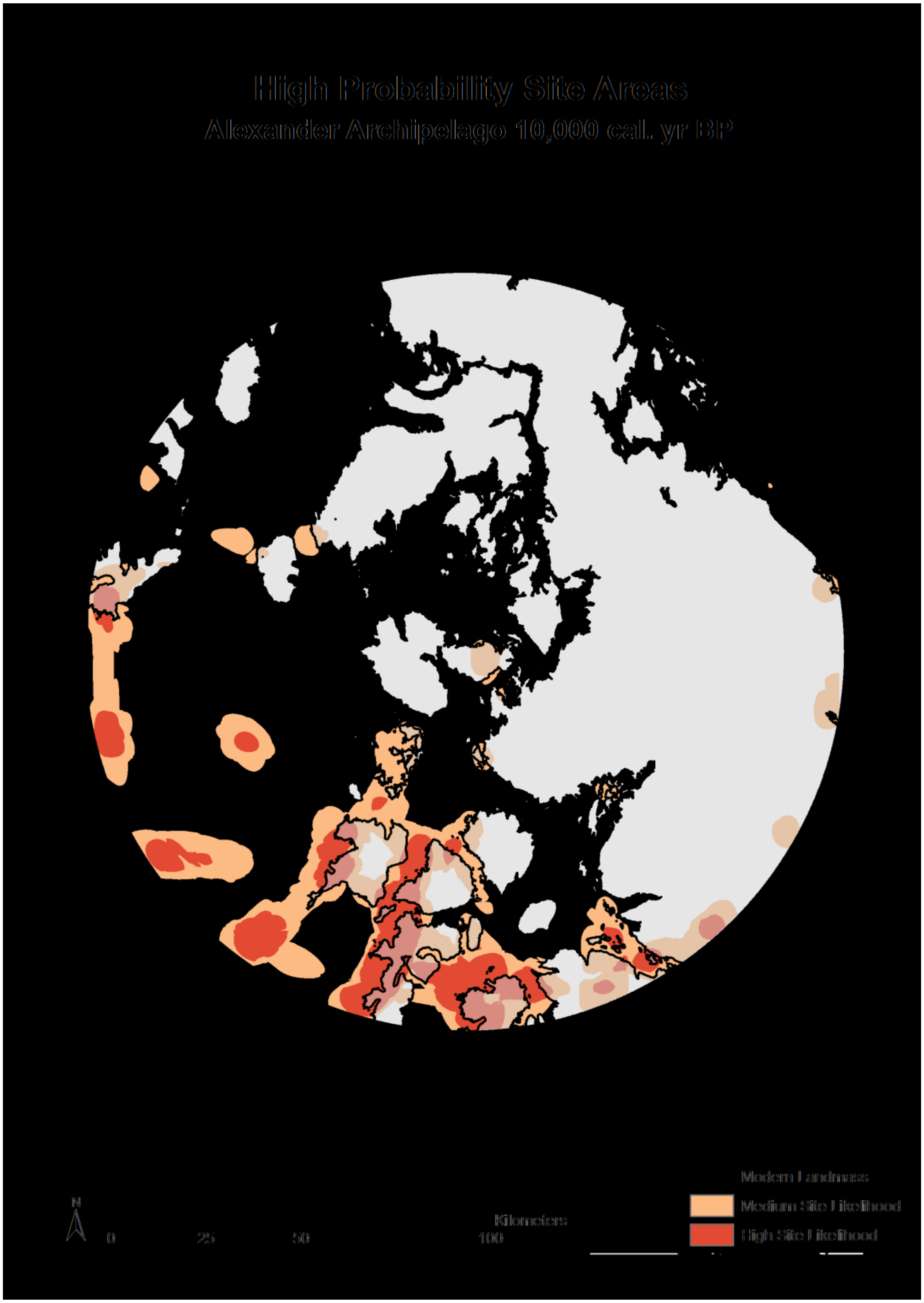
Stephens Island
Path Mean Direction 13,000 cal. yr BP
High Overland Movement Cost Scenario
Origin/Destination Points
Cultural Path Direction
Environmental Path Direction
Physiological Path Direction
Unweighted Path Direction
Landmass 13,000 cal. yr BP
N
0
5
10
20
Kilometers

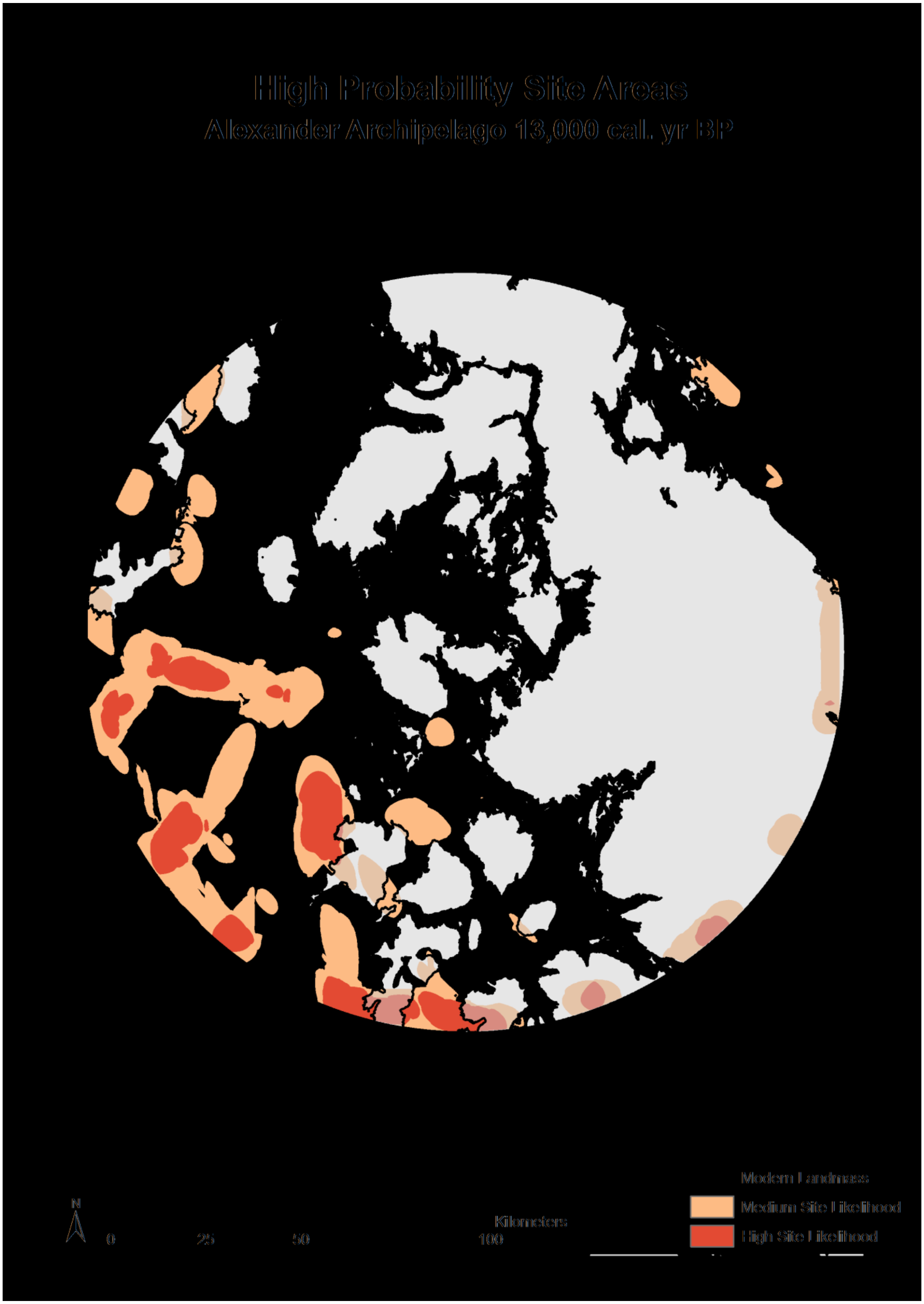
Stephens Island

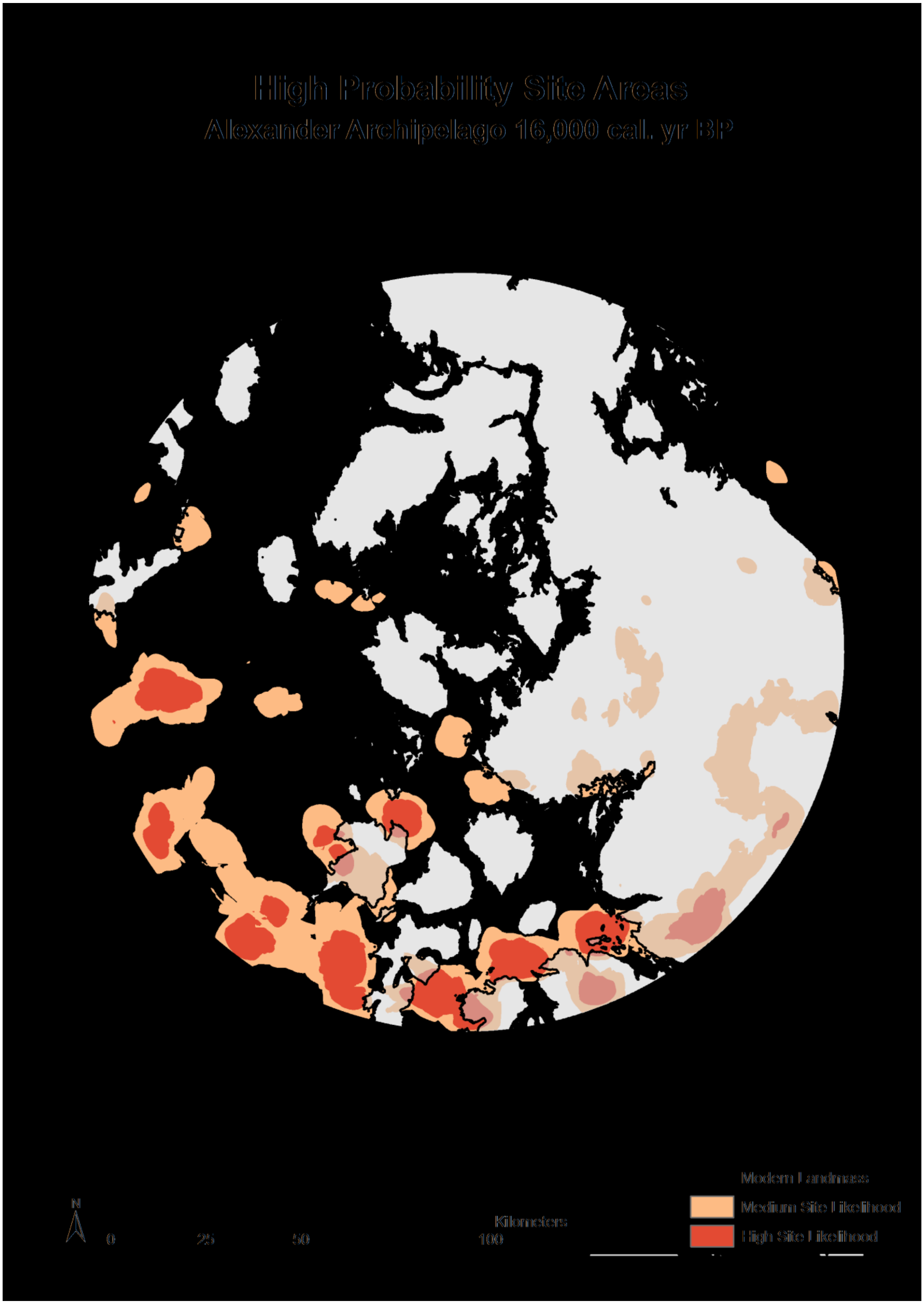
Path Mean Direction 16,000 cal. yr BP
High Overland Movement Cost Scenario



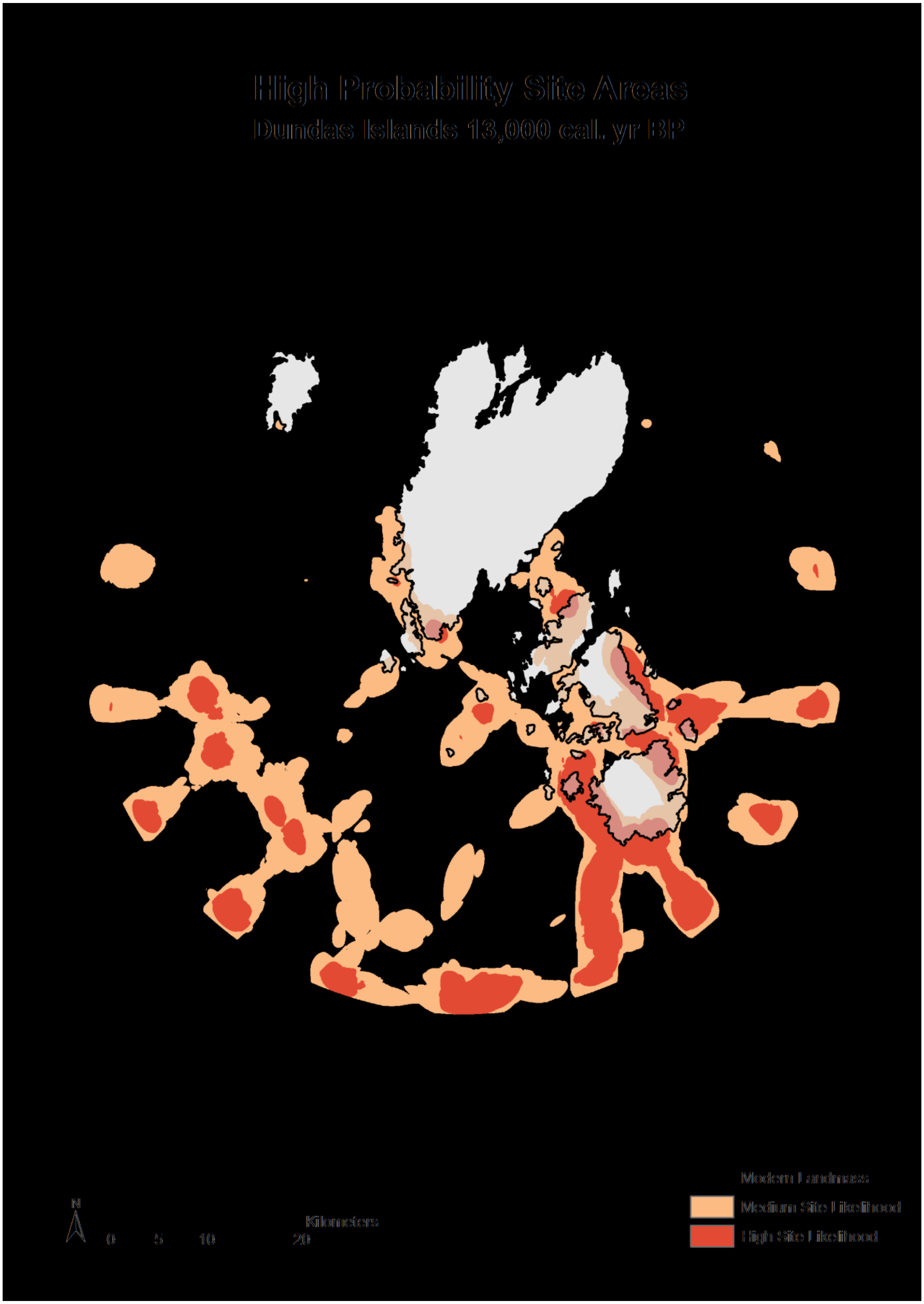
Appendix G: Line Density




High Probability Site Areas
Alexander Archipelago 13,000 cal. yr BP
N
0
25
50
100
Kilometers
Modern Landmass
Medium Site Likelihood
High Site Likelihood


High Probability Site Areas
Alexander Archipelago 16,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
Kilometers
0
25
50
100

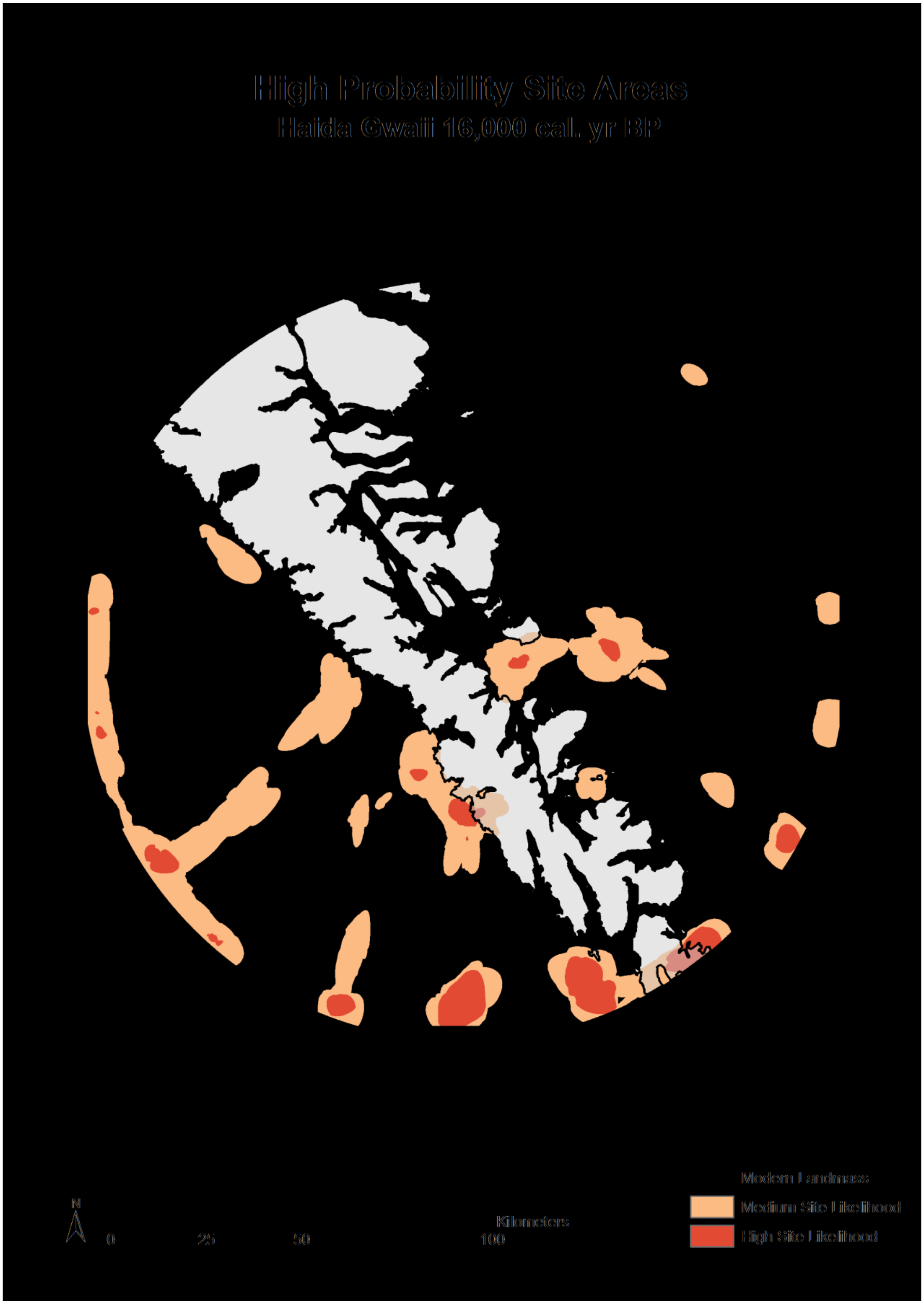

High Probability Site Areas
Dundas Islands 10,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
Kilometers
0 5 10 20

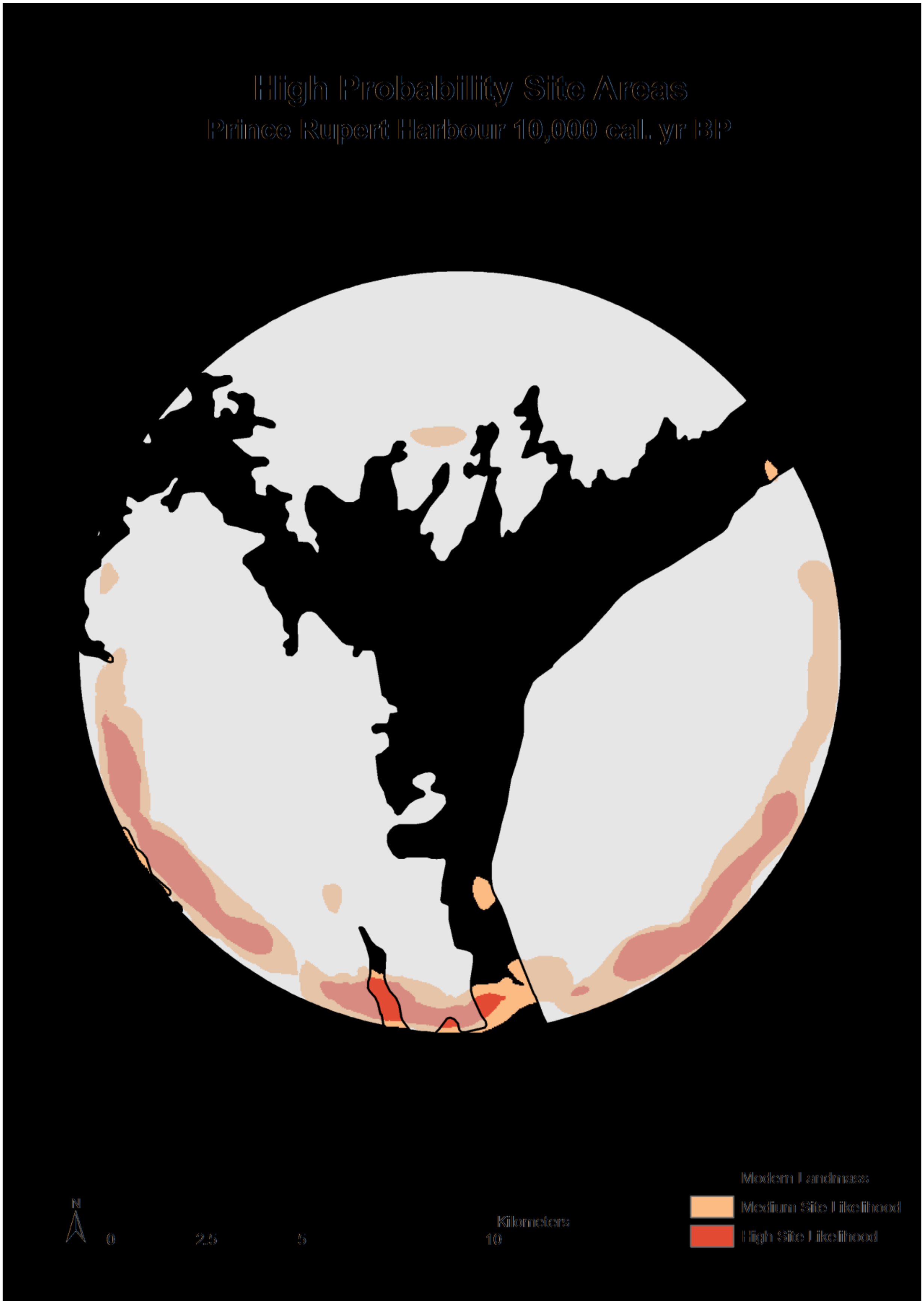

High Probability Site Areas
Dundas Islands 13,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
Kilometers
0 5 10 20

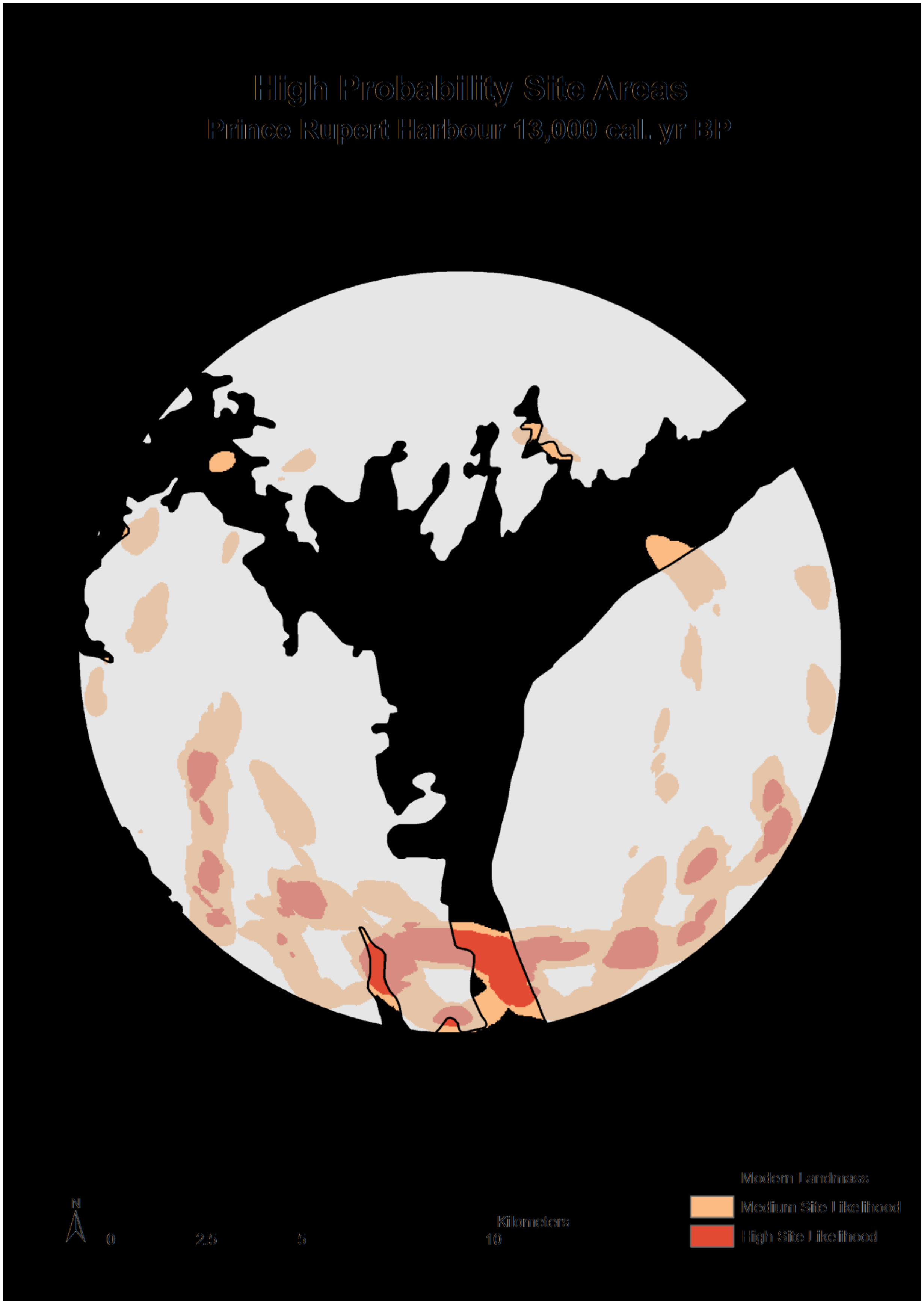
High Probability Site Areas
Dundas Islands 16,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0 5 10 20
Kilometers

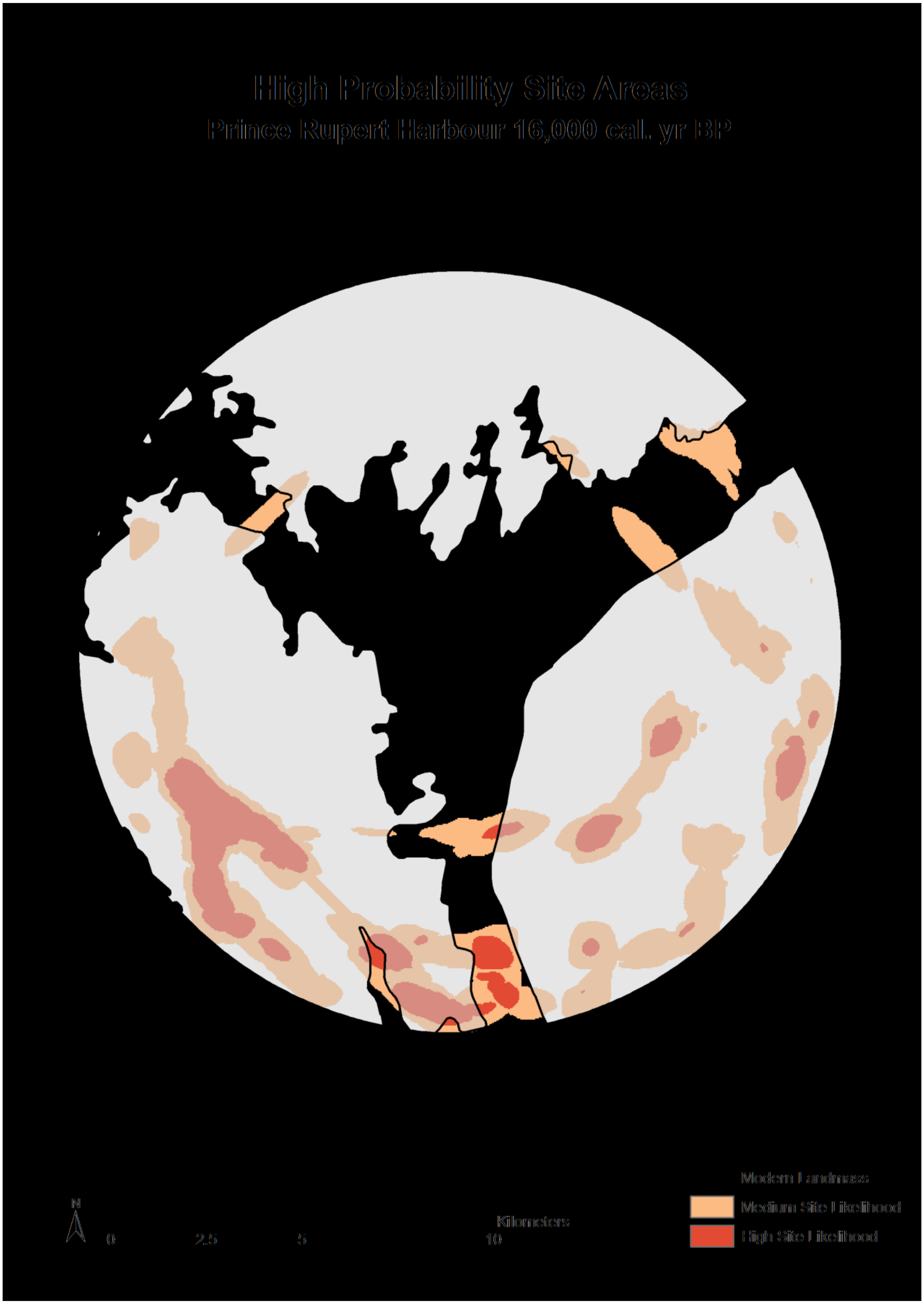

High Probability Site Areas
Haida Gwaii 10,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
25
50
100
Kilometers

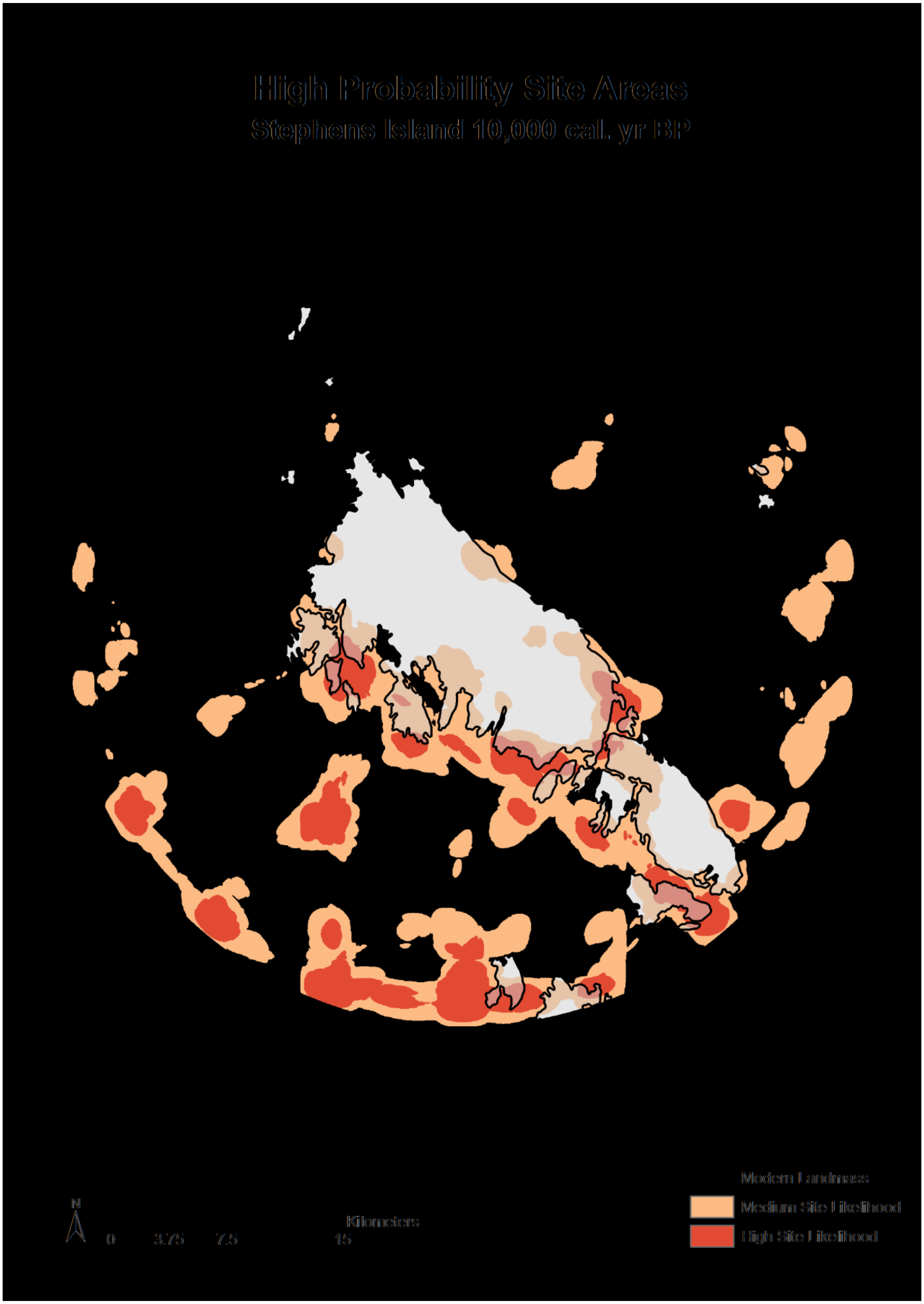
High Probability Site Areas
Haida Gwaii 13,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
25
50
100
Kilometers


High Probability Site Areas
Haida Gwaii 16,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
Kilometers
0
25
50
100

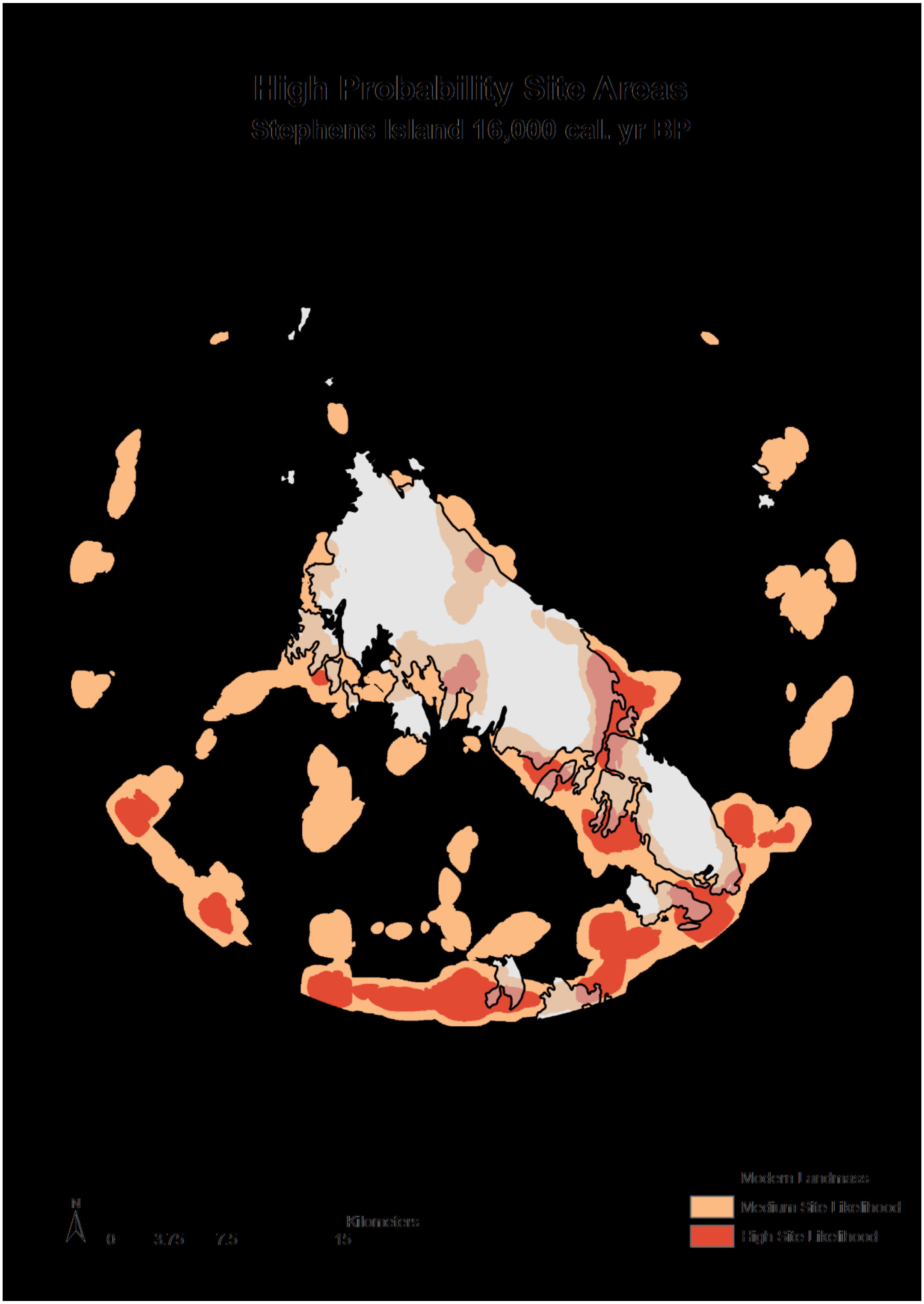

High Probability Site Areas
Prince Rupert Harbour 10,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
2.5
5
10
Kilometers


High Probability Site Areas
Prince Rupert Harbour 13,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
2.5
5
10
Kilometers

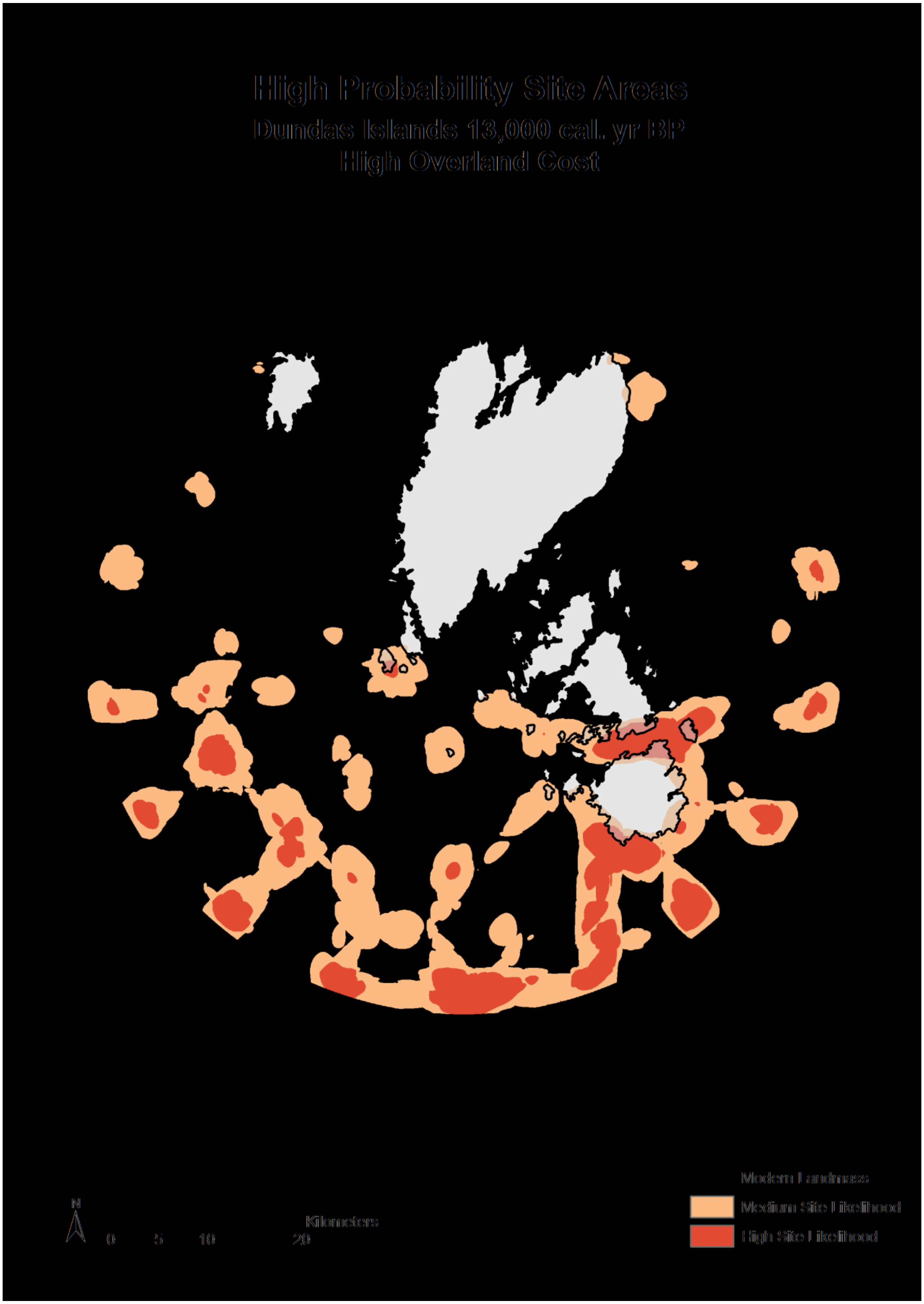

High Probability Site Areas
Prince Rupert Harbour 16,000 cal. yr BP
N
0
2.5
5
10
Kilometers
Modern Landmass
Medium Site Likelihood
High Site Likelihood

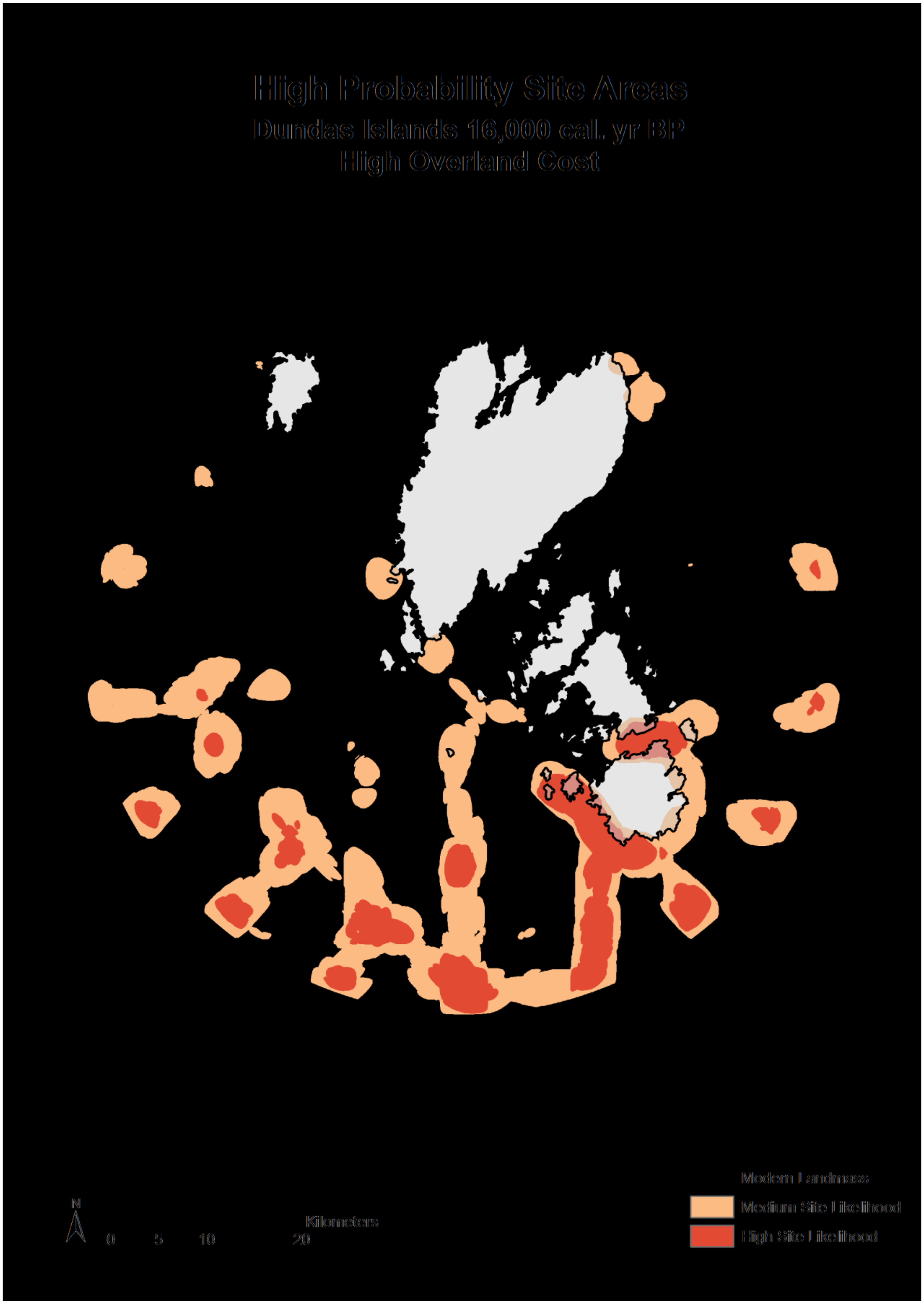

High Probability Site Areas
Stephens Island 10,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0 3.75 7.5 15
Kilometers


High Probability Site Areas
Stephens Island 13,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
3.75
7.5
15
Kilometers


High Probability Site Areas
Stephens Island 16,000 cal. yr BP
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0 3.75 7.5 15
Kilometers

Appendix H: Line Density – High Overland Movement Scenario

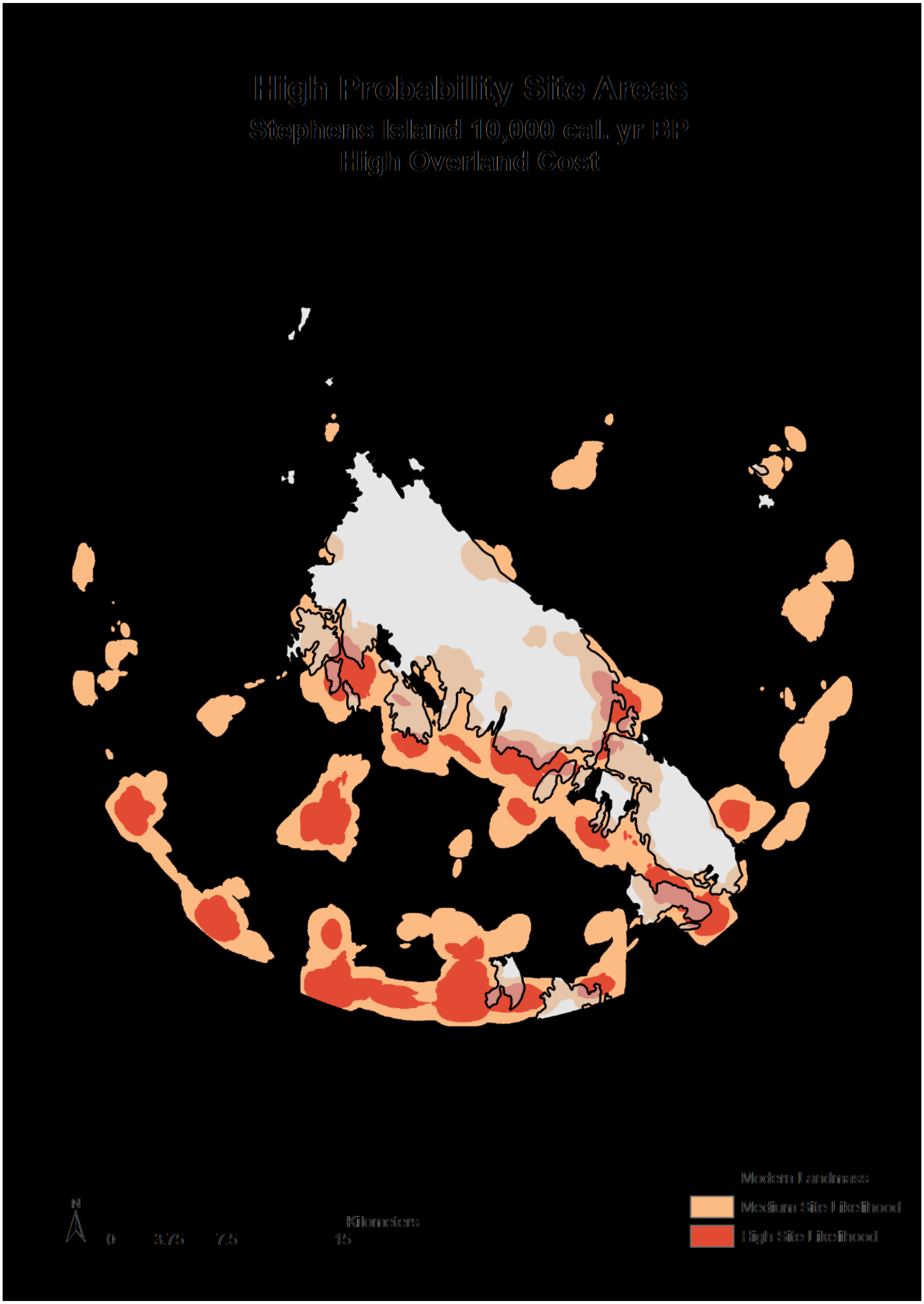

High Probability Site Areas
Dundas Islands 13,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
Kilometers
0 5 10 20

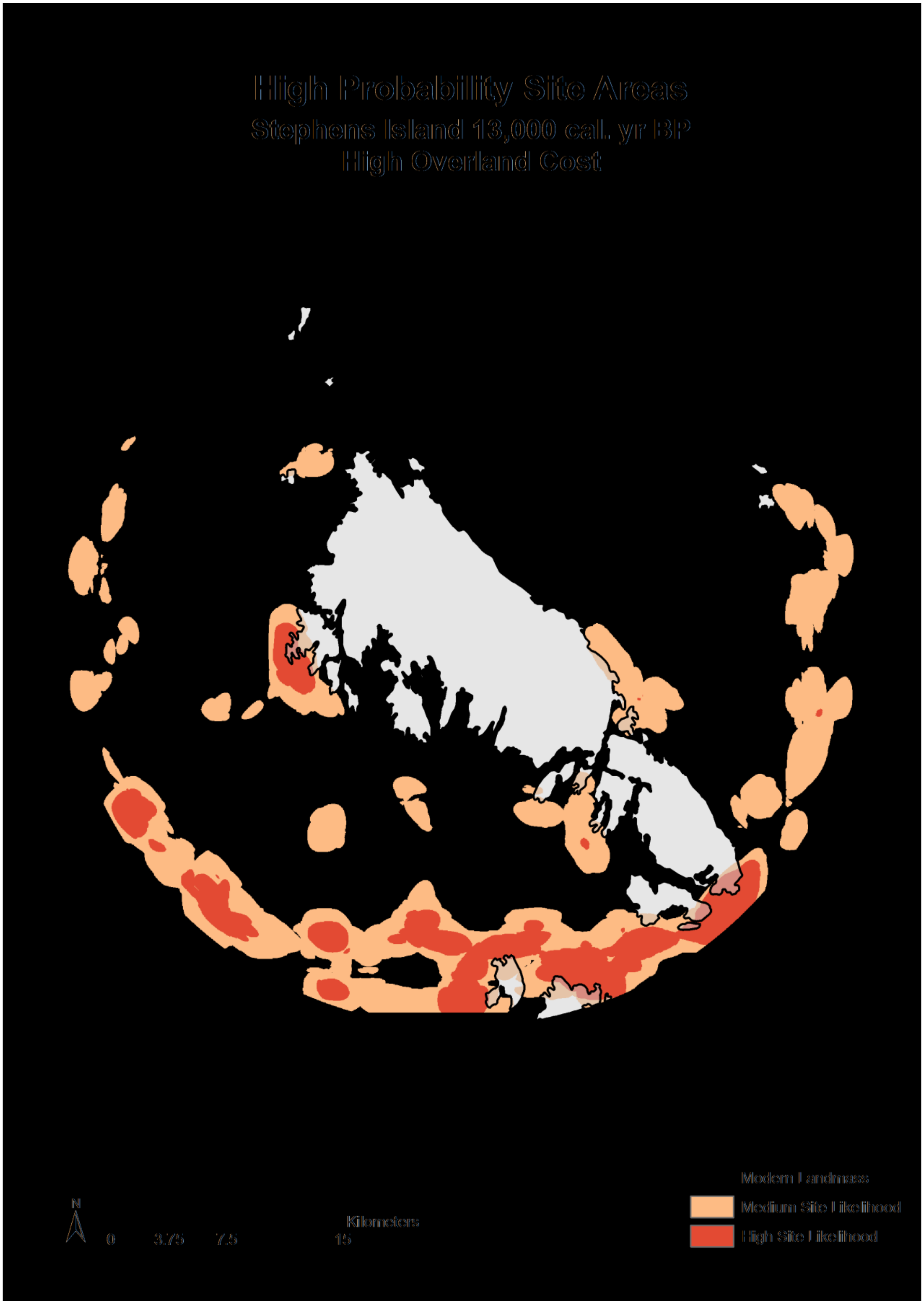

High Probability Site Areas
Dundas Islands 16,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0 5 10 20
Kilometers


High Probability Site Areas
Prince Rupert Harbour 10,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
2.5
5
10
Kilometers

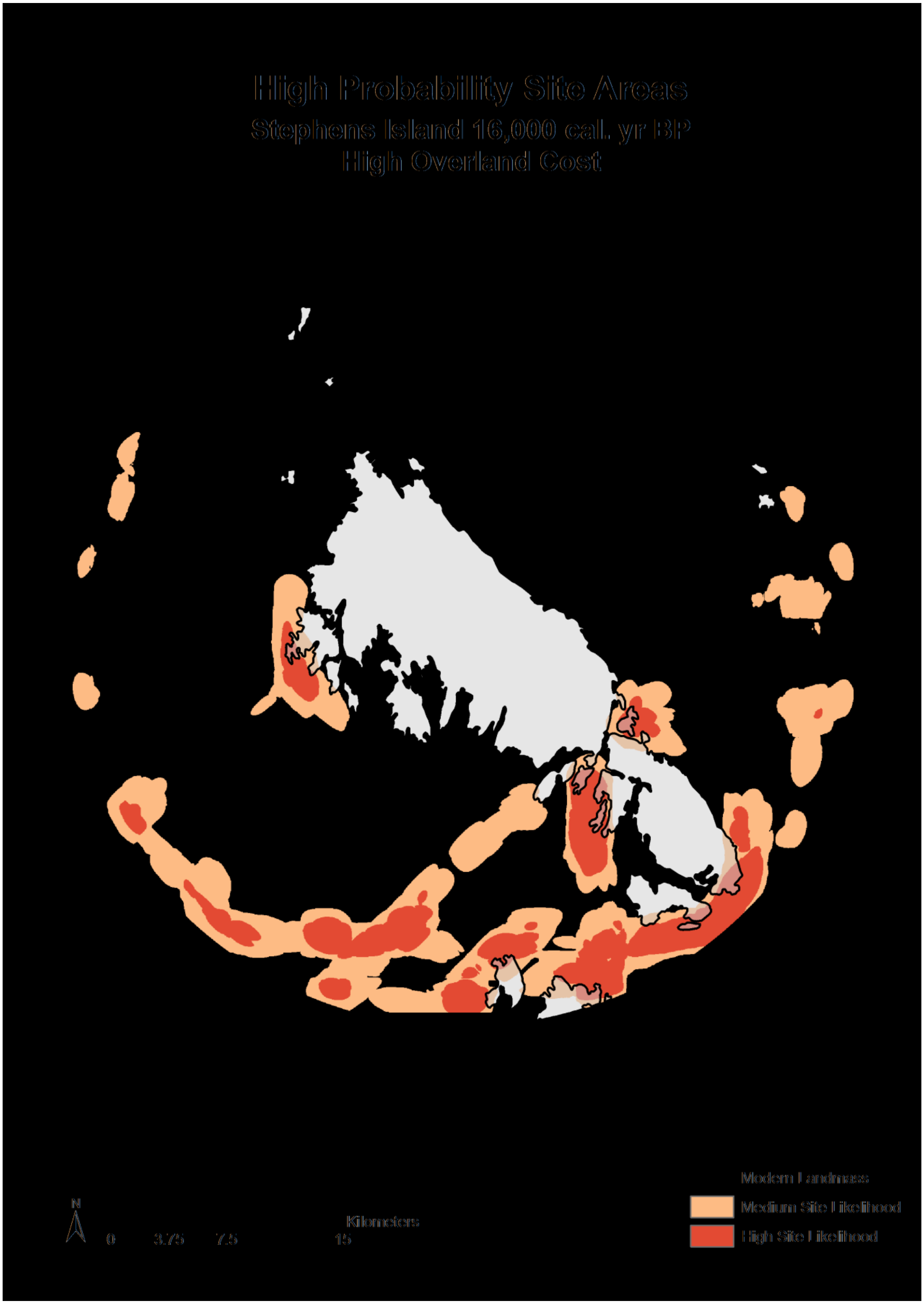

High Probability Site Areas
Prince Rupert Harbour 13,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
2.5
5
10
Kilometers


High Probability Site Areas
Prince Rupert Harbour 16,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
Kilometers
0
2.5
5
10


High Probability Site Areas
Stephens Island 10,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0
3.75
7.5
15
Kilometers



High Probability Site Areas
Stephens Island 13,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0 3.75 7.5 15
Kilometers


High Probability Site Areas
Stephens Island 16,000 cal. yr BP
High Overland Cost
Modern Landmass
Medium Site Likelihood
High Site Likelihood
N
0 3.75 7.5 15
Kilometers

Appendix I: Computer Specifications

I used two different desktop computers to calculate results for different stud areas. The first machine (Computer 1) ran Windows 7 Enterprise and was equipped with quad-core 2.8 GHz Intel i5 processors, 8 GB of RAM, and a 1 TB HDD. The second machine (Computer 2) ran Windows 8.1 Home edition and its hardware included a 4.0 GHz quad-core Intel i7 processor, a 256 GB solid-state hard drive, a 1 TB HDD, and 32 GB of RAM. Computer 1 is more representative of the average workstation and as such the Prince Rupert Harbour, Dundas Islands, and Stephens Island analyses were run on this computer. Computer 2 was used for calculating results for the larger Haida Gwaii and Alexander Archipelago study areas after discovering that the Dundas Islands and Stephens Islands were taking considerably longer to process than the results from my initial trials using the Prince Rupert Harbour data.

Designation	Operating System	RAM	Processors	Hard Drive
Computer 1	Windows 7 Enterprise	8 GB	2.8 GHz quad-core Intel i5	1 TB HDD
Computer 2	Windows 8.1 Home	32 GB	4.0 GHz quad-core Intel i7	256 GB SSD + 1 TB HDD