ROUTES OF IRON

Least Cost Path Analysis of the Possible Routes and Ways in which Iron was Transported during the Later Part of Iron Age in Scania, Halland and Småland

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Abstract

Iron is an important material in the study of societies of the Iron Age and later periods. Not only does it give its name to the period it was also an integrated part in every humans' life from the Iron Age and forward. And yet this material is many times just assumed to be there without much consideration of how it got there. In this master thesis, the author thus tries to bridge this gap in between the production of iron and the user. This is done using the spatial analysis method of Least Cost Path Analysis in order to explore what energy-conservation can tell us about routes and methods used for transportation and travel in the north Scanian, south Halland and south Småland area during the latter part of the Iron Age. The material is gathered from both archaeologic contexts and research as well as from geological data collection and research. The study is conducted using five iron production sites showing signs of production during the Iron Age and early Middle Ages. From these several paths are calculated to the destination using three different scenarios, one in which water is assigned low values and thus making travel through water very attractive for the algorithm used to calculate the paths. Then one scenario is used in which water has been somewhat restrained. Lastly, one scenario is used in which water is given the highest values possible forcing the algorithm to choose a terrestrial path. The results of the study are then looked at against a background of Iron Age society and political centres in the landscape, and what this might be able to tell us about where the iron was headed. As the calculation of least cost paths indicates areas in which movement is likely to occur in the landscape the possibility to use the results of studies like this for the prediction of unknown sites in the landscape is explored. The results of the study show that there are strong reasons to believe that the Scanian and Halland waterways have been used more extensively than previously argued for. Further, the results obtained generate good possibilities for future research into the prediction of unknown sites, and several interesting areas have been identified within the scope of this project.

Keywords:

Least Cost Path, iron, Iron Age, waterways, roads, travel, transport, Early Medieval Period, boats, wagons, hollow way, landscape

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1.0 Introduction

1.1 Background, why networks of iron?

This thesis concerns the paths and the ways in which the iron from the forested areas of northern Scania found its way out to the more inhabited areas, where it was either used, traded or reloaded for further transportation to its final destination. Iron as a material and a commodity was of large importance for the society throughout the Iron Age, not only used for weapons but also tools for the construction of houses and other constructions, rivets to hold boats together, pots and pans for food preparation, tools for making tools, personal accessories and more. It has continued to be of equal importance and even more so, in modern day society. Most of what we know and recognise in our immediate surroundings are in some way dependent on iron or some version of it. In the small room where I am currently writing this, I can see no less than 14 things made of some version of iron or steel, from the watch on my arm to the chair on which I am sitting. Even though people of the Iron Age probably were not as dependent on this metal as we are today, it certainly made their lives a lot easier, and as bronze and flint went out of use for tools and weaponry, iron would have been the only material left suited for making edged tools and weapons, as well as an array of other tools and objects. A material of this importance, as society developed, there most likely must have developed some sort of semi-organised production or directly controlled ditto, in order to supply a whole society with all of what that means of people's personal lives as well as the building of and retention of power. Ulla Isabel Zagal-Mach Wolfe has shown that an organised production of sails did exist during the Viking Age with an organisation stretching from the upbringing of sheep and harvesting of wool to the spinning of thread, weaving of fabric and finishing of the sail (Zagal-Mach Wolfe 2013). Sails were vitally important for the boats belonging to both war fleets and merchants. Equally important for boat building is iron, thus it would not be farfetched to assume a similar case when it comes to the production of iron. But to have a production of iron in remote areas is no good if you do not have good means of transporting the material from point A to point B. Thus this thesis will try to get a little closer to how this was done. There is also a clear rise in the number of smithies and the amount of slag at settlements as well as the number of iron objects in the later part of the Iron Age. The production sites also seem to grow in size as well as move closer to the source of the raw material (Björk 2009, p. 34). Yet the number of sites that today are known from this part of the Iron Age is vastly underrepresented (Björk 2009, p. 36). Can the knowledge of paths in the landscape help us understand this better? Predictive modelling can here be of help, using resources in the landscape as well as the more likely paths to derive at areas where previously unknown sites are more likely to exist.

My interest in iron is something that goes back many years, long before I even started studying archaeology. And from my first semester, it has always been there in the back of my head. And every time I read or hear something concerning how societies in the Iron Age functioned or how crafts were carried out the question has been there, "how does the availability and thus the production of iron fit into this picture?". In my bachelors' thesis, I discussed the production per se, who were the recipients and did there exist a, by the elite, controlled production. From that discussion sprung many questions concerning the ways and the networks used to bring the iron from the northern Scanian forests out to the coast and places of inhabitance and trade. Now using Geographic Information System (GIS) based digital methods and Least Cost Path (LCP) I will explore these aspects of infrastructure, trade and production of this so important material.

1.2 Aim of the thesis, relevance, and questions

Much focus within the field of iron production and sustainability is still aimed at the iron itself, how it technically was produced and how the sites were organised, all indeed relevant to the highest degree. However, in my own experience, there has been a large part missing from the research and that is how the iron got from one part of a chain to the other. A part largely missing in Swedish Iron Age research as a whole, this material that gives its name to the period is in a way just assumed to be there. But how did it get there when its production took place a long way from its final destination?

A large problem within the research of Iron Age iron production is the lack of known and dated sites from the period, in many cases making it harder to draw larger conclusions, and sometimes also making hypotheses less founded in the material as such. For this to change, what is needed is campaigns of searching for and locating of sites, as well as securely date new and previously known sites. Inventory projects have previously been conducted where sites have been searched for in areas where ore has been present and still is, by large this means in peatland areas. This has yielded good results through the years but taken a lot of effort. As I will be using LCP analysis, which if implemented correctly, shows areas in the landscape where movement more likely have occurred in history and pre-history, this could theoretically also indicate areas where unknown production sites are more likely to exist. The questions outlined for this project thus take the form of the following:

- How was the iron transported?
- Which routes were used?
- Can the knowledge of these routes in extension help us trace new sites of iron production or other actions connected to these activities?

Accordingly, what I hope to do is to somewhat bridge this gap between events, the production, and the final use, as well as to lift and advance the subject of iron trade and production into a more digitized forum where new angles and approaches can be explored.

The type of study I am doing here has, as far as I know, not been conducted on this material before. However, many other materials and cultural spheres have been subjected to these kinds of studies. LCP analysis and other spatial analytical methods have been used with great success in many cases, shedding light on movement patterns and corridors of travel as well as determine where there is a higher probability of existing undiscovered sites in the landscape.

It is important to here clarified that this work does not aim to completely explain how iron was transported or exactly which routes were used. Nor is it to be viewed as a study in predictive modelling. It is, however, to be viewed as an initial study into these type of questions, opening up for future research into communicational routes connected to iron, both of a terrestrial kind and waterways, in the research area.

1.3 Research history

1.3.1 GIS

This thesis is dependent on two, in many ways, quite different sides of research. On the one hand, it builds on the research field of iron production in southern Scandinavia, a subject that has been of interest for researchers since the early 20th century, and on the other, it builds on the much wider, younger and in certain ways more dynamic subject of GIS in archaeology. Drawing both on research conducted as early as the 1920-1930s and the very forefront of digital analytical methods, these are not always the easiest to combine into one in a smooth and coherent way. The result is a somewhat divided research history with few literary works directly related to the question at hand, as, within the subject of iron research, these questions I ask have been little explored.

To start with the digital part of this thesis, it can be problematic to point out any other work within the field of GIS in archaeology as more important than another, since, within such a fast-moving and dynamic field, work finished only a few years ago might now be less relevant or even obsolete. Any new work can thus also have a substantial impact on the field making the task of pinpointing influential and important work even harder. This is not to say that there were no important studies being done in the past, as always new research builds on previous work that has been done. And as such, all studies have the ability to shape future usage, and therefore, earlier work should not be looked down upon. The very first conference of GIS in archaeology in 1985, organised by the Society of American Archaeology, certainly produced some important work for that time and has so continued to do (Chapman 2006, p. 17). But GIS then and now is so far removed from each other that it could virtually be two different things. However, if these early versions of GIS had not been created there is no telling where we would be now.

What was of as high importance then as it is now, is the theoretical framework on which GIS must rest. This, of course also being a dynamic part of the usage of GIS, changes with the course of the practical execution, and so it must, in order to actually support what is being done. That there is room for change is crucial as new technology might put things on their edge, theoretically speaking, and sometimes these changes crave a new way of thinking. However, it does not move and change as quickly as the practical side of GIS. Often there is a lag which sometimes makes it hard to implement older ways of thinking on new methods as well as creating a vacuum for theory when the lag between the two becomes too big. Having clarified this, what will be presented below in most cases is the work of authors that have been of importance during the very recent years or decade, within the field of archaeological GIS. Further, literary works that have been of an influential character for the acquisition of information and understanding of data as well as the building of a theoretical framework will also be presented. Some have been important for my work specifically; others have affected the field more substantially as a whole.

In 1976 Ian Hodder and Clive Orton published their book *Spatial analysis in archaeology.* This work was meant as an introduction into more detailed studies of spatial analysis in archaeology. The authors argue that previous neglect of spatial methods and theory following its first introduction in 1912 by Osbert Guy Stanhope Crawford, had created a kind of vacuum in the discipline, making a reintroduction of spatial thinking much needed (Hodder & Orton 1976, p. 1f). Being published before the use of GIS was realised within archaeology, digital methods are not a topic that is discussed in this book. Rather it explains the foundation on which these digital methods later came to rest.

As the book is meant as an introduction, most of the discussions are on a general or somewhat detailed level. Explaining what spatial analysis actually entails and some of its theoretical understandings, the authors move from the more simple applications to the more advanced. Things like distribution maps and point pattern analysis are introduced and the information that is used in the creation of it and what different questions can be answered or helped with its use is discussed. In order for the reader to then understand how the answers obtained by these analytical methods can be used and how different patterns might relate to each other, different interpretive models are presented, exemplified and discussed. Patterns of sites and objects are also discussed in relation to the wider landscape as well as quantitative and qualitative methods. In order to make the reader aware of the different problems concerning the archaeological material, the survivability of artefacts, as well as the difficulties in using older material and the uncertainty in the contemporarity between sites and objects, is problematized. As an introduction into the usage of spatial analysis methods during these early days of post-processual archaeology, it definitely offered something new and important in the field. Following its publication, it spiked comments of variant form. Geoffrey Clark wrote in a review that “Hodder and Orton are sorely needed if explicit ‘systems for indirect observation of the past’ are ultimately to be developed” (Clark 1978, p. 135). While Andrew Gibb called the book frustrating as there are no conclusions after each chapter and meant that there is a lack of linking what is being said to “the broader mainstream of archaeological investigation” (Gibb 1977, p. 448). Despite its reception in its own time, this work by Hodder and Orton helped a lot with the process of integration and made the concept of spatial analysis available in a way which made it relatively easy to grasp and understand and as such it has been an important work for laying the foundation of where we are today, as the concept spatial analysis is widely used and integrated in what we do today, and perhaps most so in the many applications of GIS.

For a general overview of the usage of GIS within landscape archaeology, Henry Chapman's book *Landscape Archaeology and GIS* should be mentioned. It gives a good background to how the use of GIS has shaped and changed modern archaeology. Both in how we think of landscape and spatiality and how we technically approach questions that we today ask of the past landscape. The first brings together several researchers' thoughts and ideas of how to think about what we do as well as the development over the years. The second explains the different types of datasets that can be used and implemented in the GIS software and how these can be shaped and combined in order to obtain new information. The book ends with a series of simplified case studies showing how to execute what has been explained and can be used in real life archaeological conundrums. Having been written in 2006 a lot has, of course, happened since then within the field of GIS and landscape archaeology, and thus some parts are a little obsolete today. However, as a whole Chapman´s work provides a good basis for understanding GIS and the data available and how it can be used as well as how it should be understood and thought about theoretically.

Moving on to LCP a work that has been of importance for the theoretical structure concerning the usage of LCP analysis is *Digital archaeology, Bridging method and theory*, edited by Thomas L. Evans and Patrick Daly. Containing articles from several authors it deals with how we today should approach the usage of ICT (Information and Communication Technology) in archaeology, how to best utilise them and integrate these new tools in theoretical thinking in order to expand the limits of what is currently possible (Daly & L.Evans 2006, p. 2). The article by Ezra B.W. Zubrow in this anthology has been of help for the understanding of where the theory behind GIS has come from and to some degree, where it is going (Zubrow 2006). The article concerns and gives an overview of the history of digital methods and how theory has been and is viewed within the field of digital archaeology.

In order to understand the many ways in which LCP can be utilised as well as things that are important to think about and the technical background, the anthology *Least Cost Analysis of Social Landscape* has been a good asset for this work. Edited by Devin A. White and Sarah L. Surface-Evans it contains articles from a number of authors stretching from the more simple application of Least Cost Analysis to the more advanced using custom coding within ArcGIS. This step-like increase in difficulty and technical knowledge provides a good base for the understanding of LCP analysis for the relatively inexperienced user like myself. At the beginning of the book, the two editors go through the basic technical aspects of the method, breaking it down to its individual components and giving them a historical background when appropriate. What is being said is also linked to the articles in the coming pages, which is continued by all authors throughout the book, making it easy to know where more can be read on a specific topic.

Two authors who were among the first to spark my curiosity and interest for LCP, and how to track peoples' movements in ancient landscapes, were Gary Lock and John Pouncett in their article *Walking the Ridgeway Revisited: The Methodological and Theoretical Implications of Scale Dependency for the Derivation of Slope and the Calculation of Least-Cost Pathways.* Published in 2010 they deal with the intentional directionality based on the visibility of intermediate waypoints on a route to the final destination. Their approach takes a lot of inspiration from the work of James Gibson and his thoughts of ecological psychology, which consists of the main argument that human vision and movement are inseparable from each other in the greater sphere of the "perceptual system" (Lock & Pouncett 2010, p. 193). Their goal is to incorporate a little more of the subjective decision making that surrounds human action in order to counter one of the main criticisms of LCP modelling in GIS, that of the inevitable objectiveness of digital modelling which is present and in many cases paramount in the algorithms used in GIS programs (Lock & Pouncett 2010, p. 201).

In conclusion, it can be said that, as such a new field, GIS and digital archaeology might be one of the research areas within archaeology that produce the most articles. This could probably be seen as a product of the many different research questions that can be further informed with digital methods.

1.3.2 Iron

The subject of iron has been a large topic in Swedish archaeological research for many decades. It has mostly been focused on the production side of things, for example, the quantity produced as well as the technicalities surrounding the production itself, like typology of furnaces and organisation of the sites internally. 1907 Oscar Montelius was most likely the first person to excavate the remains of a blast furnace. His inspiration to do so came after reading the first published article on the subject in 1903 *Några anteckningar om myrjärnstillverkning och smide I Härjedalen under gångna tider* written by Erik Modins. The results of the excavation by Montelius was published in 1919 in the oldest Swedish archaeological journal *Vår Forntid.* It is not impossible that this excavation influenced Montelius division of historical periods, as to when the Iron Age began and the Bronze Age ended (Englund 2002, p. 55), the same division we still use today. One early researcher to specialise in the subject of iron was Carl Sahlin, who during the early 20th-century was one of the first to do so. He was to become a very important figure in the scene of early iron research. In earlier research, iron had only been part of an explanatory chain but now with the incitement of Sahlin, iron become a subject in its own right. Although very keen to understand this very important material, he was not a trained archaeologist. Through the work of Sahlin many new steps were taken within the field, for example, inventory work of iron production sites, excavations, the procuring of objects and material for tests as well as re-publication of much older materials. In 1922, the first, what one could call a sort of conference on the subject of iron production was held at Jernkontoret in Stockholm, much on the initiative of Sahlin. At this occasion, several researchers were given the opportunity to present their results for, among others, the prime minister and the head of the National Heritage Board. One work presented was an article by Alf Grabe which told the story of the last practitioner of the old Osmund-tradition, Fider Anders Pettersson in Nornäs (Englund 2002, p. 57). Maybe this could be called one of the first, if not the first effort to understand the people behind this production.

Two very important publications from the 1930s are *Studier rörande äldre svensk järntillverkning med särskild hänsyn till Småland* published in 1932 and *Äldre järntillverkning i Sydsverige, studier rörande den primitiva järnhanteringen i Halland och Skåne* in 1939. The author of these works was John Nihlén, a man how worked closely with Sahlin, and unlike Sahlin, he was a trained archaeologist. Being the first larger literary works of this kind handling the subject of iron they set a tone within the field, a tone that for a long time has been the most prominent one, with many researchers following the lines drawn by Nihlén. For that time in archaeology, these publications could be said to be relatively progressive in their nature including things like chemical analysis of slag and iron production sites in relation to place names. He also presents the results of what is one of the first publicly/collectively organised inventory projects ever done, a project which resulted in over 500 new and interesting iron sites (Nihlén 1932, s. 16). The two books are in the most parts the same in that they ask the same questions, use the same type of analysis and the same angles but use material from two different regions (Nihlén 1932; Nihlén 1939). What also is apparent in the two books and throughout most of the research from these early days in the field of iron research, is the strong cultural-historical approach. It is always the technical side of things that are seen as the most important, how big the quantities were, what did the site look like and what type of inventions were used in the production. Questions that we today might feel a little strange about if they are not included in a wider framework. Questions like, who were the people who produced the iron? Who was it for? How dependent was the larger society on what was being produced in the woodlands? which we today think of as central for our understanding of the past, had not really been developed yet. However, it is easy for us today to criticise what was being done before, but should we? After all, what was being done then, really has no bearing on what we do now, other than we can learn from their mistakes and build new knowledge upon some of the work that was being done in the past. With this in mind, we should, of course, be critical of using conclusions drawn in many of these early researchers' work, as they did not know what we know today, but the work itself need not be criticised any further in my opinion. And the material collected during those days are just as relevant today.

For the purposes here it is not relevant to mention all the research being done in these early years and there is not space nor time to do so either. Thus, fast forwarding to more recent research I will forthcoming talk about some of the literary works that have had a larger impact on the modern field of iron research as such but also works that have had an impact on my specific research and the knowledge leading up to it.

Lars-Erik Englunds doctoral thesis titled *Blästbruk* finished in 2002, has in many ways become almost a staple in iron and iron-related research. It is a compilation of a large amount of research and knowledge, obtained from many years within the field. The compiled information consists of everything from changes over time and space, written sources and inventory of known and new sites to experimental production of iron, handling every step in the chain from ore to the final product. Such a large project as this naturally has to operate within strict borders in order to not become overwhelming. The geographical limitation for this work are as follows; archaeological investigations to the parishes of Örsås and Tranemo in Västergötland, older written sources to Scandinavia as a whole and studies of the morphology of blast furnaces have been limited to today's Sweden. While analogical research history and analogies within experimental iron production have not been put under any limitations (Englund 2002, p. 32). In many aspects, it is a book that brings up phenomena relevant to a very large geographical area and handles many aspects of the production of iron. Thus, this is a very useful work for many aspects of iron research, both for gaining a more general overview as well as more detailed information. Critically one could say that it has tendencies towards the cultural-historical side of things, spending comparatively little time on social aspects and iron in the larger context. Be that as it may, the way that this work is used is more in the style of an encyclopaedia and not a "from cover to cover book", making it very useful when the technical side of things is what is needed.

Another researcher who, has long been in the forefront when it comes to research concerning north Scania during the Medieval period and so also the iron production during the same time is Anders Ödman. Many different projects have been the result of this geographical and periodical focus, the main one being the large project of Norra Skånes Medeltid (North Scania´s Middle Ages). Through the years several books have been the result of this project but for the research relevant here it is mainly the volumes *Vittsjö en socken i dansk järnbruksbyggd* and *Skeningeborg, borgen som Saxo glömde* that has been of importance. In the first of these volumes the parish of Vittsjö is looked at in the context of it being an important resource for the Danish crown during the Middle Ages. For this project, 70 ^{14}C-samples were taken for analysis, which yielded very interesting results. According to these some areas started to produce iron much earlier than what was previously thought. Some of these sites are used in this thesis, namely the ones dated to Iron Age as well as the ones dated to early Medieval times, pre-1300 AD. However, because of financial limits, only one sample was taken from each site (Ödman 2001, p. 131), which might lower the accuracy of the dates somewhat but as a starting point in an otherwise largely undated material, this has to be seen as good enough for the time being. As the aim for the project Norra Skånes Medeltid is to understand how this region fits in with the changes and power-struggles of the Medieval Period this work goes to great length to understand the production in a much larger context which is apparent through the many different lines and possibilities it examines. This also increases the overall usability of the work as it, in turn, fits in with many other branches of research. The book *Skeningeborg, borgen som Saxo glömde,* briefly handles the subject of transportation of goods, among these iron, along Scanian rivers and streams, mainly Helge å. Arguing for the existence of common transport routes through rivers and lakes. Analogies are drawn to Torneälven and other rivers in the north of Sweden where transportation of large amounts of different goods, among which iron had a big presence, continued up into modern times. The reason for this larger presence of evidence for river transportation in northern Sweden is said to be that adequate roads were lacking long into the 20th century, making waterways the only viable option, whereas the roads became standardised much earlier in southern Sweden and Scania making transportation less dependent on waterways earlier on (Ödman 2005, p. 147-150).

The book *Det Förlorade Järnet* by Bo Strömberg is one of the most recent and larger literary works concerning iron production in Scania during the Iron Age up to early modern times. It aims to deal with the production within a larger setting, trying to understand the social contexts as the formation of more exclusive groups of iron makers and recipients started to be formed. Using patterns of colonisation, visible in the northern parts of Scania south Halland and Småland from early Medieval times and the material of known production sites, Strömberg attempts to understand the premises of an emerging proto-industry and get closer to the people behind the production. This also underpins attempts to understand how a process like colonisation and a greater need for a certain material may fit into one another. Taking a holistic standpoint Strömberg shows that a lot can be achieved from what we know today but that there are definitely pieces missing needing more research, for example, the fact that several sites show signs of long continuation and even reuse in later periods (Strömberg 2008, p. 92). Strömberg's work, I believe, has been influential for how the tendencies within the research field have turned more and more towards the social and political aspects of iron and the organisation behind it. The same can probably also be said about the works of Anders Ödman. Ödman's work has also likely influenced some aspects of Strömberg's research.

Just like the previous researchers, Eva Hjärthner-Holdar has contributed a lot to the modern, more science-minded, field of iron research. She is an archaeometallurgist with a clear emphasis on experimental archaeology and the production of iron through time. In her dissertation *Järnets och järnmetallurgins introduktion i Sverige* she explores the earliest traces of iron production in today's Sweden. This work stresses the technical side of iron research and production, after which it is put into a larger context of the earliest sites known. Early production sites from several different counties are analysed as well as ore and slag, early iron objects and the contexts they were found in are looked at from several different angles. From this, analogies to Eurasian materials are drawn. Besides this, she looks at how the spread of Bronze Age production sites and how this might have influenced the spread of the earliest iron sites. The studies conducted lead to many new and very interesting observations and ideas, some of which made the knowledge up to this point somewhat questionable. The 111 sites included in the study were dated with a combination of typological studies, stratigraphically observations, studies of ancient monuments and ^{14}C-dating. What is concluded is that the earliest production in Sweden could be put to the later part of the Bronze Age, period IV (Hjärthner-Holdar 1993, p. 94, 183). Further, the study shows a high level of technical knowledge already this early, with a clear evolution in furnace types (Hjärthner-Holdar 1993, p. 184). Not much emphasis is put towards the transportation of either raw materials or the finished product. The big emphasis on the technical side of things goes hand in hand with the trend within iron research during this time. The same trend that to some part is the biggest even today.

In one of the latest published articles, *By Who, for Whom? Landscape, Process and Economy in the Bloomery Iron Production AD 400–1000,* published early 2018*,* the four authors, Eva Hjärthner-Holdar, Lena Grandin, Katrina Sköld and Andreas Svensson, tried to understand a production site in close proximity to Motala ström in Östergötland in a larger regional context. Several discussions relating to the site is brought up in the article, for example, oven-type in a chronological sequence, the closeness to raw material and settlement, a communicative favourable location and the status of the blacksmith or iron maker in society as well as the level of organisation in the production. Discussing these things, they try to find links and connections between this and changes in society during the period AD 400-1000. Analogies are drawn to similar conditions in Norway, where a large, what seems to be an organised production has been shown by Axel Christophersen in the later part of the Iron Age (Christophersen 1989). Similar to what Strömberg has noticed, the article shows that the site in question has been in use over a time period of about 400 years (Hjärthner-Holdar et al 2018) opening up for many interesting interpretations. It is one of few articles handling Swedish iron production sites which also bring up the subject of communication and transport, not so much the means of transport though but more emphasising the importance of a good communicative location. I see this article as a continuation of the tendencies within the subject as involving more and more social aspects and striving towards placing the iron production site in society not outside it as has often been the case. Even though it might be likely that distinct social groups have been the ones producing iron as suggested by among others Söderberg (Söderberg 2008, p. 79ff), maybe even living separate to the rest of society, they are still a crucial part of the ancient society and should be considered as part of it.

1.4 Ways of transport and traveling

To understand movement in the landscape and to understand the amount of effort that went into travel and transportation of goods over long distances, one has to first ask the question of how travel and transport was conducted. What means of travel was available at this time and place and how did the landscape in turn affect how people moved and the means of their movement. For us today in a big part of the world, moving through the landscape is easy. We have paved, asphalted and gravelled roads stretching to almost any thinkable destination in the landscape, and if we want to go somewhere fast we have a great many choices to pick from in order to fit our own needs of comfort and speed. Distance is no longer a hindrance and the landscape does no longer contain the troubles and dangers it once did for the people seeking to reach destinations far from their own home or other place of departure. The distances for us today have therefore shrunk to just a fraction of what it would have been in a time before any modern infrastructure in terms of time and energy expenditure. It is important to understand these changes, both the physical ones occurring in the landscape but also the changes in how people thought of distance. What was far away and what was an everyday travel distance? And if different means of travel was available how did this mindset effect how people thought and what lengths were people prepared to go to in order to obtain a more energy efficient way of travel and transport? These questions are of course not the main objective for this thesis and could probably easily fill a book, therefore it will not be explored to any greater length beneath. But these questions serve as a good reminder and gives you food for thought when discussing the subject in the following chapters. In the following, I will instead give a record for the different ways of travel and transport as well as what roads seems to have consisted of during Iron Age in Sothern Scandinavia. In order to make the different scenarios of travel more diverse one can also look at travel during different seasons. Studies have been made concerning travel during wintertime when presumably there was the possibility to travel over frozen lakes by sledge. And finds have naturally been found of sledges from the Iron Age for example from Vossakavlen snowdrift glacier in Norway. However, for the purpose of this thesis wintertime travel have not been used as a variable, as summertime, or any other snowless season, arguably must have seen a large amount of travel and transport as well. Large parts of the Iron Age also saw a warmer climate than later periods, which would have contributed to milder winters. This, as well as the probable need for year-round transport, in my opinion makes transport without the help of snow and ice just as, if not more, probable.

1.4.1 Roads

What we today think of as roads are far from what was the reality in Scandinavia during the Iron Age and earlier as well as in later periods. The archaeological evidence points towards something that more resembles wider tracks through the landscape with occasional strengthening of the ground to make it more resistant to wear and to keep the surface less likely to transform in to a mud track (Jörgensen 1996 p. 48ff). It is important to stress the difficulty of dating roads and especially hollow ways as the road in most occasions only shows the most recent wear as the surface is constantly in motion unless material in the form of strengthening is added to make the surface more resistant (Carlie 2001, p. 77). However, if archaeological material is found on the road surface this can of course give a date of *terminus ante quem* (Winkler 2001, p. 44).

In 1998 a road and a ford were discovered during excavation work prior to the construction of a new railway outside Saxtorp in Scania. This road and ford lay in direct conjunction with the outskirts of a larger settlement showing signs of habitation in two main periods. First from the early Neolithic to middle Neolithic and a second habitation period from early Roman Iron Age to Migration Period. The road itself was dated with ^{14}C to Roman Iron Age with a concentration during 80-390 AD. The construction consists of two ruts, one on each side of the presumed road surface which had a diameter of 4 to 7 meters (Artursson 2001, p.15-16, 31). The construction of the road is in some parts rather un-cohesive and the circumstances of these parts are unclear. In other parts, the structure is more unified and the function of a road leading down to two fords over a creek and the river Saxån stand out more clearly (Artursson 2001, p. 19f). There seems to have been no clear road surface, that is, no material has been added on through the years of usage, and no clear signs pointing towards the use of wagons or the like were reported during the excavation (Artursson 2001), which is a point that will be stressed a little further down in this part of the text. The whole road system and settlement that was excavated at Saxån gives the impression of a larger settlement well organised with roads running internally in the settlement as well as leading out to different functions in the landscape. The presence of a larger stone built ford also gives the impression of a travel route, which is strengthened by the fact that a ford is present in the same spot on the oldest map of Scania from 1684, Burmans map (Artursson 2001, p. 26). Another interpretation that was made during the excavation was the road system would have made it easier for the herding of cattle (Artursson 2001, p. 39). This in conjunction with that no added road surface material was found, must have made it a very muddy and rugged road indeed.

The same year, 1998, another road was excavated in Södra Sallerup near Malmö in south-western Scania. This road showed to be of a rather substantial type with a stone paved surface showing clear signs of heavy use of carts or wagons. The traces of wheeled transportation were present in the form of long depressions parallel to each other which had thicker layers of stone packed in them, suggesting a higher degree of wear along these specific areas (Winkler 2001, p. 42ff). Based on finds of ceramics that could be typologically dated to middle to late Bronze Age as well as ^{14}C-samples from a hearth penetrating the surface of the road, the structure could be given a *terminus ante quem* of middle to late Bronze Age, around 1420-780 BC. The finding of this type of road was somewhat surprising as up to this point no stone paved roads had been found in Scania from this period. Furthermore, their first appearance in Scandinavia by large is disputed, some meaning that the road type does not exist at all in Scandinavia during the Bronze Age (Harding 1998, p. 42f; Mohen 1998, p. 21f). However, other researchers state that this type of road is known here from around 1000 BC (Jörgensen 1997, p. 157f). The road was found in conjunction with a settlement which makes it easy to draw the conclusion that it was built by the people living there, however the dating of the settlement is very unclear and the remains of a house located on the road, cutting the stone paved surface, making the link between the two even more unclear. Furthermore, the lack of burnt stone, a common filling material in roads located near settlements, in the ruts of the road surface ads to this confusion (Winkler 2001, p. 46). Three stretches of road were found, in two different types of terrain, slope and flat land. Mogens Schou Jörgensen, states that roads were strengthened only in areas where the terrain demanded it, for example over bogs and sloped areas (Jörgensen 1982, p. 142f). All three parts of the Södra Sallerup road have varied degrees of stone paving, which makes it stand out in this respect. However, the part that goes over the sloped area seems to have been subjected to more ware as more stone paving was present here. That even the flat area was stone-paved can be explained with the climate during this time in history being very rainy, and therefore the need for repair of the road surface more acute (Winkler 2001, p. 44f). The part of the road that transverses the sloped terrain shows signs of adjustments so that the road surface is level in contrast to the sloping ground. This further strengthens the thought that the road has been used heavily for transport with wagons and carts as the way these were constructed made them sensitive for strain of the wheels and axels in the direction horizontal to the axel, making even ground very important for this type of transportation (Winkler 2001, p. 46 & there cited literature). When it comes to circumstances that do not fit in to a common pattern we have to remember that nothing is set in stone, so to speak. There are always going to be circumstances that do not fit in perfect to a certain larger picture, which can be ascribed to the individuality of humans. And of course there might always be circumstances which for us today are not that obvious or indeed visible at all.

In the landscape today one can see many traces of previous centuries travel in the form of hollow ways, often visible in slopes where sometimes multiple hollow ways have been formed (Carlie 2001, p. 80). Often this can be ascribed to travellers choosing different paths, probably as weather and terrain conditions have shifted. Where these traces of traveling are visible they sometimes converge to one main route and sometimes it takes the form of many possible ones, creating corridors of traveling. Sometimes these corridors, in turn, take the shape of areas more than hundred meters in width where a new track has been created as soon as the old one has been too messy to bother with (Jörgensen 2001, p. 7). If material has been added on to the surface, sometimes to the degree that it creates the illusion of an actual road surface, these events can sometimes be dated (Jörgensen 2001, p. 7). However, the common problem with hollow ways is that they are very hard to date as they always show the very last period of use as the older material is the one that is eroded away through use and rain (Carlie 2001, p. 80). Several interesting observations have been made in Halland concerning the mode of transport people have used when traveling down the hollow way and how their shape correlates to this. Two main types of hollow ways have been identified, V-shaped cross section and trough-shaped (trågformad) cross section. The trough-shaped variant can likely be but in connection with the use of wagons, because 1) there seems to be a connection between the stretch of these types of hollow ways and the later road networks of the modern era and 2) when the two types have to go up a steep slope, the V-shaped hollow way takes a more or less straight path up the slope whilst the trough-shaped type takes a serpentine-like path up the hill. This suggests that this type is more suitable for the usage of wagons as going straight up the hill with wagon and load would put unnecessary stress on the draught animal. Interesting is that the V-shaped variant is by far the more common (Carlie 2001, p. 80). This could perhaps suggest that travel by horse and foot or foot and pack animal has been more common than transport by wagon. Another very interesting and important observation made during excavations of a road in Stenstorp in Halland is that two ruts or furrows on either side of the road cannot alone be seen as evidence for the use of wagons or carts. When draught animals are used to pull a wagon the hoofs of the animals are what causes the material of the road to become lose and subject to quickened erosion, not the wheels. Furrows along both sides of the road could just as well be explained by the fact that animals and people when being free to go as they like tend to keep to either side of the road and not the middle (Carlie 2001, p. 84). This makes the detecting of wagon use even harder, and perhaps previous observations thought to point towards the use of wheeled transportation might, in fact, be signs of travel by foot and hoof.

In contrast, many of the Danish roads that have been found, more than 500 localities, could with the introduction of ^{14}C-dating in the 1950s be given a more secure date for their usage, most of them ended up being from late Medieval to early modern times. The construction of roads also does not follow any chronological patterns over time, rather the ways in which they were constructed have always been a response to how a particular problem in the landscape had to be overcome (Jörgensen 2001, p. 4). This makes the dating of a road, from the way it is constructed, a very insecure method that should be avoided.

These examples show widely different approaches to how roads were built and maintained. The first example gives a picture of something that seems more like an indicator of a general direction leading two a passage over a tricky obstacle, in this case a river. And even though the road must have seen heavy use both from the people living at the settlement and from people living further away it has not been maintained in a way that is visible today. While the second example paints the picture of a heavily maintained road that saw equally heavy use by people animals and perhaps also wagons. Both roads are close to settlements which would mean that they are more likely to have been maintained as more people would have used the road on a regular basis. Roads then in rural areas of low habitation seem to mostly take the shape of hollow ways with low or usually no maintenance, and if the track got too messy to bother with, a new track was simply created alongside the old one. This seems to indicate that the further you go from more centralised areas the less road like the pathways become, and if we move even further out from inhabited areas would there have been any roads or paths to speak of at all?

1.4.2 Wagons and beast of burden

The usage of wagons for long transportations in the rural landscapes of northern Scania, southern Halland and Småland, is a phenomenon that in ways seem rather unlikely. For wagons to be used effectively and not become a hindrance for progression a solid surface is needed. Thus, boggy ground and other non-solid surfaces need to be stabilized before wagons can be used (Jörgensen 2001, p. 11). And according to Jörgensen this is the main objective of the road, to create a solid surface over loose and boggy ground. He states that this is visible in the archaeology in the way that the road is lost as soon as you reach outside the area of unstable ground (Jörgensen 2001, p. 7). Scania and Halland had an abundance of waterlogged areas and lakes from pre-history up until the latter part of the 19th century when a huge campaign to create more arable land was undertaken, running ditches through the landscape and draining many areas that previously were wetlands. The ancient landscape was one full of obstacles that if wagons were going to be used, had to be overcome, which would have meant building many stretches of road over land not otherwise suitable for transportation with wagons. As previously mentioned, observations made during excavations of a road in Stenstorp suggest that two furrows on either side of the road cannot alone be seen as evidence for the use of wagons or carts. A big rock was here present in the wall of a hollow way which had an interesting effect on the two furrows on either side of the passage. When the rock was reached the furrow on the same side as the rock stopped, leaving just one furrow. So unless people drove on just two wheels over this part in the road the furrows must have another explanation (Carlie 2001, p. 84). This makes it clear that what may appear as evidence for the usage of wagons and carts not always have to be so. Despite this there is of course also hard evidence for the usage of the same in the form of remains of wagons, predominantly preserved in bogs.

The archaeological remains of wagons found in Sweden are relatively few, counting only three at the present moment. One from the now dried out lake of Filaren in Södermanland, one from Västra Karaby in Scania and one from Skirnäs Mosse near Växjö in Småland. All three of these finds can be dated to the later part of the Iron Age, the two first finds to the Vendel period and the last one to the very end of the Vendel period. It is interesting that all three dates fall under such a short space in history (Skoglund 2001, p. 90). And although the number of wagon finds are too few in the present moment to serve as any sort of basis for a hypothesis of when wagons started to be used more frequently, it is an intriguing thought that all known finds can be dated to such a tight window in time. When talking about the find from Skirnäs Mosse an interesting thing can be noted, which is that parts of the wagon were not recognised as belonging to a wagon until about 55 years later, following the excavation of the finds in 1946 (Skoglund 2001). What this tells us is that certain parts of a wagon do not necessarily have to look very wagon like. Perhaps then, there does exist other finds of wagons, stored in museums and warehouse, waiting to be recognised as for what they really are. This is, of course, total speculation, but not entirely impossible.

Lastly, what can be said about beasts of burden are that pack animals seem to have been used more substantially for transportation than wagons were, based on the evidence from the hollow ways, where the V-shaped type is the much more common one of the two types suggesting a higher degree of transportation by other means then that of wagon and cart (Carlie 2001, p. 85). Although the problem with dating of hollow ways still remains. Consequently, it is hard to put these observations into a time frame.

1.4.3 Boats

Boats obviously have been a very important part of communication and transportation throughout the Iron Age. Not least so during the Viking Age when very long communication routes, building on communication instigated in much earlier periods, reached its peak.

Many boats have also been found from many different time periods within the Iron Age, ranging from the largest ships like the Norwegian Oseberg and Gokstad ship burials, dated with dendrochronology to AD 834 and AD 887 respectively (Bonde & Christiansen 1993, p. 581), too much smaller vessels like the Björke boat from Björke By near Gävle in Gästrikland, ^{14}C-dated to the 4th century AD (Westerdahl 1985, p. 128f). In Denmark several pre-Viking Age vessels have been found, the most substantial one being the Nydam ship with its 27 meters and 15 pairs of oars and dated with dendrochronology to 310-320 AD (Gould 2011, p. 112). Of interest here is mostly the smaller vessels like the Björke boat, light crafts that would easily have been carried where rapids or other obstacles would force the travellers to portage. This type of boat, which is called an expanded log boat, have been found inland at two locations in Sweden Björke By (as stated above) and Tuna in Badelunda parish, county of Västmanland. The Badelunda boat has been dated to ca 850 AD. The Badelunda boat as it has been named (grave number 75), is the most famous of the boats found at Badelunda and was found as a boat grave within a grave field with seven other boat graves that all were discovered and excavated in the 1950s. Six of these eight boat graves contained boats of the type expanded log boats, the oldest dated to between 600-800 AD and the youngest to 950-1000 AD (Nylén & Schönbäck 1994b, p. 156). The three first boat graves that were excavated within the grave field were a source for confusion, as the poor taphonomic conditions meant no remains of the boats themselves survived. These boats were sewn together meaning hardly any iron (particularly rivets) was present in the grave, otherwise the usual tell-tale sign of the presence of a boat. First with the excavation of the forth boat grave, the Badelunda boat, the answer became apparent as better taphonomic conditions had preserved large parts of the boat showing intrinsic details of its construction (Nylén & Schönbäck 1994a, p. 64ff). Another boat in a similar size to the Badelunda boat, 6-7 meters, is the Halsnøya boat from Norway dating to AD 335 ± 65. This boat also belongs to the tradition of sewn boats (Brögger & Shetelig, 1971 p. 34f) however it is not an expanded log boat. Both sewn boats and expanded log boats have very long traditions continuing up into modern times in Finland and other parts of Scandinavia as well as Russia and the Baltic states (McGrail 2001, p. 192 & there sited references; Nylén & Schönbäck 1994a, p. 68ff), the building of such a boat was documented in both the 16th century by Olaus Magnus and in 1935 by Eino Nikkilä in Finland (http://www.fotevikensmuseum.se/sewnboat/tunaboat/asp.html).

The remains of boats are many and the finds suggest everything from small vessels of around 4-5 meters up to big ships of 20 meters and more, which speaks of their wide use in Iron Age society. And the continued use of boats of almost exactly the same type in modern times for river travel might say something about how effective, important and perhaps also how common they were.

2.0 Method and theoretical perspectives

2.1 Least Cost Path Analysis

For this study, I am going to use Least Cost Path analysis (LCP) to explore the possible routes that people transported iron from the production areas to the areas where it was either used or traded. This function within GIS is available in all large software packages, but for the

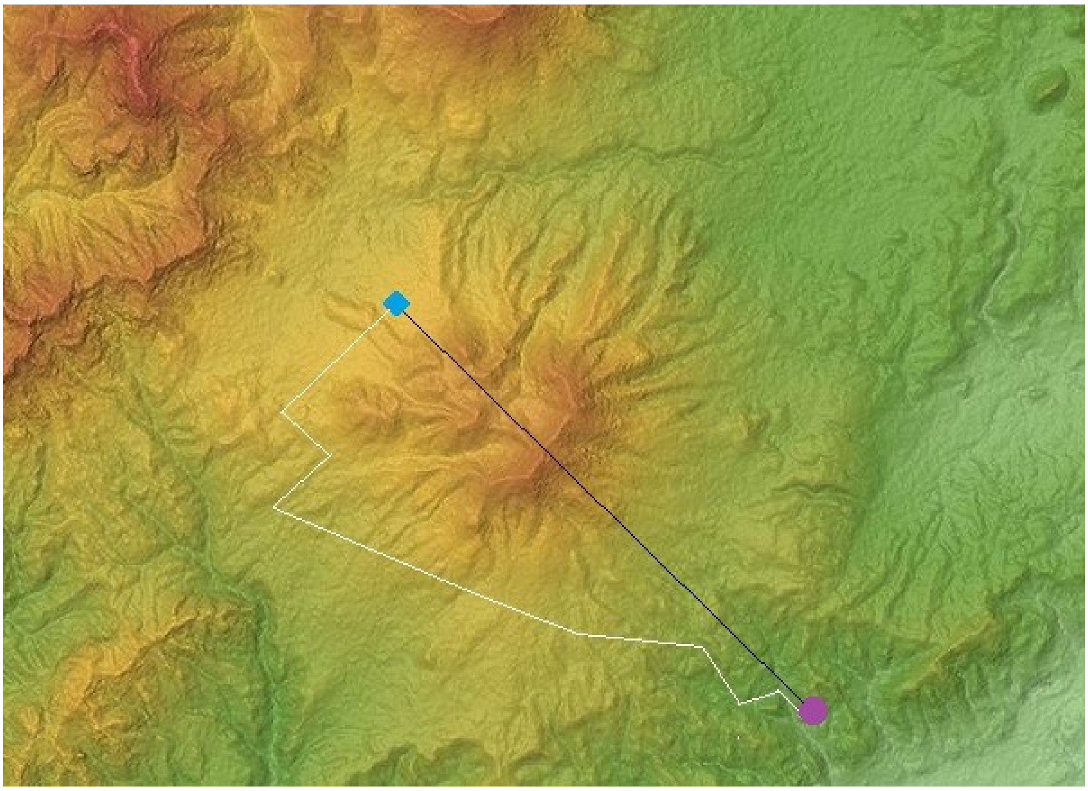


Fig. 1. This is a simplified illustration of the basic logic behind the application of Least Cost Path analysis. There is no doubt that the black path is the shortest and the white the longer. However, because of the changes in the topography, the black path will have to transverse very steep terrain, and spending a lot of energy in doing so. The white path instead cross much more even terrain with only gradual changes over longer distances and for the most part the sloping terrain is crossed perpendicular to the slope. Meaning that the curve of energy expenditure for the white path is much more even than for the black one. If the hypothetical traveller also is transporting something the white path would be the preferred one as moving heavy loads in steep terrain increases the expenditure fast.

purpose of this thesis, Esri ArcGIS 10.5 is going to be used. Tests in QGIS 3.0.1 is also carried out in order to compare the two but for the analysis itself, ArcGIS was chosen because of its user-friendliness. Least Cost Path analysis makes use of the idea that humans tend to reduce the amount of work needed to procure something, whether it is travel distance, speech or any other important function with an end goal. This observation has been defined and termed by the philologist George Kingsley Zipf as the Principle of Least Effort (PLE) (Zipf 1949). LCP analysis makes it possible to model hypothetical networks between several cultural nodes in an ancient landscape, building a reconstruction of something that otherwise would be largely hidden. In this way, complex questions of a political, social and economic nature can be explored.

In its simplest form LCP analysis can be described as using a raster dataset (that is data consisting of cells or pixels which all have values assigned to them), a path from point A, at one side, to point B on the other side has to be found. An algorithm is applied to the dataset which evaluates the surface and finds the path of cells adding up to the lowest total value possible. If the cells would all have the same value, the fastest path would be a straight line from A to B. When the values assigned to each cell in the raster dataset equals a real-life situation, for example, a hill or depression in the topography, the cells will all have different values making the calculation of the path more complicated as the algorithm now has to find the neighbouring cell with the lowest value, move to this cell and do the same thing again and so on. This all, of course, gets done in a matter of seconds depending on the size of area evaluated. In this way, the algorithm finds its way through the dataset from point A to the finish at point B showing the path adding up to the lowest amount of cost (Surface-Evans & White 2012, p. 2f). Different choices can be made by the user as regarding what algorithm to use for the calculation of the LCP. The two main ones used within the world of least cost analysis as well as the game developing world is the Dijkstra and the A* (pronounced A-star) algorithms. The Dijkstra, proposed by Edsger Dijkstra in 1959, works in the way that it performs a search of the whole surface, when the least costly path has been decided the algorithm can be stopped, usually saving time. It has been described as a *greedy* algorithm for the reason that it searches for the least costly route without regard to things like accumulated travel distance. The A* algorithm was proposed by Hart, Nilsson, and Raphael in 1968 and builds on the Dijkstra algorithm but it executes the search of the surface in a different way. It follows the path of lowest cost but in the same time it keeps in memory other possible paths to take, and if the cost of the path that is being followed suddenly exceeds the cost of another path the algorithm switches over to the new path. Until the algorithm reaches its destination this procedure is repeated. The fundamental difference between the use of these two algorithms is that Dijkstra is certain to return the path with the lowest cost every time it is run, the sacrifice is that it might take longer to do so. The A* algorithm is faster but the accuracy is not as good (Surface-Evens & White 2012, p. 4). Because of these fundamental differences, the one most commonly integrated in GIS software packages is the Dijkstra algorithm. So is the case with ArcGIS which is used for this study.

The type of data used in the process can be a mix of several types of data as long as it is in raster format. Usually, it consists of a Digital Elevation Model (DEM) showing the topography of the landscape in the form of a raster, as described above, and another raster dataset showing other things in the landscape such as vegetation and water, this is typically referred to as a Land Cover Map or a Land Use Map. Several such maps can be used to make the process more informed. Also, the impact of certain cultural aspects such as territory and religious areas can be included in the dataset. You can then either restricting movement through the area or allowing it by assigning either high or low values to the cells within the area (Surface-Evans & White 2012, p. 4f). If LCP analysis is implemented right is has the ability to make visible the most cost-effective route for travel through the landscape. In effect making it possible to foresee the areas where people in the past most likely moved themselves and goods, which also means that these areas are more likely to contain remains from human activity (Risetto 2012, p. 12 and there cited references). Thus, LCP is an important tool in predictive modelling. However, when using these methods, it is very important to understand the limitations of the same. It is not a magic process in which you input whatever data you have and get a clear answer in the end. The data that you put in, as well as your knowledge of the many parameters that can be changed in order to affect the result decides the quality of the analysis, and the results still need to be interpreted by the archaeologist in order to actually mean something. It is just a tool, and like any other tool, the job is done by the one holding the tool, not the tool itself. Further, of utmost importance when working with these kinds of spatial analysis tools is that the usage of it is accompanied by critically evaluating the method and discussing it from both a methodological as well as theoretical standpoints, highlighting issues derived from both (Surface- Evans & White 2012, p. 1f).

2.1.1 Usage in the field

To illustrate a typical way of using LCP modelling in the field the example below was chosen. In many ways, this study by John D. Rissetto has a lot in common with my own study in that it is evaluating distance in comparisons with the cost for paths in the landscape and uses settlement areas as well as procurement areas to pinpoint the areas to be connected.

In this article Rissetto performs a re-assessment of the models for procurement of resources in the high relief landscape of northern Spain. The old models used straight line measurements and a radius of about 25 km to determine the likely area for resources to be collected. When testing this model, he found that the majority of traceable procurement areas ended up outside this radius of 25 km thus instigating the need for a modified approach (Rissetto 2012, p. 11). Unlike the old models which are hard to modify to fit the individual researchers own interpretations, Rissetto states that LCP offers the opposite. More data can be tested and the analysis can be modified easily to fit the individual’s needs. He also points out that the use of LCP allows the researcher to determine new areas of interest for the localisation of new sites, thus predictive modelling. Through the studies of lithic materials, the geographic distribution of groups in the landscape are defined. And through further studies of the lithic material, for example petrographic and trace element analysis, the material can be traced to geological formations in the landscape. The results thereof establish whether the material is sourced locally or nonlocal. From this, questions regarding social interaction can be drawn, for example exchange and trade, migration of groups and personal contacts (Rissetto 2012, p. 13). The information from the lithic studies pinpoint areas of procurement in the landscape in connection to settlements. Between these areas LCPs are generated to find the most cost effective route through this high relief landscape. The results of his study showed that the distance of the generated lowest cost routes in many occasions were about double the distance of that generated with straight line measurements. And that the old assumed distance of travel of 25 km for the procurement of lithic materials is not a realistic one. A strong relationship between the distance to each procurement area and the percentage of lithic material from that source could also be seen. Rissetto points out a few problems with LCP modelling, first he argues that the calculated paths may not be true to the reality as people do not always act according to the principle of least effort. Things like individuality, culture and environment all have an effect on how people choose to do things. Secondly, it is hard to archaeologically test whether a certain path was in use or not because of the nature of the archaeological circumstances concerning the traces of paths. However, Rissetto states that despite these difficulties, the usage of LCP far exceeds the old models in usability as well as how well it represents real events. The generated paths are based on topographic slope which in a high relief landscape can be expected to have changed little since the Upper Palaeolithic period. Because of this and if it can be assumed that Paleolithic hunter-gatherers over time kept to economically efficient strategies, it can be argued that the use of LCP makes it possible to build an empirical and heuristic model of past human movements (Rissetto 2012, p. 26f).

This example of the usage of LCP in the field really highlights its capabilities of renewing our understanding of patterns in the landscape, adding to a more fluent and reality-based modelling approach. In the case of the critique towards old models in this article, the inadequate usage of straight line measurements in a high relief landscape cannot be stressed enough. And even though this application of Least Cost Analysis is at the more simple end of the scale it shows great capabilities. And as Rissetto points out at the end of his article, adding more and different data to this study would make it more informed. And tweaking the methodology to include things like anisotropic measurement of direction and human biodynamics, that is caloric energy expenditure, could potentially yield slightly different and more informed results (Rissetto 2012, p. 28).

2.1.2 Limitations

As most of this thesis handles and talks about the applications of GIS as well as the many advantages of the different methods to which GIS is an essential part, I will in this part discuss the limitations of GIS and its uses. Every application of methods and tools has its limitations, and it is important to understand these just as well as the things that are possible to achieve with the same.

One thing that is of great importance but that at most occasions are hard to get to is the effect cultural beliefs, traditions and other things alike, have on the course a road takes, as pointed out by Rissetto above. Some things are easier to include as for example territorial borders and perhaps religious areas, but what we know of the beliefs of people of the past is supposedly only a fraction of what their culture contained of “do's and don'ts” as well as of stories shaping how they saw and interpreted their soundings. In a landscape as remote as the forested northern parts of Scania, south Halland, and south Småland, during late Iron Age, it is hard to evaluate what cultural aspects might have shaped the course of the path. What we know today there were no major settlements that could have changed the course of travel, either to go around or through. Presumably, the goal of transport was to get to the destination as quickly and as safe as possible. Safe though might be split in two different categories, the avoidance of immediate physical danger and the avoidance of danger on a more spiritual level. We know that for example seafaring people in more modern times, the 1600s, 1700s, 1800, and 1900s, were part of a whole world of taboos, omens, and rituals in order to avoid danger and death (Westerdahl 2008, p. 21ff). To say that the people of late Iron Age, subjected to similar or different dangers would not have had a similar world of things to do and avoid would be to put the Iron Age people in a different box of humanity than more modern people. What this means is that we always have to view the data we use for spatial analysis, as well as the data we obtain from the same, for what it is, part of a plausible chain of causes and events. It is not something that is written in stone, and the full picture is never obtained. This, of course, is something that goes for all archaeological research, but it is something that can easily be forgotten when you, from a digital analysis, get what can appear to be a clear and final answer. The reality is always so much more nuanced than it might appear at first glance.

When trying to predict the existence of unknown sites in the landscape one should perhaps be a little sceptic to a too avid use of this method to explain humans' relationship to the environment (Conolloy & Lake 2006, p. 35). Predictive modelling has been accused of being somewhat "environmentally deterministic" (Witcher 1999, p. 4), reducing the past to a chain of events completely dependent on the landscape, eliminating the human aspect of cultures and settlements. As previously mentioned there are a number of things that are undetectable and that most certainly had an impact on people's decisions in the past, these sensuous geographies, as well as auditory and emotional geographies, are of apparent reason hard to get to. The world of the past is not just visual and what we perceive of it is bound to our own culture and therefore shifts through time (Witcher 1999, p. 7).

Thus, what is important to remember is that in order to be as sensitive and objective as possible we need to understand that we cannot assume that people in history were different from us in that they had the same basic needs, both physical and spiritual. At the same time, we have to see that just because the first might be true does not mean that we can assume that their experience of and outlook at the world was the same as for us today.

It is important to take into consideration the landscape as a whole when talking about traveling, and specifically how the landscape appears at the level of the traveller. It is easy to get stuck in our birds' eye view that is available to us today, making it easy for us to see the big picture. But, in doing this it is also easy to lose the scale on which ancient people saw the same environment. The ability to create viewsheds in GIS can at occasion be of help here. Constructing a digital model of the elevation (DEM) of the landscape makes it possible for us to see and calculate how much of the landscape a person on that specific spot is able to take in under ideal conditions. The limitation of this is that the viewshed itself does not contain any information of the ancient landscape and environment as it is a model of what is there now in modern times. Meaning that if the landscape has been changed in any considerable way this information will be overseen, and further the environment in the form of woodland is not accounted for either. It almost goes without saying that a heavily wooded area is harder to navigate through than a grass plain. For the sake of this limitation, viewshed is not used in this study. In order for it to be really applicable in woodland areas a way of remodelling the ancient tree growth has to be developed, otherwise, the information obtained from the viewshed analysis could easily be misleading.

2.2 Theoretical underpinnings

2.2.1 Networks

As previously stated, this thesis will try to form a better picture of the intricate world of goods transportation, principally iron, and try to make visible the networks behind this goods trade during the latter part of the Iron Age up to the early Middle Ages in the north of Scania, south of Halland and south of Småland. The goal is to get a little closer to an understanding of the possible communication routes that people took when transporting iron through the landscape. Different possibilities are examined using Least Cost Path Analysis applied to a case study of two areas which show signs of iron production during the latter part of the Iron Age up to the early Middle Ages and have access to good communication routes, namely Lagan and Helge å. Iron production commonly makes use of three main assets in the landscape, forest, closeness to water and ore, that is fuel for the furnaces, water either for transportation or, in later times, power and raw material for the making of iron. What is more, we are humans and thus need water to survive. Following will be a theoretical discussion concerning transportation and networks as well as continuity and peoples' movement in the landscape, and what theoretical perspectives can help to enlighten the analysis and understand the results thereof. Theories of entanglement, networks, and spatiality will be discussed, I also briefly get into some aspects of ethnicity as this aspect has evolved within the field of iron and become an interesting debate in recent years, regarding people involved in the production of iron.

The one theoretical perspective that most strongly caught my eye when reading the literature was World System Theory (WST). Initially developed by Immanuel Wallerstein in 1974 who first exclusively applied it to the fifteenth and sixteenth-century capitalist world of Europe, it was soon picked up by other researchers and applied to much earlier periods (Harding 2013, p. 378f). It is in many cases used to study the links between core areas and peripheries and how the first effects the second through trade of, among other things, prestige goods and how this affects inequalities of power in the periphery societies. In its most basic form, it is a means of describing or maybe understanding why one area becomes dependent on another and in extension how changes in the first shape the second (Harding 2013, p. 379). WST is a top-down approach looking at the larger world and the connections in it, trying to see where the connections are and how the networks flow. A drawback of this thinking can be, as when applied to Bronze Age Europe, that strong influential contacts can be viewed as more important for innovation than they really were, the “Mycenaean fascination” as it was called by Henrik Thrane (Thrane 1990 in Harding 2013, p. 389). Although it is called World System Theory it has been showed that applied to a more localised context one can derive at much more plausible conclusions and more clear narratives. The average person living during the times we study would most likely have experienced the local world first and foremost (Harding 2013, p.394), and if it is through these people’s eyes we are trying to see the ancient world, maybe this is where we should focus our attention. As argued by Carl Knappett, WST is by large forgetting the individual and the contact taking place on an individual level, as well as leaving things like gender and identity at the door. Further, its ability to distinguish periphery from core areas is flawed (Knappett 2011). As a top-down approach, this way of thinking might have a limited usefulness for my research questions as not much of the network of trade flow of iron in this area is known in a larger context, that is how, if at all, different nodes are connected. In other words, as no clear image of this network exists applying a reverse engendering way of thinking will have limited effect. Analogies to other more well-known networks can, of course, be drawn as applied by many archaeologists around the world. This tactic is among others used by Anders Ödman in trying to understand transportation of iron during the Middle Ages in connection to Skeningeborg in northeastern Scania and Helge å area (Ödman 2005, p. 147- 154). This way an initial picture can be painted on to which more localised information can be applied, gradually building a new unique picture.

Instead, what is needed is a bottom-up tactic which starts with the detailed data building a bigger picture from this. Network approaches like Actor Network Theory (ANT) might provide a better way of thinking here. Examining the specific data of individual contexts, identifying links to other contexts, building a picture of nodes and how goods flowed through them (Harding 2013, p. 391). As Harding says, “In identifying links we need of course to have regard to what we know about workshops, in other words, where objects were actually manufactured, before examining where their products ended up” (Harding 2013, p. 392). This will seemingly not be a problem for the material concerning iron-distribution as the sites where the production took place is most clearly visible in the archaeological contexts. A big advantage with ANT, and other branches of Network Theory, is that the bottom-up approach remains true to the archaeological data as well as allowing for the addition of new data, making it easy to test hypotheses. It also means that the archaeological material has a chance of being contextualised before it is attempted to be understood within a wider context (Harding 2013, p. 394). But of course ANT also has its problems, one of which if not addressed can have unwanted effects on my own work. Knappett argues that ANT tends to forget or does not go far enough in exploring the structure of networks, both up close and from afar, and thus misses key factors to the behaviour of the networks in question (Knappett 2008, p. 141f). When humans and non-humans are bunched together in complex collectives there must emerge some sort of network, even if it might be shifting and dynamic. He continues to say that there is a big bias in ANT towards the idea that any gradient of complexity must be either “chaotic” or “commanded” when in fact the typical social network falls outside both of those categories. Instead, they usually form a hybrid of the two having both aspects of commanded and random appearances. This requires that we, in the study of networks, have to be more flexible and develop more particular methodologies to apply to that specific network currently studied (Knappett 2008, p. 142). However, this is of course in much a process of trial and error, and should not be something that is expected to work out perfectly the first time. ANT in its purest form, if one can use such terms describing theory, should then perhaps be seen with more critical eyes and instead a more dynamic and fluent approach should be taken. One does not want to be stuck within the borders of one’s own tools, we as archaeologists must make the tools work for us, not us working under the circumstances set by our tools. The implications this has for how I will approach my own research questions is that I have to be mindful of not getting stuck in my own methods, but I also believe that in using a bottom-up approach the methodologies have to be fluent in order to get anywhere at all, tweaking it to fit the circumstances of each individual site used. ANT definitely has a lot to offer to the way I approach my material only it requires that the nature of my material is allowed too chose the particularities of the methodology I develop. And as Knappett suggests, focus more on things like the contiguity, factorality, causality, connection and resemblance of collectives, more then has traditionally been done in the past, in order to say something further about how the network behaves (Knappett 2008, p. 143).

Not only the purely actor based aspects of network, as mentioned above, are of importance when it comes to study of networks in the landscape. Of great importance is the natural landscape itself, how it is shaped and how it allows movement. Arjun Appadurai opposes this view, and in his article *How Histories Make Geographies: Circulation and Context in a Global Perspective*, he states that we need to lose the idea that there is a spatial landscape on which history plays out, and that we need to recognise that history (actors, institutions and powers) creates geographies and not the other way around. There were no pre-existing landscapes in which people could act (Appadurai 2010, p. 9). Although this is true for landscapes of economy, religion and other inherently human based geographies, it is simply not applicable to the physical natural landscape, the geography of the physical world. Thinking in this way when studying networks of trade and flow of goods would leave out a huge factor which is the limitations and the possible advantages of the landscape when it comes to how people move and interact in the physical world. As in the case with Knappett’s critic towards commanded and random networks, I believe that one cannot force the geography, in this case the landscape, in to a single category of either natural or as created by historical actors. Most certainly, humans do not build mountain ranges or create rivers. The shifting environments that people of historical and prehistorical times lived in surely was affected in many ways and to different degrees by these actors themselves, but how and which actions affected the surroundings most likely has to do with how nature was shaped in the first place. As in the case with iron production, localities for these activities were chosen because of the abundance of raw material and perhaps also ease of transportation. Thus, none of these activities would have affected the surroundings, if nature had not been providing the necessary ingredients. In a similar way as to how the landscape has had an effect on how networks were shaped, probably so has the thoughts and perspectives of Path Dependence. Path Dependence (PD) can give us some new and very interesting understandings into why some networks are shaped the way they are. It can also help us track previously unknown contacts through the study of, for example, objects that are not locally produced, which instead has been brought in overseas and traded close to the coast. If these objects then are found further inland, we would presumably be able to say that they have ended up there by means of secondary hands. Thus a hypothetical link can be drawn between these two nodes (Blake 2013, p. 10). The basis that PD rests upon is the notion that it is easier to take the already existing track instead of creating a new one. And collaboration with people that one already shares a history or common ethnic grounds with are much easier to interact with. If this is the case, then one way to trace networks is to look for these shared ethnic or otherwise material similarities. These two then has a higher likelihood of also being connected with each other in a network either directly or through other nodes. Further, if there exists already fixed infrastructure like roads or waterways between two or more nodes the chance of the pattern to change over time or suddenly is very slim (Blake 2013, p. 5ff). The implications that this might have on the work of tracing the paths that the iron took from the production sites to the places of commerce are twofold. First, as stated above, contexts sharing similar objects or maybe sharing the same time horizon, can be linked together. In this way the number of contexts can be thinned out leaving the ones of interest. Secondly, activity in or around the production sites belonging to earlier, or indeed later periods, which can also be linked to the coastal areas, should not be leaved out of the equation, because of the factor of PD. The answer to why a particular pattern looks the way it does, maybe should be sought in earlier periods. This all emphasises the need of not being too focused on one thing, in this case the iron itself, but actually widen the perspective to include other material culture, looking at the regional distribution of these other objects (Sindbeak 2013, p. 73) and tracing the iron through the actors not through the iron, as it itself cannot travel. Søren M. Sindbeak talks about “affiliation networks” which basically means that groups sharing some type of material culture, artefacts or other, runs a higher chance of having had some type of contact, be it trade or some other type of relationship, then those that do not share any type of material culture (Sindbeak 2013, p. 75). Thoughts of affiliation networks can have some positive effects in this study of networks but then again it can be argued that Iron Age Scandinavia by large shares much the same material culture and perhaps even more so on a regional level and thus it would be hard to distinguish affiliation. As an example of when this type of correspondence methodology does not quite work, one can mention a study by Thomas L. Evans carried out in 2004. The study looked at burial practises and artefacts of Hallstatt Finale and the La Tène Moyenne periods in north-eastern

France, trying to get to a closer understanding of social status and gender using affiliation. The conclusion was that the material showed predominately similarities (Evans 2006, p. 52f, 58) and thus not much could be said in the end. But let's return to PD for a little while. The difference between the Scandinavian iron production and the example of pre-roman trade and ethnicity brought up by Emma Blake in her article *Social Networks, Path Dependence, and the Rise of Ethnic Groups in pre-Roman Italy* is that she is working with groups that already before contact were established social and ethnic collectives. This seemingly has not been the case with the iron producers of northern Scania, whom presumably belonged to the same ethnic sphere as the people using the iron in the end of the chain. However, as being a well-studied area, ethnicity has many times been shown to be something that is created in opposition to something else. In other words, new ethnic groups have been created within the same larger social sphere throughout history (Lucy 2005, p. 184, 191f). Thoughts of us and them may well have circled in these areas of production and thus in time created different ethnic groups. This is something that Bo Strömberg has begun to explore to some extent in his book *Det förlorade järnet*. He builds his argumentation on a discussion by Mats Mogren in which Mogren discusses borders and how they are predominantly something that live in the mind of people and are created in a cultural setting. They can create identities and make people think in terms of "us and them" and likewise they can also create a feeling of fellowship among people in the periphery and feelings of hostility against centres of power (Mogren 2008, p. 190). Strömberg states that when the barrier to the un-utilised landscape of northern Scania, south Halland and south Småland were crossed, and new knowledge of how to best take advantage of the resources present there was being built, this also initiated the shaping of a new local identity (Strömberg 2008, p. 77). Therefore, ideas of PD as connected to affiliation might still be useful as there is the possibility of there being differences between the hypothetical groups, thus making possible similarities appear in a new light as indicating a linkage not just the same cultural sphere.

Yet another way of thinking of the group producing the iron is as partaking in the "frontierial push" expanding in to the relatively uninhabited areas of northern Scania, Halland, and Småland. Perhaps backed by influential powers in more central regions in order to secure different resources, being a direct link to other regions and perhaps even a subject to the ones with power. Frontiers, no matter where they have occurred have in different ways been the catalyst for fusion of groups into new ethnicities and new ways of life. Usually, the frontier is recognised as a sort of "no man's land" between two areas of two influential groups, sometimes forcing people to live in a new way in order to deal with new circumstances (Naum 2010, p. 101-104). The resulting group of this fusion would then bear ethnic components from more than one group, a fusion group. But in the case of Scania, Halland, and Småland there are no groupings pushing back and to interact with. But as argued before, a new ethnicity can still arise built on differences like power, wealth and a feeling of otherness. Maybe these potential attributes are somehow traceable and somehow might shed a little more light on how the networks of iron trade in the area were constructed during late Iron Age up to the early Middle Ages. It is most certainly safe to say that any network regardless of when or where is extremely hard to understand in depth. And working with something that in most parts are ideas and thoughts, of those who inhabited those networks that we study, makes it even harder as we are trying to find meaning to objects location and journey. Trying to find patterns and at the same time being painstakingly aware of the fickleness of humans.

Not all the different perspectives presented here will be used in the coming chapters, as this would require many more pages to fully explore. Of these predominantly network-based theories, the two perspectives that will make up a large part of the theoretical framework for this study is Path Dependence and Actor Network Theory.

2.2.2 The theory of GIS and LCP

Perhaps one of the most important things to understand concerning GIS and digital archaeology in general, in order to apply and use these techniques correctly is its limitations and drawbacks. Equally important is it to understand that digital methods, regardless of which, is not an end in itself but a means to an end (Surface-Evans & White 2012, p. 1). However, for it to be used as a means to an end it has to be applied right otherwise problems will occur down the line, making data hard to use or even unusable. This has been a problem in commercial archaeology, where a lag in the adoption of techniques as well as inappropriate use of task-specific programs and hardware has led to work being unusable in later steps of evaluation and interpretation (Backhouse 2006, p. 44). Furthermore, when applying the arguably right methods it is vital that the model builds on documented actual past human conditions, constraints and actions, in order to put out an answer that can be used as an argument in the discussion (Binford 1980).

Two main views exist within the application of digital methods in archaeology. Followers of the first view argue that digital methods are at their core methodological, used to solve problems instigated by theoretical as well as narrative questions. These methods are seen as being almost anti-theoretical, in the sense that they themselves do not have any theoretical bounds but can be used to serve any theoretical line of thought, which make them no different from ^{14}C-dating or techniques of environmental reconstruction. In the second view digital methods are seen as a catalyst and even the creator of new theory. Mainly this would be because digital methods have been able to reintroduce the individual as the main actor, getting closer to what mentally would have been the drive for a certain action, while still being able to keep the big picture (Zubrow 2006, p. 9). I would argue for the existence of a more malleable third view as a mean between the two. The second view is not only the one most frequently referred to but also the one needed to actually use new methods empirically. Claiming methods as anti-theoretical as in the first view just means that a theoretical discussion is deliberately avoided as all methods we use are affected by our subjectivity as humans. However, to know where we are going we need to know where we have been, and to simply make up new theory and discard the old that has been borrowed from other applications is arguable as narrow sighted as the first view. A third view then would allow for both to have their place, creating new theory but doing so by really evaluating the old, and also not over-theorise, as this might lead methodological and theoretical blockage.

In landscape archaeology, of which GIS very much is a big part, three trends within theoretical thinking can be spotted. These also vaguely reflect the history of theory in GIS (Chapman 2006, p. 18). The trends have been termed normative, processual and theoretical. The first one is the descriptive method of recording and interpreting patterns through the distribution of objects, building theories on which boundaries defining different cultures, among other things, are based. Because of the fact that these boundaries are made up and pretty much no place is left for cultural anomalies, critics accuse this approach of being descriptive as well as deterministic. Change is often described in terms of migration and diffusion and less so on evolutionary grounds (Binford 1964) and what is derived will usually be descriptive in nature (Chapman 2006, p. 19). The second trend, processual, gets a lot of its elements from New Archaeology. And as the paradigm developed in the 1960s-1970s, more attention was given to striving to become more scientific and multidisciplinary, explaining instead of describing. Positivistic thinking influenced many aspects of this trend. And as in natural sciences, the testing of theories, in order to with larger certainty say something, is important. Critics argue that this way of approaching the landscape inherently forces one to draw general conclusions from the results retrieved, because of the nature of archaeological material (Chapman 2006, p. 20). Some argue that even this approach is deterministic in nature (Bradley 1984). The last trend, theoretical, is as it sounds the most theoretical in nature of the three, taking a predominately humanistic view on the archaeological material. The unseen aspects of nature and culture are at heart here, bestowing the landscape with meaning in itself. And people's relationship to said landscape is a non-fixed connection continuously changing, and thus the landscape is also continuously changing on a physical and metaphysical level. One could, of course, put forward the critique that this approach never will go beyond speculative answers and thoughts as it in large parts moves in realms of information that is and will always be, unobtainable. Only the physical changes of the relationship between actors and nature lend itself for measuring and investigation (Chapman 2006, p. 20). As digital methods are applied to landscape studies, largely GIS, one finds oneself in a theoretical tug between the two last approaches (Chapman 2006, p.21) if not actually all three. Zubrow ascribes this to the fact that GIS still, and definitely in the 1990s, is a relatively young technique, meaning it has had less time to mature (Zubrow 1990, p. 69). However, now somewhat 27 years later, I would argue that the tug is still very much present.

What can be seen from these two examples of approaches within digital methods generally and in landscape archaeology specifically is that the usage of these methods always seem to fall outside the existing theoretical approaches, borrowing from several approaches if not all, not being static but moving as the questions change. This leads me to think that GIS and digital methods in large perhaps by their changing nature, dependent on the application in question, cannot and perhaps should not be expected to find its place, so to speak. Not saying that it is anti-theoretical, but more theoretically fluent, creating and lending theory as it evolves and moves in different directions.

One critique of the application of digital methods on human conundrums that is important to keep in mind is that we try to fit these conundrums into the boxes of numbers and statistics. Turning human actions, driven by a huge variety of circumstances, into a graspable graph possible to be explained in some form or another. We try to do this even though it has been proven and proven again that the human brain does not operate in terms of numbers. It does not follow the rules of sequential actions that algorithms do (Zubrow 2006, p. 15). This means that digital archaeology can never be used to paint the whole picture, however, it is a good tool for the engendering of approximations for the filling of gaps in the information we can obtain from other sources and to make connections between the two (Evans 2006, p. 52). The people of the past did not have GIS in order to find the least costly route or the area with least amount of travel needed to obtain sources of food and material. Completely different reasons may lie behind the placing of a site on that specific spot. However, there are some aspects of humanity that seems to lend itself to make some observations as well as conclusions when it comes to saving energy. The theory at heart for the application of any type of least cost analysis is the Principle of Least Effort (PLE), presented by George Kingsley Zipf in 1949 in his book *Human behavior and the principle of least effort: an introduction to human ecology*. It argues that humans tend to economize whatever they undertake, whether it might be travel, speech or any other activity. For humans in the landscape this means that depending on the topography when moving from and to different points, this is done in accordance with the lowest cost possible. This in extension makes it possible for us today to trace these paths of lowest cost (Surface-Evans & White 2012, p. 2). This also goes hand in hand with Path Dependence, as discussed above. The least cost idea can thus be observed in a large number of different settings and studies.

In order to make the answers from the calculated LCP as informative as possible, the user should prior to the analysis, choose an appropriate measure of cost to display the differences between calculated scenarios. It is this choice of measure that makes it possible to say something about the reasons behind different choices that were made by people in the past. It is also the hardest and most abstract part of the whole analysis as is entails trying to think along the lines of the people we are studying. Three specific measures of cost can be said to be the standard and these are distance, time and energetic expenditure. The two first ones have been shown to have a lot in common and can almost be interchanged (Surface – Evans & White 2012, p. 5f). It has also been shown by Thomas R. Etherington and Penelope E. Holland that for the calculation of connectivity, that is what is measured between destination and source, the use of distance and time as measures are far exceeded by the use of accumulated cost thus energetic expenditure. They argue, as well as show, that in many examples, using distance and time as a measure, does not give more than using euclidean distance (Etherington & Holland 2013). How cost is measured also involves the means of transportation, and the different options we assume that the people we study had available to them (Surface –Evans & White 2012, p. 6).

To conclude this chapter, one could say that it rapidly becomes obvious that to really be able to use these methods in any other way than just as a means of measuring distance, LCP has to be accompanied by the right theory, and which theory is the right depends on the user and the material studied.

2.3 Material

Data from several different sources were used during this project, chosen for the different aspects that they display. The data was critically and carefully evaluated before being included in the study. Another important factor in the choice of data was time. For the sake of processing times and data storage space as well as managing, not all possible data sets were included and compromises concerning resolution hade to be made in order to keep the size of files down and processing times to within the limits of the project.

Following is a list of all datasets used.

- DEMs derived from the Swedish National LIDAR survey, the average point resolution of this data is 0,5-1 point per m2. This data is then used to produce two different sets of DEMs, one with point spacing 4 and a cell size (pixel resolution) of 4 meters and then one with point spacing 1 and cell size 1 meter. Provided by Lantmäteriet.
- DEMs from the Shuttle Radar Topography Mission (http://dwtkns.com/srtm30m/). These have a resolution of 30 meters.
- Multispectral satellite imagery (Landsat 8) (https://earthexplorer.usgs.gov/)
- Soil type maps from the Swedish Geological Survey in shapfile format (SGU)
- Historical shoreline data in shapefile format of Scania, Halland, and Småland, provided by the Swedish Geological Survey (SGU).
- Orthophotos, modern, provided by Lantmäteriet.
- Orthophotos, 1960s, provided by Lantmäteriet.
- Historical maps provided by Lantmäteriet (https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/Historiska-kartor/)
- All iron production sites in Scania, Halland, and Småland as provided by FMIS (http://www.fmis.raa.se/cocoon/fornsok/search.html) processed and assembled by Andreas Svensson, Lund University.
- All known sites of sunken pathways in Scania, Halland, and Småland, provided by FMIS (http://www.fmis.raa.se/cocoon/fornsok/search.html).

To make some of the work in GIS easier, such as aligning historical maps and getting the names of streams right, information of parish borders and streams and rivers were used. This information consisted of:

- Parish borders, provided by FMIS (http://www.fmis.raa.se/cocoon/fornsok/search.html).
- All recorded water bodies, rivers, and stream, provided by Viss (Vatteninformationssystem Sverige) downloaded from "Länsstyrelsernas Geodatakatalog" (https://ext-geodatakatalog.lansstyrelsen.se/GeodataKatalogen/)

The study of ancient activities in contemporary Sweden using tools of remote sensing is made relatively simple when it comes to the gathering of data. Through agencies like SLU, Lantmäteriet, The Swedish Heritage Board and SGU data is available for immediate download or through a simple mail conversation. The LIDAR data provided by SLU, but gathered by Lantmäteriet, is of fairly high resolution (0,5-1 point per m^2) and can be made into whatever resolution one desires as long it does not exceed the resolution of the original data. Running an analysis on the highest resolution may cause problems in the form of long processing times and very large datasets. To remedy this, lower resolution can be used for large areas where a high degree of precision is not needed. When focusing on a smaller area higher resolution can be used in order to catch finer details, for example, the topography inside a settlement.

The LIDAR data, orthophotos and soil type maps were downloaded from SLUs online database GET, one of several places where this data is available. The data arrives in compressed format and has to be extracted. After the extraction the data was organised in to folders with appropriate names for easy access and organisation. The orthophotos, and soil type maps are ready to be used straight after the extraction, however the LIDAR data has to be extracted once more as the file format after the extraction will be in .RAR. After selecting the .RAR files and extracting these they will instead be .LAS-files. In ArcMap these files are then turned in to raster DEMs through the tools LAS to multipoint > create TIN > TIN to raster. As the area for this project is relatively large, the resulting amounts of raster DEM files are too many to work with in an efficient and practical way. And in order to use it in the creation of the LCPs the files have to be merged in to four larger DEMs. This applies for the smaller areas which will have the higher resolution in order to provide more details in critical areas, however for the larger areas the DEMs provided by NASA will be used. This is done predominately because of time and file size. All of the areas could be done in high resolution but would mean much longer processing times and much larger storing space needed.

2.3.1 Reflections of the datasets

Some things should be said concerning the circumstances and quality of the datasets listed above. As stated, the retrieval of data is made relatively simple today with all the available web-based databases providing said data. When it comes to the topographic data and orthophotos the quality is in large part very good and much better than what one could assume to have access to only a few years ago. The LIDAR data provided by Lantmäteriet, used to make the DEMs, do sometimes have problems with poor swath alignment making areas where lines of LIDAR points meet a little problematic. Another problem which can occur with the same data is that the filtering of the points sometimes leaves things to wish, meaning that for example traces of buildings can still be visible after the filtering of the points in to separate classes. This is not a particular big problem for this study as few developed areas of more considerable size are included in the study area. The density of the LIDAR points is as stated above 0,5-1 points per m^2. This is far from the highest resolution possible, comparing it to the Danish LIDAR survey which has a resolution of approximately 4 points per m^2, however for the applications here this is more than adequate. If higher resolution was available this could still not be used as the file size of a dataset with that resolution would be far too big to be practical. Already the difference in size between the 4 meter resolution and 1 meter resolution DEMs is considerable with the first averaging around 40 MB per area while the second one is averaging 600 MB.

The soil-type maps are in need of some discussion as well. This data is accompanied by a PDF explaining how the data has been obtained as well as the history of how it has been recorded as this has changed with the digitalisation of recording technique. The information in this PDF is what forms the basis for the argumentation in the coming paragraph.

The data is comprised of several decades of surveying in the field which begun in the 1960s, meaning that there are differences within the dataset, in the form of shifting accuracy as well as quality. From the 1990s the data started to be recorded digitally but up until this point all recording was done in paper format. This has, of course, meant that the earlier information had to be digitised from paper maps. This in combination with the fact that every surveyor in the field would use a slight variation in how and what is recorded means that some caution has to be taken when using said material. Before and during the process of this thesis project, an eye has been kept on this material to see if there are any large variations in comparisons with other data types showing, in this case, wetlands and areas of peat. However, no large variation was spotted and the conclusion was therefore drawn that the data is accurate enough to be used.

Some critic can be raised when it comes to using the soil type maps provided by SGU for the extraction of where in the landscape peat is present today. The way this information is used in this study is to estimate where there might have existed wetlands during history and pre-history. A short explanation of the creation of bogs is needed. When water levels rise and the wetness of the ground is altered in certain areas this leads to plants losing their habitat and dying. This in combination with the raised water table leads to anoxic conditions as the water prevents the breakdown of the plant matter. This makes for perfect conditions for peat moss, *Sphagnum*. As this group of species grows it covers large areas and soon it starts to cover itself as the first layer starts dying. Thus, a raised bog or mire is created. As it starts rising it also becomes separated from the hydrology of the area making it completely dependent on precipitation. As these mires grow they alter the landscape from dry to wet and thus can have large effects on the cultural use of the landscape (Chapman 2006, p. 120f and there cites literature). The problem here is the growth, making it almost impossible to know the exact extent of said type of wetlands during pre-history. A lot of these bogs were, of course, drained when the large-scale agricultural reforms during late 18th to 19th century proclaimed that wetlands should be diked out in the hunt for more arable land, thus stopping their growth. But the exact extent of these type of bogs in pre-history is hard to know in detail. The fact that so much of the wetlands have been drained in modern times makes it at least possible to say that the amounts of wetland present in pre-history would have been much higher. Because of this, I argue that the modern surveys of where peat is present today give a good approximation of where wetlands would have been present. Now, there is a difference in how different types of peat are created. In areas with low amounts of precipitation, peat created in fens are more common (https://www.sgu.se/om-geologi/). This would then mean that this type of fen-derived peat would reflect areas where higher water levels were present, like lakes or marshy land. What we have here then is two types of peatland indicating two possible historical or pre-historical conditions.

Moving on to the historical shoreline data, this is arguably the data providing the biggest uncertainty with its use. It is made by comprising digital height data with mathematic models for the calculation of shorelines. The model for these changes was introduced by Tore Påsse in 2001. It is based on observations of glacio-isostatic uplift and eustatic sea level rise, that is the rising of the land after being compressed by the inland ice sheet during the latest Ice Age and the rising water levels as a result of melting ice around the world. The glacio-isostatic uplift seems to have started around 16 000 BP following a period of deglaciation. It was then slowed down by a regeneration of the ice around 11 000–10 300 BP in turn followed by a fast deglaciation around 10 300-8 500 BP (Påsse 2001, p.10). Two main components can be observed in the uplift of the land. First there is the fast component, present during the deglaciation of the ice sheet, this made changes of shoreline occur fast. Then there is the modern slow component, giving way to gradual shoreline changes. This is the product of the slow uplift still occurring today (Påsse 2001, p.15). These changes are observed in conjunction with the modern shoreline to which values of the shifting slope through time has to be added as this is also affected by the presence of the inland ice sheet. From these observations mathematical models can be drawn which explains the shifts in the sea level both back in time as well as in the future (Påsse 2001, p.38). Both the course of rivers as well as the width of lakes has been affected, shaping a picture quite different from the hydrologic landscape we know today. However, the data created from this process, it has to be remembered, is almost completely derived from digitally modelling the process of shifting shorelines. The data has not been, as far as I have been able to find, tested in the field in an archaeological research context. Being estimations, the data cannot be expected to be the most accurate, meaning that if used to look at very detailed shifts in the landscape or chains of events, caution has to be taken.

2.3.2 Site criteria

The five sites used in this study were chosen for their character concerning length of use and placement in the landscape as well as their general dating. It is argued by among others Bo

Strömberg that many production sites could have had a long period of usage or seen periods of reuse in Medieval times (Strömberg 2008, p. 92). Something which definitely could be the case for many sites and can be seen at several excavated sites, showing a continued use of 400 years or more (Hjärthner-Holdar et al 2018). All sites have been dated with ^{14}C-dating and lay between the middle of the latter part of the Iron Age to early Medieval times. This window spans the time

Table of the sites used in this study and their ^{14}C-dates

	Number of samples	14C-dating
Markaryd	3	261-527 AD, 256-410 AD and 261-433 AD
Vittsjö 92:1 Lehult.Ö	1	1210-1400 AD
Vittsjö 25:1	2	1010-1280 AD and 1150-1400 AD
Farstorp	1	1160-1450 AD
Vankiva	1	170-620 AD

Fig. 2. The ^{14}C-dates for the site Markaryd are retrieved from Larsson, A-C. 2004. For the sites Vittsjö 92:1 Lehult. Ö, Vittsjö 25:1, Farstorp and Vankiva, these are retrieved from Ödman, A. 2001.

in history of which we know the least of the production of iron in the area. A time of many social changes, and it spans right to the start of when it is thought that a large expansion up into the uninhabited areas of northern Scania and Småland begins. As the size of this study has to be limited, relatively few sites were included. A larger material would probably be better, but as a springboard for further studies this is thought to provide a good start. A certain aspect of time also affected the choice of sites, as these sites were relatively easy to find in the literature.

3.0 Analysis

Before letting the analysis of a project like this commence it is a good idea to carry out some test prior to actually doing the work that is going to result in the final statements or ideas. This ensures the quality of the data that you have chosen, and it provides a good opportunity for learning and on a deeper level understand the tools available in the software chosen. Although the quality can easily be validated in the early stages of the work-flow, for example when calculating the statistic of the individual LAS-files. There will also probably be a number of things that have not been obvious when studying the data beforehand, which does not have to do with the quality itself but involves things like modern interference in the landscape such as modern roads, rerouting of waterways, modern earthworks, traces of modern buildings in the filtered points and more.

The tests done for this project can be found in the Appendix under the title *Testing the data, LIDAR and SRTM, and learning the tools.*

3.1 The two study areas

For this project, two areas of interest were chosen. These are the areas west of the river Helge å and south of the river Lagan, encompassing the rivers themselves. The two areas were derived from studying the spread of securely dated and somewhat loosely dated iron production sites in and around the area of northern Scania, south Halland, and south Småland. This is an area where a lot of sites containing slag, ranging from proto-industrial scale to just a few pieces, has been recorded. During late Medieval times up into the 17th century, this area grew into the largest iron production landscape in southern Scandinavia (Strömberg 2008, p.73). Thus, it is not strange that a lot of attention has been devoted to this area by several researchers ranging from the very start of iron research up until today (Nihlén 1932, 1939; Ödman 2001, 2005, 2009; Englund 2002; Strömberg 2008; Björk 2009 and others). Another reason why this area was viewed as interesting for this study is that the two rivers more or less have access to the same landscape but with good transport possibilities to two different coasts, west and east, lending for the possibility of many different scenarios. Moving outward from the larger rivers of Helge å and Lagan, through streams and lakes one reaches areas of intense and less intense, iron production from both the Iron Age, Middle Ages and Modern times, as well as a lot of undated activity. For reasons of limited time and work burden, strong restrictions had to be made concerning the number of sites included. The sites included were derived by a combination of dating and location in the landscape where the above mentioned link the two larger rivers were an important factor. For this study, five sites were chosen whereof only one can be associated with Lagan and the remaining four are in close proximity to Helge å. All of the sites have been dated with ^{14}C, although the accuracy of some of these dates can be discussed as some of them are based on only one sample. However, it is still an indication of activity during the time period in question. It might be seen as strange to try to get closer to an understanding of transport and movement during the latter part of Iron Age by looking closer at sites dated to early mediaeval times, but as outlined in the chapter Theoretical Underpinnings, important for this project is the perspective of Path Dependence. That is, an established track is often the one that sees continued use, as keeping to what is already established requires less of the individuals involved. Continued use of production sites has also been proved by excavations, for example at Motala ström in Östergötland where a production site showed signs of continued use over a period of 400 years (Hjärthner-Holdar et al 2018, p. 38), and at Ödeshög in Östergötland, a large site where 17 furnaces were excavated showed continued use from the Roman Iron Age in to the Migration Period with a possible continuation in to the Viking Age (Räf & Norr 2009, p. 59, 67).

When studying the two areas Helge å and Lagan from orthophotos, historical shoreline data, soil type data and proximity to streams, a few interesting observations can be made. To begin with, all sites except Farstorp are in direct contact with historical lakes. These lakes are now gone or have shrunken to the degree that the sites no longer are in the proximity of open water. Where these lakes once were there is now predominantly peatland, wetlands, and bogs. When including all dated and undated sites bearing evidence of iron production one can clearly see that the predominant part of sites are in close proximity to what today is peatland/wetlands, many of which were lakes in the past. When looking at the landscape from a hydrological angle it becomes clear that the ancient hydrological landscape is a completely different one from today. The number of lakes was much higher and the sizes of many now existing lakes were much larger. This makes it possible to loosely date some sites as clearly younger than the older shoreline of the lake in question. However, the data is not detailed enough to say anything more than that the site is belonging to the early modern/modern period, rather than Iron Age/early Medieval period. The data of historical shorelines provided by SGU does however not include the historical streams and rivers. Their particular extent during prehistoric times is not included, however, the older extent of Lagan and Helge å is obtained for this study from historical maps, but this data is a loose approximation at best as it reflects the extent during the 18th and 19th century and not prehistory. What it does is that it provides a picture of a time prior to large damming projects and hydroelectric plants in Scanian rivers.

3.2 The ancient terrain of Scania, an overview

For the remodelling of the landscape, I need to draw some assumptions regarding the landscape and how it might have appeared during the Iron Age. The assumption that there was more forest then than there is now is, of course, an easy one to make and it is in most part probably true, but as assumptions are only based on our expectations it is not particularly good to leave it at that. In order to remedy this, our assumptions have to be based on observations.

It is clear that it is the human factor, that is the biggest agent behind disturbances and deforestation during the Holocene. Developments in societies in terms of land use, technology and so on have all left their mark. These marks are in turn visible in the paleoecological material as phases of expansion and regression. In order to trace the land use of pre-history, the Indicator Species Approach or the Multivariate Correlation Technique can be used. The theory behind these is that as land use practices used in pre-historic times have also been used in modern times. Observations concerning species thriving in those conditions in modern times can thus, be used to trace the same kind of land use in pre-historic times in the paleoecological material, mostly by pollen (Berglund 1991a, p. 31 and there cited references).

Studies conducted using the above technique as well as among other things, coring, within the scope of the project *The cultural landscape during 6000 years in southern Sweden* showed some interesting results. The study is focused on the Ystad area of Southern Scania, but the changing conditions can be said to be valid for the whole of Scania. This is because the effect shown is mostly as a direct consequence of human interference, meaning that where there were fewer people the effect would just be less obvious and therefore the conditions more stable. In fact, similar conditions can be argued for in the whole of southern Scandinavia as similar conditions have been observed in the Danish islands (Berglund 1991a, p. 35 and there cited references).

Several interesting processes and correlations have been observed in the Ystad area. It seems that the climate during the Roman Iron age was favourable for human expansion with warmer temperatures indicated by retracting glaciers in the Scandinavian area. In around 400 AD they started expanding again, indicating cooler temperatures (Karlén 1988). In around this time, late Pre-Roman Iron Age and Early to early Roman Iron Age there seems to have been an expansion of wooded areas. This expansion continues in 300-600 AD. It is possible that this is an effect following that the villages of Iron Age society in Scandinavia starts to be more tightly organised during this time and thus structuring the land use more tightly in around the village (Berglund 1991b, p. 78; Näsman 1988, p. 204ff). This coincides with the so-called "crisis of the migration period" which stretched from around the 3rd to the 7th century, but not equally so for all areas. This period of decline in Scandinavia as a whole has been described by Näsman (1988). It can also be seen from pollen diagrams that forested areas became more closed thus less grazed forest from 500 to 800 AD, suggesting less cattle farming in outland areas (Berglund 1991e, p. 223). As previously stated this period also saw cooler temperature, perhaps a contributing factor.

From around 700 AD a large agricultural expansion started, coinciding with an increase in temperatures in around 900 AD and increasing the human impact on the surrounding landscape. This increase seems to have in general continued up until the 1600s. What can be seen from pollen diagrams is also that from around 800 AD up to 1500 AD there is a decline in forested areas and an increase of open land (Berglund 1991c, p. 82; Berglund 1991d p. 112; Berglund 1991e p. 223).

As stated at the beginning of this section it can be argued that the effects here shown in the south of Scania also reflects a pattern in more northern areas. The effects of human actions are to the largest degree what affects the spread or regression of forested areas. The human-caused regression is something that has been shown to increase with time, because of this the same effect can be followed backwards in time. Thus, this suggests that the landscape by large was more wooded during the Iron Age and that large areas of what today is arable land was covered with forest or shrubby terrain in pre-history.

3.3 Remodelling the landscape

In order to remodel the landscape closer to how it might have looked like during the Iron Age, Land Cover maps or Land Use maps are used. These are a combination of several types of information. Firstly, it consists of maps derived from multispectral images in which different colour returns have been assigned with different values corresponding to various types of vegetation and terrain. To make this process more efficient and to also make it easier for the naked eye to see the differences between for example thick forest and shrubs, the three bands of near infrared, blue and green was selected. The process of Supervised Classification is then used to assign the landscape with the different values. This is done by creating Signature Files which are samples of how the colour return for different types of vegetation looks, that is, which type of wavelength bounces back from which type of vegetation, simply put. As the same type of vegetation can give multiple types of returns, several samples have to be taken for each type of vegetation. But not only vegetation has to be sampled but also water and different types of bare ground, the more samples per different kind of vegetation and terrain the better. Each sample taken is bunched together into types of terrain or vegetation and are given their appropriate names. To create a good Land Use map around 5 or 6 different categories are a good reference. When this is done the tool Maximum Likelihood Classification (The Multivariate toolset in the Spatial Analyst toolbox) is used to classify the entire image (http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/how-maximum-likelihood-classification-works.htm & http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/maximum-likelihood-classification.htm). This gives me an approximation of where in the modern landscape forest, agricultural land, water, grassland and so on existed. The values for these different categories, that is how hard it is to travel through the different terrains, can then be decided by the user and based on, among other things, the observation that large parts of what is now farmland would then have been forest, the same value can be assigned to farmland as to forest. The output of this processes is a map in raster format. Secondly the Land Cover map can be added to from many different sources to more closely resemble a possible historical landscape. To do this it first has to be converted into a shapefile, which is done using the “Raster to Polygon” tool. Sources that can be used are for example historical maps, with which observations of the older landscape, like now gone forest areas, wetlands, river flow and the like, can be accounted for. Further data showing for example information concerning the geology to tell things like soil type and historical lakes from further back than maps can show, can be included. This information is stored in the form of shapefiles and the correct attributes for the areas are specified in the attribute table. In order to combine all these datasets, the “Erase” tool as well as the “Union” tool is used. Firstly erasing the area of the input data from the underlying features and then patching it up with the input data. After this is done the combined dataset is turned from vector data into raster data as the input of maps for LCP analysis is raster grid.

The values that are assigned to the different terrains are approximations of how labour intensive it would be to travel through the different terrains in comparison with each other, with the number of ten being assigned to the most labour intensive and the number of one to the least. These approximations are very important for the result of the analysis and it is necessary to understand one’s own influence on the final result with this step. However, subjectivity is something that never can be completely excluded and so, as long as the parameters for the study are clearly recited, this is okay.

3.4 Preparing the data

As previously explained the DEMs with the higher resolution (4 meters) will be used for the part of the landscape containing the source point to the intermediate destination. These DEMs now have to be made in order to get the analysis underway. The LAS files, first of all, go through the process of calculating statistics in order to make the process more informed. In doing so all the information available in every LAS file, like the number of points in every return category and thereby the accuracy for a certain category, is displayed and can be evaluated by the user. This step is also required for the next step which is clipping the LAS data so that only the files that are needed will be included. Calculating statistics and clipping the data is done with the external toolset of LAStools created by Martin Isenburg (https://rapidlasso.com/lastools/). This is a toolset created external to ArcGIS aimed at filling a gap which is not covered by ArcGIS itself. The tools used are lasindexPro and lasclipPro. After lasindexPro has been used to calculate the statistics, a polygon with the shape of the area that one wants to clip is created. This polygon and the folder, containing the LAS files as well as the lasx files created during the calculation of statistics, is then used as impute to the lasclipPro tool. The output of this process is a folder containing only the LAS files located inside the polygon used. With files located on the border of the polygon, only the points inside the polygon is kept. This step of clipping the LAS data is important as it makes the runtime shorter and the storage space required smaller.

The next step is to create the DEMs. This is done with the process of first turning the LAS data into multipoint files using “LAS to multipoint”. Using this tool, it is possible for the user to choose which class of returns to display, in this case, the ground. It is also at this point that the user can decide which point spacing to use, that is, if every point is supposed to be used or every fourth point or every tenth and so on. As previously explained, every fourth point is used in this case. From these multipoint files, Triangulated Irregular Networks (TIN) are created, using the tool “Create TIN”. What this does is that it connects every point making them nodes in an irregular network, effectively displaying the topography. The last tool to be used in order to create the final DEMs is “TIN to raster”. With this tool, the irregular networks are turned in to raster files displaying the information in cells instead of the more fluent structure of the TIN. It is now that the user can specify the exact cell size to be used, the right cell size is dependent on the intended application of the data. For the purposes here the same cell size as point spacing is used in order to match the two as best as possible as this approximately gives one point per cell. This is also the maximum resolution for this data as anything finer then cell size four would mean that data starts being interpolated from the surrounding values (http://desktop.arcgis.com/en/arcmap/10.5/tools/environments/cell-size.htm).

3.5 Generating the LCPs

In order to make the calculation of the LCPs as smooth as possible, I use Model Builder in ArcGIS. The Model Builder has many advantages compared to making every step one at a time. A Model in ArcGIS can be described as a workflow in which several different geoprocessing tools are linked together. The output of the first tool in the sequence becomes the input for the second tool, which continues down the chain until the final data emerges. For every tool used you can customise the environmental settings in order to eliminate the need for changing the settings every time the model is run. Some advantages of the Model Builder include: it keeps everything structured, an important factor when working with large amounts of data, it saves time as it allows you to save the model and thus, make it easy to implement it on whatever dataset you like, minimising the amount of clicking that has to be done and last but not least it makes it easy to display the workflow for other people, thus contributing to the transparency of the work.

The input data to the model created in model builder is the source point and destination, land cover map, slope and depending on from which point the LCP is calculated either the 30

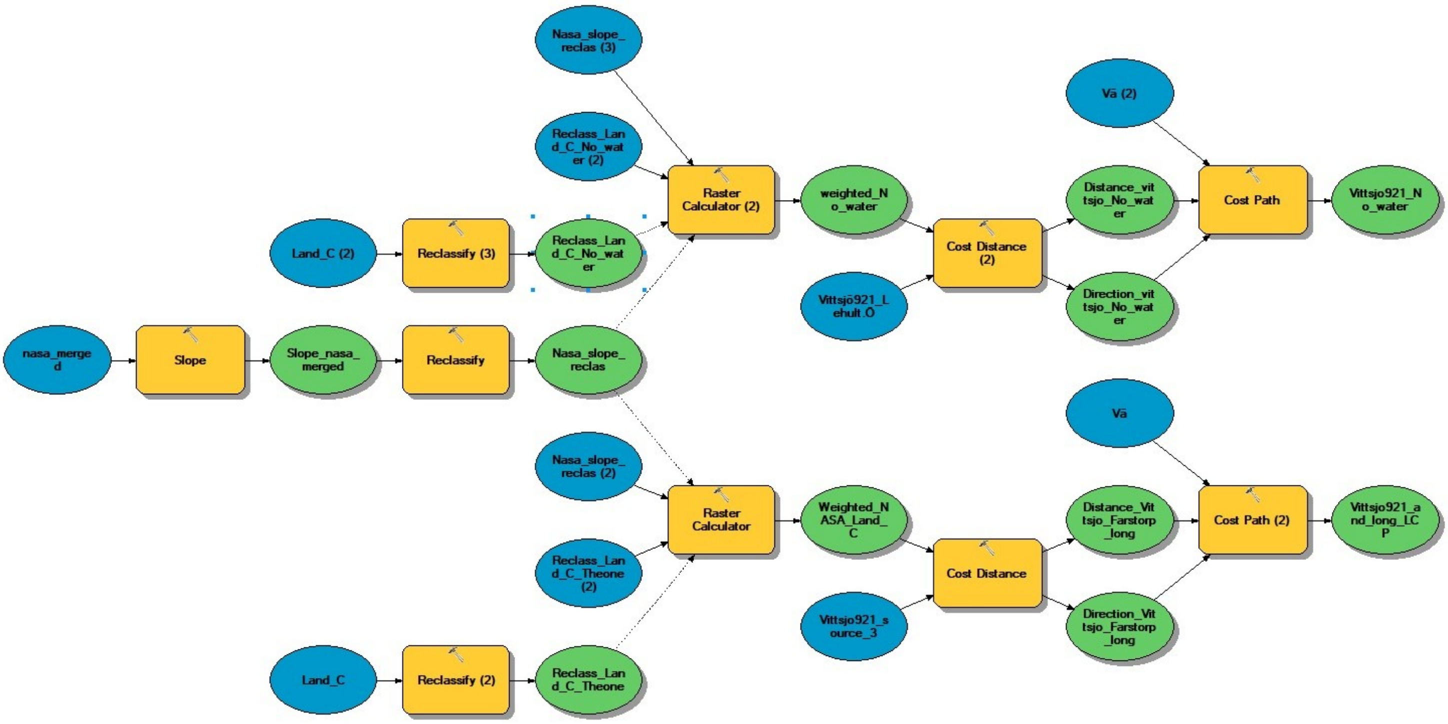


Fig. 3. The model constructed in Model Builder in ArcGIS. Blue bubbles represent the initial input data, yellow is the tools used, and green is the output of the tools which then becomes the input for the next tool in the pipeline.

meter DEM or the 4 meter DEM. The model used is by large the same as the one used for the tests (presented in the appendix) but with the addition of the land cover map in order to inform the process of the historical landscape. A second pipeline was also created which calculates a least cost path in which water is excluded, thus forcing the algorithm to the highest extent choose a land-based path. The tools used in the model can be seen in yellow in the picture above.

3.5.1 Setting up a strategy

To make the process of generating the LCPs as smooth and also as trustworthy as possible a strategy has to be developed as it is important to remember that you cannot just input the data, click "OK" and hope for the best, then blindly trust the results. With a strategy is meant: evaluating the source point's location in the landscape and from this make a decision of where the intermediate destinations will be placed. As suggested by Lock and Pouncett (2010) intermediate destinations would have been used by people when navigating their way through the terrain. Although I am not using viewshed in my analysis as they do, it is my opinion that intermediate points are still important as on the one hand I am focusing on the waterways and therefore need the intermediate points to make the algorithm follow the logic landscape, an on the other, even though the points would not be seen as such by the travellers, using intermediate destinations, I would argue for, is a human function, as suggested by Lock and Pouncett in their article. This is similar to what we do when for example traveling to our own homes, recognising the surroundings and assessing the distance and time left. This is also an extensive research topic for urban planners among others, as people often chose the route they take based on their evaluation of how costly certain options are (Livingood 2012, p. 175). This phenomenon is called Subjective Distance and is the product of three main observations that humans make regarding their surroundings, namely, environmental features, travel time and travel effort (Montello 1997). Of these three, studies have shown, environmental features are the most important aspect (Sadalla & Staplin 1980). These studies support the usage of intermediate points as it is a natural habit of humans to evaluate their surroundings in that manner. It is, of course, hard to know what intermediate points would have been used by people of the past, but looking at the hydrology, perhaps lakes functioned as such features for physical as well as cognitive orientation. This means that some assumptions have to be made as to regarding a general direction of movement when testing the hypothesis that water transport was utilised. Building on what has been presented in the theoretical part of this thesis, the assumption that people will utilise the closest resource possible is here used to argue for that the movement would have happened from the sites to the closest body of water lending to further transportation. The flow direction of the smaller streams is also taken into consideration as this might play a part in the direction of the movement. When testing the terrestrial path possibilities this kind of approximation does not have to be made as tests carried out here examine the straightest path through the landscape, without intermediate destinations.

Following is an account of the strategy developed for this project as well as an explanation of the tools used in the model to calculate the LCPs.

Three different cost rasters representing land use or land cover were created in order to run three different scenarios. In the first one water was given very low values (2 for rivers and 1 for lakes) then one where water was of moderate ease (2 for rivers and 3 for lakes), thus making the algorithm more likely to choose water when moving forward, and lastly one scenario was run where water was given the highest value possible in order to make the algorithm choose a terrestrial path. These values were given to the rivers and lakes in order to test, first one scenario, where flowing water was assumed to make travel easier because less energy has to go to moving the vessel forward, then a second scenario, which was meant to mirror a potential higher energy expenditure because of the need for higher alertness when moving in fast flowing water. The reasoning behind this was to see how big of a difference this would produce, and how big of an influence my own choice of values for the waterways would be. The cost raster where water was prohibited was made as a comparison in order to show the difference in cost and length between the different ways of travel in the landscape, created from the different historical and modern sources.

Two types of cost rasters were used to model the landscape. Besides the cost raster described above a cost raster representing the topography was also used. This is a reclassified slope raster, consisting of a slope created with the Slope tool, using a DEM as input. The output has then been reclassified, using the Reclassify tool, in order to be combined with the data provided by the land use cost raster. The tool itself is used to assign new values to each individual group of cells in the raster, in this case, the values represent the increase in sloped land. The reclassification is done using the Equal Interval method and is classified into ten classes. The default in ArcGIS makes use of Natural Breaks (Jenks), this according to the online help for ArcGIS, does not work well if the data is to be combined with other datasets. Thus, Equal Interval was used as the method best applied to datasets based on percentage such as slope (http://pro.arcgis.com/en/pro-app/help/mapping/layer-properties/data-classification-methods.htm#ESRI_SECTION1_A0FBB74753CA4B4089D6B38F078F5017).

These two rasters were then weighted using the Raster Calculator tool. The weighting is an important step as it provides the process with the vital information of what information is more critical to the movement. Weighting is done by assigning different percentages of importance to the different cost raster's which when added up has to equal 100%. If more than two cost rasters are being used, this is where all of them are combined into one weighted raster. For this analysis, it was decided that a 60% importance would be assigned to the land use cost raster and 40% to the slope raster. The thinking behind this is that as Scania is a relatively flat landscape, so the different terrains and vegetation would probably have been of greater influence in determining which routes people travelled in the past. A 60 and 40 percent ratio would hopefully give the land use raster a little more influence while not ignoring the possible influence of slope in the landscape.

For the areas where the high resolution DEMs were used, it was necessary to combine the slope raster which has a cell size of 4 meters with the land use raster, which has a cell size of

30 meters. When combining several raster datasets using the Raster Calculator they should ideally have the same resolution (http://desktop.arcgis.com/en/arcmap/10.5/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm). However, this is not always practical as data can be derived from so many different sources and catchment techniques and thus it might be impossible for the researcher to obtain datasets with the same resolution. Further, one might not want to lose the details of one dataset by resampling it to the cell size of the coarser of the two datasets. When combining two datasets with different resolution the default in ArcGIS is to resample the finer raster to the resolution of the coarser using the resampling technique of Nearest Neighbour. This allows the output raster to retain the original values of the input raster as no new data is created. This is the resampling technique that is supposed to be used with categorical data such as land use where values have been assigned to the different categories. One can set the environment parameters to a specific cell size (the finer of the two) is used instead of the default of using the coarsest one, this ensures an output with the resolution of the finer inputs but without creating new data outside the extent of the coarser input (http://desktop.arcgis.com/en/arcmap/10.5/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm). It is recommended that the proper analysis environment has been specified before using a Map Algebra tool as Raster calculator. The tool itself could be described as the Swiss army knife of ArcGIS, it functions as any other tool but with the ability of being able to execute any of the spatial analysis tools from one single interface as well as combining and weighing datasets. It is also specifically developed to be easily utilised in Model Builder allowing for extended use within this environment (http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-raster-calculator-works.htm & http://desktop.arcgis.com/en/arcmap/10.5/extensions/spatial-analyst/map-algebra/a-quick-tour-of-using-map-algebra.htm#ESRI_SECTION1_9E69B85807144B748B05C93CC106C83C).

The tools used in the model can be seen in yellow in figure 3. Slope, Reclassify and Raster Calculator have now been explained and their application has been described. When the weighted raster has been obtained from the Raster Calculator only two steps remain in the process to visualise the LCPs. These two tools are the ones that evaluate the cost rasters that have been obtained from the previous steps. The first one to be used is the Cost Distance tool which uses the cost raster as well as the source LCP as input. From this, it calculates the distance raster and backlink raster, also called the direction raster, which both are mandatory for the calculation of the final LCP (http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/cost-path.htm). The first output is the distance raster, this is calculated by evaluating the cost surface and from this classifying it into a number of classes based on the ease of travel from the source in all directions (http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-distance.htm). The second output is the backlink raster, or direction raster, which retraces the least cost route from all possible destinations to the source. This is really the data which makes the most likely routes visible (http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-back-link.htm). To make the final LCP evident the last tool called Cost Path has to be utilised. The two rasters created with the previous tool as well as the destination is used as input to the tool. What this tool does, in a nutshell, is that it identifies the one path with the least amount of cost from the source to the destination and displays it as a raster layer with the width of one pixel (http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-path.htm).

All these steps are, as explained, part of the model created thus, the process described goes relatively quickly and the final LCP can be observed within a few minutes after the first data has been put in.

For the individual sites the following strategy was decided on:

The LCP will be run between the source point, through the intermediate points and finally to the destination point. The source is naturally the sites themselves, the destination, however, is not as obvious. For the sites of Farstorp, Vankiva, Vittsjö 25:1 and Vittsjö 92:1 Lehult.Ö the destination will be the village of Vä outside Kristianstad. This place was chosen as it has a continued habitation from 200 AD all the way to the Medieval Period and up into today. It has also proved to be an area where secondary iron operations, purification of iron and blacksmithing, have been carried out in higher degrees (Helgesson 2002, p.66ff; Björk 2009, p.42; Ödman 2009, p. 28). For the site of Markaryd the coast was chosen as the destination for the path. This is because the main areas of habitation during the Iron Age in Halland was close to the coast and somewhat inland along the larger rivers (Lundqvist 1998, p. 194).

For the site of Markaryd, a LCP was first generated from the source point to the nearest historical lake that was in direct contact with the river of Lagan, using the lake as a destination in the form of a polygon in order for the algorithm to find the best place to enter the lake. The place where the path enters the lake a new source point was created and from this intermediate point a second LCP was generated to the coast.

The site of Farstorp is the one furthest from direct linkage to any larger historical lakes or streams with direct linkage to the river of Helge å. For this site, a slightly different strategy was chosen. Instead of running it from the source (the site of Farstorp) to the river of Helge å directly, it seemed more logic as to first run the LCP southward to another historical lake connected to a stream called Almaån, incidentally also the stream closest to the site of Vankiva. And then from this point calculate the LCP towards Helge å. The closeness to the site of Vankiva made it feasible to run one singe LCP from the historical lake to Helge å. A fourth DEM with the resolution 4 meters was also created for this for this portion of land that was not covered by the DEMs previously created for the calculation of the shorter distance.

The site of Vankiva is perhaps one of the sites that it is the hardest to derive at a trustworthy result. This is due to the area being highly modified in modern times. The first strategy developed for this site consisted of running a LCP from the site to a historical lake in direct contact with Helge å, and from there running the LCP to the final destination. However, after testing this and realising that in doing so the algorithm acted somewhat irrationally skipping an area of around three kilometres where the stream it was following did a sharp bend. Another strategy was tested in which more intermediate points were added. This, of course, has the negative effect of influencing the algorithm's choice of route more which in turn might make the results less trustworthy, so in the end, also this strategy was abandoned and the first LCP generated is the one included.

The sites of Vittsjö 25:1 Björkefalla and Vittsjö 92:1 Lehult. Ö are both close to historical lakes with linkage to Helge å. The first of the two sites are somewhat strangely located directly in a body of historical water. A test excavation on the spot was conducted in 1998 under which the samples for ^{14}C-dating was taken. These fell between 1010 and 1280 as well as 1150 and 1400 AD calibrated age (Ödman 2001, p.74 & 137). There is not much difference in the water levels between 1500 year ago and 500 years ago according to the maps from SGU which makes it more likely that this location of the site is due to un-precise representations of the water condition in the past. The LCPs of these two sites will be run from the source directly to Helge Å, using a part of the river as a polygon for the algorithm to find the best path to enter the river. And from this point, the second LCP will be run to Vä.

3.6 The results of the calculated LCPs

From the analysis, two types of data were retrieved, first, of course, was the most economical path through the landscape derived from the different datasets. This tells us how the path moves in the landscape but does not say how cost effective it is compared to other paths. Second, is the accumulated cost for every path as well as the length of each individual path. This data will be able to shine a light on what type of transport would have been the most cost-effective under the circumstances, terrestrial or water based. This data is presented in the tables below (figure 4 and 5).

From the first table, we can see that when using the cost raster where movement through water is encouraged by assigning low values to these areas (Fields ending with Easy) the total distance travelled is at its highest for all sites except Vankiva. When using the cost raster where movement through water is slightly less encouraged (Fields ending with Medium) the distance is 2 to 3 kilometres shorter for all except Vankiva. Comparing this to the cost raster where water is prohibited, we see that here the distance shrinks considerably, from 11 to 28 kilometres shorter for the Easy cost raster and 9 to 25 for the Medium cost raster. If distance would be the only variable important for this analysis the terrestrial path would definitely be the preferred one. However, the distance has to be compared with the accumulated cost in order to be put in its right context.

From the second table, we can see that even though the distance from the source to the destination is considerably shorter when moving over land the cost of doing so is always

Distance from the source to the destination for the three different cost rasters

	Distance Short Easy	Distance Long Easy	Total	Distance Short Medium	Distance Long Medium	Total	No Water
Markaryd	4	52	56	3	51	54	45
Vittsjö 92:1 Lehult.Ö	21	57	78	20	55	75	50
Vittsjö 25:1	16	57	73	15	55	70	47
Farstorp	38	23	61	36	23	59	42
Vankiva	23	23	46	23	23	46	31

Fig. 4. Table showing the calculated distances for each part of the LCPs as well as the added up distances from each site to the destination for both the water based paths as well as the terrestrial paths. As can be seen the distance is longer for the water based paths in all cases.

Accumulated cost for the three different cost rasters

	Cost Short Easy	Cost Long Easy	Total	Cost Short Medium	Cost Long Medium	Total	No water
Markaryd	7467,385	61758,97	69226,355	10852,98	105678,1	116531,08	175986,4
Vittsjö 92:1 Lehult.Ö	37003,44	84493,88	121497,32	54440,5	122606,8	177047,3	190905,8
Vittsjö 25:1	34047,52	84493,88	118541,4	45065,48	122606,8	167672,28	178213,8
Farstorp	71507,82	35654,29	107162,11	100140,66	55565,62	155706,28	155781,4
Vankiva	36643,38	35654,29	72297,67	58362,43	55565,62	113928,05	118560,8

Fig. 5. Table showing the calculated cost for each part of the LCPs as well as the added up cost from each site to the destination for both the water based paths as well as the terrestrial paths. As can be seen here, although the distance is longer for every water based path the cost is always less than for the terrestrial paths.

higher compared to the cost when moving through water. And this is the same for all the sites.

All maps referred to in this part are available in the appendix.

When viewing the LCPs of the shorter distances, from the sources to the intermediate points, against an orthographic image or DEM, it becomes clear that when using the cost raster where movement through water is most encouraged the algorithm follows the streams in the landscape rather consistently as can be seen in map 1, 2, 3 and 4. The only area where the algorithm completely abandons the water and goes cross country is the first distance from Vankiva to Helge Å, which is also the second distance for the site of Farstorp (Map. 2). Instead of following the river in a rather long sharp turn the algorithm chooses to cross the land in between the first and second turn. This might, as pointed out before, be due to that this area has been affected by modern activities in recent times, making the landscape more appealing for the algorithm to cross as the landscape is flatter.

When using the cost raster where water is a little less encouraged the algorithm does not follow the streams as closely as in the first run. However, it still runs within a relatively short distance from the stream, probably taking advantage of the flatter terrain in the valley of the stream. In many cases, the algorithm continues in a straight line where the stream bends and reunite with the stream in the next bend making the distance shorter (Map. 2). For the long distances, the same trend can be seen, even though the river is much more clearly defined against the rest of the landscape as well as having a more uniformed cost value over a longer as well as wider distance. This can perhaps indicate that using a remodelled area of a river, vectorised from historical maps and then turned into a raster and assigned with a lower value, does not influence the algorithm too much in a negative way as there is still enough room for the algorithm to consider different paths. When using the cost raster where water is at its easiest to move through, the algorithm sometimes also chooses less obvious paths diverging from the vectorised river. This is seen as a positive thing as this also indicates that there is still room for the algorithm to make its own decisions, so to speak. Out of the two cost rasters used, the one that seems to reflect a more real-world scenario is the one where water is at its easiest to move through. The argument for this is that if using boats, it is less cost effective to jump in and out of the river than staying in it and following its flow. In some areas where historical lakes are present alongside the present day river it is possible that the LCP indicates the existence of a past connection between the two, in one place, indications of this can be seen in the ploughed soil between the river and the historical lake where a darker area appears to connect the two water bodies. Darker areas indicate more organic material in the soil, possibly deposits of mud from a previous period of submergence. In fact, several wavy lines can be seen in the ploughed soil, usually, this indicates older flow directions of the river or stream (Map. 6).

When studying the results of the land-based LCP in conjunction with all dated an undated iron production sites as well as all traces of sunken pathways and roads, some interesting things can be spotted. First of all, the paths from Farstorp, Vittsjö 92:1 Lehult. Ö and Vittsjö 25:1 are all going through parts of the landscape where areas of peatland are fairly common, indicating either present or historical wetlands. For Vittsjö 92:1 Lehult. Ö there are few undated sites along its stretch. Although in the beginning of the path it goes through a dense peatland area, maybe a place in which to look for previously undetected sites. When it reaches in height with Hässleholm it crosses over the water-based path leading from Vankiva. In this area, the path passes close by two sunken undated hollow ways (Map. 7). Vittsjö 25:1 passes at the beginning of its stretch a large peatland area which could be viewed as an area for future investigation. The path then leads down to the area of Farstorp and joins the terrestrial path from this site. This is an area of more detected activity with several undated sites. The joined path then continues down north passing through four undated sites and close by a fifth.

When the three paths, Vittsjö 92:1 Lehult. Ö, Vankiva and the joined path from Vittsjö25:1 and Farstorp, reaches closer to the coast and Vä (Map. 8), the three paths all pass in close proximity to securely dated production sites from Iron Age. These, however, in turn, are all in close proximity to waterways as well, making it hard to judge if they are more likely to have made use of waterways or terrestrial routes. At any rate, it is an interesting observation and conundrum which would not have been visible without the addition of information provided by this study.

A final observation is that all terrestrial paths have to cross water at several places. These places might be interesting to look closer at after traces of fords, landing spots or bridges.

4.0 Discussion

4.1 Answers to questions

In the following discussion, the results and findings of the analysis will be discussed in conjunction with previous knowledge on the subject of transportation in the landscape during the Iron Age and Medieval times, iron production, and hubs in the landscape. Further, the observations made of the landscape relating to things other than transportation will also be considered. But let's start off by reviewing the questions stated in the beginning. These were: How was the iron transported? Which routes were used? and Can the knowledge of these routes in extension help us trace new sites of iron production or other actions connected to these activities?

The question is now, can these questions be answered satisfactorily following this study? The answer is "yes" and partly "no, not yet". To start with the first question "How was the iron transported?" The result of the analysis shows that there is a great deal of energy to be saved by taking the waterways as opposed to the terrestrial based paths. Sometimes the amount of energy saved is more, sometimes it is less, but in all generated scenarios the cost of travel by water was less than that travelled by land, despite the distance travelled by water being 9 to 28 kilometres longer than the land-based routes. Following the theory of PLE (Principal of Least Effort) this would suggest that the waterways are more attractive for transportation of goods and people. In the analysis, the factor of the weight of the load transported was not factored in. If this would have been included this would, by and large, mean that the difference in effort going into moving a specific load by boat and by wagon/pack animal or by foot would be even larger. This would arguably be the case as adding weight would not affect the boat as much as it would land-based transportation. A boat thus retains its higher cost effectiveness even though the load for the two is increased equally. This is of course not a concrete answer and neither is it a conclusion that boats always will be the most cost-effective choice of travel in the Iron Age Scanian landscape. There are several factors that have not been accounted for which may change the picture, some of which will be accounted for below. The cultural factor, as discussed in previous chapters, is really a big part of how to view past actions and signs thereof, and it is this factor that is the hardest to get to as it encompasses knowledge, that for us today, is impossible to find in the archaeological material. What we can grasp and understand is what is visible through the material culture and possibly written sources which then have to be interpreted by us. However, the cognitive part, as to what really shaped the minds of past people will to the largest degree stay hidden. Judging from the results of the analysis, based on the observable aspects of the material culture and the knowledge of human nature, I suggest that there is a large likelihood that the waterways would have been used more extensively than previously argued for, thus making them an important aspect to be considered when discussing movement and transport in the landscape.

The second question, “Which routes were used?”, can with a little more certainty be answered. From the data included in this study, on which this answer is dependent, the LCPs in the landscape are relatively clear. What the LCPs allowing travel by water shows is the quickest as well as the straightest path through lakes and rivers. At some points the LCP strays from the river or stream, these points indicate areas where the cost of going in the direction of the river or stream would mean too much of a detour making the choice of going cross country more appealing. However, the path always re-joins the river or stream a little further down. The same goes for the terrestrial paths, showing the best way to navigate through a landscape of many wetlands and lakes taking in to account the topography as well. Sometimes these paths cross water and wetlands, suggesting the same thing here, that the cost of going around is too high in comparison with the alternative. When transporting by water, it is arguably advantages to do so downstream as much as possible as the flow of the water helps propel the vessel. So in the cases when a choice has to be made between travel upstream or downstream to reach further transportation routes, the later should be viewed as more realistic. It is of course also so that the drainage basin moves in the direction of the larger river which means that travel upstream almost always takes you further away from the coast. The conclusion of this would be that the paths derived would reflect paths or corridors in the landscape that theoretically actually have seen more movement. When evaluating the terrestrial LCPs, these also on several occasions move through or in close proximity to other sites showing signs of iron production. And when compared with the material of sunken pathways in the landscape it can be seen that in some areas the LCP move in close proximity to these. Although it can of course not be said that these sunken pathways are direct traces of Iron Age movement as most of them have not been investigated any further and as shown in the introduction, it is very problematic to date sunken pathways. However, it has often been shown that the same stretch of road can have a very long continuity, which makes a lot of sense in regards to Path Dependence. A possible relation between the sunken pathways and the generated LCPs in these areas could therefore be argued for, as the sunken pathway shows an area where movement to a higher degree has occurred, and so does the LCP.

The last question, “Can the knowledge of these routes in extension help us trace new sites of iron production or other actions connected to these activities?”, cannot wholeheartedly be answered within the scope of this thesis project as there has been no time to go out in the field and test the results thereof. What can be said is that there are areas where there is a higher degree of probability for the existence of unknown sites. As previously stated, LCP analysis and the results thereof can be used as a method in predictive modelling to establish areas of interest (Risetto 2012, p. 12 and there cited references). As a correlation between sites and closeness to wetlands can be observed in the material, and as the generated LCPs indicate areas where it is more likely for people to have moved in pre-history, some initial areas of higher interest can be spotted in the landscape. Areas that, according to this reasoning would have a higher degree of probability of containing unknown sites, as shown on map 9 and 10. A correlation between the presence of pre-historic lakes and the sites used in this study could be seen. Many of these areas which were then covered with water, usually are peatland today, which makes it look like the site is located near a wetland area when in actual fact it was located in direct linkage with a lake. This observation has two implications. One is that the knowledge of these pre-historic lakes and their location could be used to narrow down the size of the area in which we are searching for unknown sites. And in conjunction with the LCPs this could make searching for them even more effective. Secondly, the assumption is often made that bog-ore has been the predominantly used raw material if a site is in close proximity to now boggy land. However, these findings might suggest that ore from the lakes have been used for the production on these sites. Another interpretation of this observation might be that being close to open water lends for a better communicative placement when transporting by boat, which then would support the idea that water transport has been more extensively used than previously argued for. Yet a third possible interpretation would be the usage of wind furnaces, this is a furnace that makes use of the wind for providing the fire and reduction process with oxygen. These type of furnace is favourably placed in an open area where the wind often is more prominent. However, the existence of these furnaces in Scandinavia is a topic for discussion as no unequivocal evidence have been put forward and the placement near lakes is not in itself evidence for their existence (Englund 2002, p.244). The last possibility might be the least plausible. However, the two first ones could be seen as more likely and perhaps a combination of the two.

4.2 The larger picture

With this study, what has been attempted is, to more deeply understand the flow of iron from the inner landscape to the more inhabited areas along the coast, trying to get to the particularities of routes used and methods of transportation. Of course, being an initial study, all the particularities have not been able to be explored, but the knowledge provided does give more details to be added to a wider discussion. Following Actor Network Theory, these particularities will now be attempted to be fitted in to the larger context of social groups, political influence and settlement in late Iron Age and early Medieval Scania, Halland and Småland. Furthermore, how do the results of this study fit with the shift from iron production close to the farmsteads to a production near the raw material source in Roman Iron Age as advocated by Bo Strömberg? And how does it fit in relation with the Principal of Leas Effort as suggested by George Kingsley Zipf? It will also be evaluated how the answers to the questions appear in conjunction with more detailed information concerning iron production sites. What has to be kept in mind here is the critique towards ANT, as being too categorical, assuming that networks are either commanded or chaotic, when most studied networks show signs of both. As suggested by Knappett (2008) a more flexible thought process is applied.

4.2.1 Vä - a hub in the landscape

For the LCPs generated in the Helge å area, Vä was chosen as the destination. This is for a good reason as Vä shows clear signs of being of importance as both a trading place and political center with signs pointing towards royal power during the Middle Ages (Helgesson 2002, p. 33) as well as a place where iron has been secondarily worked in large scale, that is forged into objects and perhaps cleaning of half-finished iron blooms, during Medieval times and Iron Age. So much in fact that it can be said to characterize the area (Björk 2009, p.42). Ödman states that part of the explanation for this large-scale secondary handling is due to the area being used for the cleaning of iron produced as a form of taxation to the Danish crown sometime around 1200-1300 AD (Ödman 2009, p. 28). If production of iron was carried out in Vä it is hard to say as the large masses of slag found from the Medival period as well as Iron Age has not yet been analysed to any higher degree (Björk 2009, p. 42). The periods in Vä that are the best represented in the archaeological material is the time around 400-600 AD as well as Viking Age/early Middle Ages and further up in the 12th century AD (Thun & Anglert 1984 in Helgesson 2002, p. 67). However, depending on how one views continuity of a place like Vä, the periods presented above can be made more nuanced (Helgesson 2002, p. 67). Also the area surrounding Vä shows many signs of being important within a larger regional area where Helge å eventually meets the sea. Indications pointing towards this have been uncovered in the form of seasonal as well as permanent living quarters, finds in the form of imported glass beads, coins from western Europe and the middle east, weights, Slavic ceramics and more (Svanberg & Söderberg 2000, p. 286ff). Bertil Helgesson is advocating a Scania divided up into five domains with five central areas during 500-600 AD, where Vä is one of them, controlling the landscape of northeastern Scania as well as up into Småland and Halland (Helgesson 2002, p. 156ff). Also Johan Callmer is advocating that the Åhus region, to which Vä is very much connected, bears signs of being a distinct area of power during the later part the Iron Age as well as being the most settled area in northeastern Scania (Callmer 1991a, p. 32; Callmer 1991b, p. 271; Callmer 1998, p. 31). This would mean that Vä is controlling most of the waterways located here including Helge å. This area near the sea, with good communicational routes inland as well as outward, seems to have been of a larger regional, and as suggested by imported goods, inter-regional importance. As a place with such an importance it would be odd if its location in the landscape did not supply it with good communication routes. Further, if said routes were ignored what good would an advantageous placement be? To conclude, if Vä has had the important position that Helgesson and others argue, the waterways would have been a great asset, and most likely used to a greater extent.

4.2.2 The coast of Halland, home of the Hallin

A very interesting source which gives insight into the social division of the landscape of Western Scandinavian peninsula is the 6th century historian or writer Jordanes, and more precisely his work Getica. It consists of essentially a list naming social groupings or people that supposedly existed in Scandinavia nearer to the coast, but also somewhat inland, during the latter part of the Iron Age. If this work of Jordanes actually reflects reality has been well debated through the years. Being fundamentally a copy of the works of the historian Cassiodorus the accuracy of Jordanes work can be debated to some degree. It has however been found that the names on this list do correlate relatively well with many modern names. These names are assumed to distinguish different social groups or people who formed political units in the landscape. The extension of these units have been traced via place names and geographic areas in medieval and early modern sources, as well as via the names as corresponding to groups present in the Medieval landscape (Callmer 1991b, p. 258 & 262). One such people were the *Hallin* which is thought to have inhabited a large part of the Halland plain, and because this group later came to name the whole region it is assumed that this group was the most politically influential one in the region during the latter part of the Iron Age. Earlier settlement patterns show a concentration predominantly on the plain of Laholm and Halmstad as well as along the larger river valleys of Lagan and Nissan. This area is thought to be "the original Halland" (Callmer 1991b, p. 260 & 271). Another social group named in the list is the *Finnaithae,* thought to correspond to the area of Finnveden, an area well known from Medieval sources. This groping can be traced predominantly to the area further up the river Lagan and Nissan forming relatively limited settlement areas (Callmer 1991b, p. 260). Johan Callmer believes that these groups could have an inner power structure similar to that of Funen in Denmark as suggested by three rune stones which mentions figures in society called *Goðar.* These have been interpreted as political as well as religious leaders and are known from the Icelandic sagas, and just as these rune stones can be used to, at some level, reconstruct the social territories of Funen, so can monuments like graves and place names be used in for example Halland (Callmer 1991b, p. 265 and there cited references).

The picture that emerges from this, is that of an area which has much in common with the Vä and Åhus area. Strong political regional centres with a tightly settled area around the coast and extending up along their large rivers. And the fact that they both are located close to big rivers is an important factor to consider. A large river provides many important things like drinking water, protection, possible food source and arguably the most important one, good communication options.

4.2.3 River transport

It has been said that the Scanian rivers have not been used for travel and transport in historic or pre-historic times (Stjernquist 1963). The basis for this statement has been that, for example, Helge å has been impossible to travel up and down because of its rapids and falls (Ödman 2005, p. 148). Anders Ödman argues the opposite and states that in practically all regions of Europe waterways have been utilised extensively for transport of both people and goods so why not in Scania (Ödman 2005, p. 147 and there cited references). This is a very good point, and indeed one can wonder why this would be the case. The findings of this thesis certainly suggest that the river would be the preferred way of travel, looking from an energy preservation point of view. And when widening the scope and looking outside Scania towards and upward the Swedish east coast to Torne älv, we see that boats have been used for transport up and down the river even though it is just as hard to do so in places as Helge å. Heavy loads of iron and ore was here transported in light clinker built crafts during summertime as late as 1789 as described by the topographer Abraham Hülpers. According to him, many rapids are tackled in the boats, all but the biggest rapids and falls (Ödman 2005, p. 150). The boats used here and the ones still being traditionally built and used in these areas as well as Finland and Russia, as described in the introduction chapter, bear resemblance to the small boats found in Iron Age graves dated to the later part of the Iron Age, boats like the Björke boat from ca 400 AD and the Badelunda boat from ca 850 AD. They are relatively long and narrow but small in compresence to more sizable vessels, making them good for going through rapid water and relatively easy to portage where the water is too rapid or where there are falls, hindering the journey.

Much the same conditions apply to both Lagan and Helge å. They are of similar size, reach the same areas and are similar in terms of rapids and challenging areas to go through. What does make these two areas different from each other though, is the scale of habitation during the Iron Age. According to a compilation by Johan Callmer the area surrounding Helge å is relatively inhabited up to about the Vittsjö region, gradually thinning out from the junction of Helge å and Almaån (Callmer 1991b, p. 270). The area of Lagan, on the other hand, is according to Lars Lundqvist just inhabited near the coast and a little bit inwards along river valleys and lakes where there today is open land (Lundqvist 1998, p. 194).

4.2.4 Energy expenditure

That people in historic times have been well aware of the energy to be saved when using water transport versus land-based transport as illustrated by the prices of transporting goods in the late 19th century. The cost of transporting one barrel of cereal by land between Laxå and Göteborg was 74 öre while the same barrel only would cost 60 öre to transport by sea from Stockholm to London (Ödman 2005, p. 149). This really indicates and projects the principle of least effort on a real-life situation in the past. Even though one should be careful when drawing analogies between events too far apart, this is definitely an interesting observation speaking for that since people were aware of the benefits of water-based transport. To really understand these benefits, we would have to understand the meaning and the work going into building a boat typical of the time and area (Westerdahl 2008, p. 18), with all that this involves, from finding suitable timber to maintaining the vessel through its use. This would then have to be compared to the energy going into making land-based transportation possible, with all that is required for this. If assuming that wagons would have been used, the wagon itself first has to be made from suitable materials. Breeding of draught animals is required as well as seeing to that the surface on which to travel is in good shape, and not to forget the maintenance of the wagon. This kind of information would give us a good picture of what actually goes into the different kinds of transportation. This kind of thinking goes hand in hand with what has been suggested by George Kingsley Zipf, implying that to fully grasp the pattern of when changes in organisation occur we have to understand what goes into every step of the process which leads up to the change (Zipf 1949, p. 348f). Further, Zipf takes the standpoint that it is the individuals "average rate of work-expenditure over time that is minimized in his behaviour" (Zipf 1949, p. 6). An ability to plan for the future, to make justified decisions in the present based on events thought to occur in the future. This underlying strive to minimize work, *principle of least effort,* is what according to Zipf steers an individual's entire behaviour, from labour to speech and everything in between (Zipf 1949, p. 6, 19ff). It might be easy to say that by applying above scheme one easily reduces the individual to a small piece in a large machinery, however it has to be remembered that the principle of least effort does not just include thing measured in terms of weight, length, time and so on, but also things not possible to be measured, like for example the effect of culture and religion on an individual's actions. The problem lays in, to what degree would cultural and religious aspects affect said individual, how much effort would it have to induce in order to offset something else?

4.2.5 The changing conditions in society in conjunction with LCE and higher organisation during Roman Iron Age to Viking Age

As previously mentioned in the analysis the Roman Iron Age in Scandinavia saw somewhat milder, that is warmer, temperatures allowing for expansion of human activities and thereby regression of forested areas. This is visible in, among other things, the pollen diagrams from coring in wetlands and lakes in Scania. Bo Strömberg is promoting a model for how the production of iron shifted in this period from close to the farmstead to located near the raw material. His model coincides with this rise in temperature and builds on observations from production sites in the form of quantitative and qualitative observations, observations of the sites location in the landscape as well as being grounded in earlier discussions concerning the evolution of iron production in Scania, Halland and Småland (Strömberg 2008, p. 38). What his model shows is a shift in Roman Iron Age from production near the farmstead, when raw material and fuel had to be brought in from the surrounding landscape, to a production located at the source of the raw material, making fuel more readily available. This move, Strömberg states, is partly fuelled by a higher need of iron in society (Strömberg 2008, p. 38). This goes well with what the paleoecological information shows, in terms of expanding use of the landscape in the Roman Iron Age.

A move towards cooler temperatures can be observed in around 400 AD when the glaciers in Scandinavia started expanding again after a time of regression following the warmer temperatures. This time is of colder temperatures is not visible in the material of iron production sites, however, judging from the relatively low number of dated sites, this can well be a question of representation, making more detailed regional pictures hard to spot. Around 300-600 AD the growth of forested areas can be put in connection with the villages becoming more tightly organised and activities being more structured. This development, visible in pollen diagrams, in some part in contrasts what several researchers have advocated, suggesting a move towards an expansion of the farm and establishment of new farmsteads (Wraning 2004; Carlie & Artursson 2005; Strömberg 2005). The crisis of the migration period as described by Näsman (1988) affected the whole of Scandinavia, which is suggested by expanding woodland and reduction in the amount of pollen derived from crops in coring samples from wetlands. This crisis lasted from around 200 AD to 600 AD but seems to have affected different regions in different ways and during shifting periods, meaning that the effects of it would occur at different places at different times. If the hypothesis concerning this crisis is correct this would probably mean that we should expect fewer production sites during this period in time. However, again it could be argued that the representability of dated sites is too small to make any clear judgment of the circumstance thereof. One clear area sticks out in this regard though, and that is Snorup on Jutland in Denmark. This area saw a vast production from about the middle of the 4th century AD to sometime during the 7th century AD when probably a shortage of fuel forced the production to cease (Strömberg 2008, p.70f and there cited references). The area as a whole shows signs of being very well organised with the sole purpose of providing iron to surrounding societies. Longhouses on the site are dated to the period of the production, but none from before and none after (Nøbach 2003, p. 101, 106 in Strömberg 2008, p. 68). Judging from the evidence present at Snorup as well as other sites, Strömberg states that very large quantities of iron must have been made on Jutland during the period of 150 AD to 600 AD (Strömberg 2008, p.68). Perhaps this production supplied a larger region, including parts of what is today southern Sweden. And maybe the decline in production quantities in Denmark also fuelled a higher demand of iron in Scania, Halland, and Småland, thus being one of the reasons why we see a shift from production near the farmsteads to production near the raw material. This shift would also make sense when viewed against a background of Zipfs model of how the PLE effects the chain of procurement of materials and the like. Applying this way of thinking to what has been outlined indicate that: when the production on Jutland is able to sufficiently supply a wider area with the iron needed for society to function well, lesser energy is spent on the production of iron in the areas of Scania, Halland, and Småland, mirroring a smaller production near the farmstead, as suggested by Strömberg. To fill the gap between what is needed and what can be bought or traded from Danish areas, some production has to be carried out within the farm's sphere, creating the need to go some distance to procure ore and fuel, but not enough to change the social organisation. When the production on Jutland declines, this creates a larger and larger void in the need for iron in the societies of Scania, Halland, and Småland, forcing people to produce more iron themselves. This, in turn, starts to affect the amount of energy going in to procuring ore and fuel, increasing the amount of work needed to go back and forth between the farmstead and the procurement area. Eventually, the amount of work going into transporting ore and fuel between these two nodes offsets the amount of work needed to move the production to the source of ore and fuel. Thus the shift from production near the farmstead to a production near the source has occurred. The same thinking can, of course, be applied to the transportation of both iron, ore, and fuel, both by waterways and terrestrial paths. When the need for transportation increases, this creates a need for making it more efficient, perhaps a catalyst for making a change from transportation over land to water. It could also be a catalyst for the building of roads or foot-bridges to transverse wetlands which otherwise would have to be avoided by going around them. When the amount of energy saved by increasing the efficiency is offset by the amount of work that would go into making the change happen, the change will most likely occur.

From around 700 AD an agricultural expansion starts followed by an increase in temperature in around 900 AD. This increase in arable land then seems to continue up into modern times. This increase in farmland could be said to reflect a rising population, and with this increase, the need for iron would also have grown, in turn making the need for efficiency greater. The principle of least effort also comes into play when looking at already established paths. Many other ideas of energy conservation stems from the idea of PLE, and as brought up in the theoretical part of this thesis the theory of Path Dependence is one of them. If there was a process of new identities being formed with the move of production to the source of the raw material, from which new ethnic groups were formed, it is possible to argue for a link of interaction between these ethnic groups of iron producers and the ones nearer the coast, for example, Vä. In the case of Halland and Lagan, as previously stated, further up the river the people of Finnveden resided, an already established ethnic group in the landscape. These links would, by the thoughts of PD, be unlikely to change in the coming future, as this would mean an uncertainty of supplies, going both ways, as well as the formation of new links requiring a lot of work and energy spent. This, I believe, makes the including of younger as well as older sites very much relevant when studying the transportation networks of Iron Age Scandinavia. Further, it is not just the cultural link that would make a change in question of who you do your trading with unlikely. The physical paths equally are unlikely to change unless the social organisation surrounding said function changes so that a much higher demand is created. When a path has been established through the landscape, what most likely will be the reason for it to change, is an increase in the amount of traffic. As the usage and the dependence on the route rises it will at some point become economically advantages to make the route more efficient, and as soon as the amount of work going into doing so is offset by the success of the new path, a change is more likely to occur (Zipf 1949, p. 348f). This notion can also be viewed in later periods in the area when royal power during the 17th century decided that the roads in the landscape needed to come up to a certain standard and also display the correct distances to common destinations, for example, Stockholm (Söderpalm 1967, p. 24-28; Nordin 1991). The reason behind the decision to make the road network more effective can among other things be traced to the economic factor of being able to calculate the right cost for stagecoaches to take people from one place to another (Nordin 1991, p. 11). One could also think of other economic reasons, for example, the increased need for woodland products in early modern times like tar and iron, as well as the need for easier access to the landscape for military purposes and more.

4.3 Future developments and possibilities

The largest problem for this kind of study on the material of iron production sites from the Iron Age in Scania, Halland, and Småland is the relatively poor representability of the number of sites. Meaning, what has also been said earlier in this thesis, the low amount of securely dated sites. This is not a problem only for the study of Iron Age production but all periods, perhaps with the exception of the most modern production sites as these often show a very large unmistakable production, however as argued in the text, sites have on many occasions shown a continuity stretching hundreds of years, and there is the possibility of sites being reused in later periods as argued by Strömberg (Strömberg 2008, p. 60). What is needed is more fieldwork aimed at evaluating the many sites we know about but that are undated. Currently, another problem is the representability of areas in the archaeological material as some areas naturally have been more developed in modern times, these have in many cases also seen more activity in the form of inventory lending to the identification of more sites. And in this way, the picture of intensively used areas can perhaps be somewhat misleading. In this study, for example, more sites along Helge å were used as opposed to Lagan, mainly because of the problems outlined above. This can of course in extension lead to a somewhat lopsided result, not saying that this is the case but as always it is a possibility. Including more data in the form of, for example, areas of political influence, individual farmsteads found in the landscape and things alike could all help to better inform the results of this and new studies in the future.

Some aspect of the landscape has not been included in this study, mainly data relating to the flow of the rivers. What has been left out is areas where the water potentially would have been too rapid to travel through and thus would force the travellers to portag their vessel and potential load. This could of course somewhat change the accumulated cost of the river paths. But to model these areas, it is required that more detailed studies are utilised, after the areas in question have been identified. Data that could help identify these areas is, for example, historical maps and studies of the flow of rivers as dependent on the topography. A big factor which is not included at the moment is the return trip using the waterways. The backlink raster does the job of calculating the return and includes this in the accumulated cost, but this calculation does not include the fact that when traveling upstream you have to fight the current. It has been calculated that the average increase in energy expenditure when traveling upstream is about double that of traveling downstream (Livingood 2012, p. 178). At the moment though it cannot be assumed that travel upstream was done in exactly the same way as downstream. Another factor to include is the one of the weight carried in both directions. Both for land and water-based routes have the weight been excluded, because of too big uncertainties as well as a shortage of time. Linking to all this is the ability to include human biodynamics, that is caloric energy expenditure, which in turn also could make the results more informed.

What continued work along the lines of this thesis will have to include, is fieldwork in order to reach a conclusion of whether the knowledge of transportation routes can help us find new sites. In conjunction with this, something which cannot be stressed enough is the need for more securely dated production sites. The vast majority of sites are undated and thus it is hard to build a larger picture of production during the Iron Age, or any time for that matter. This calls for more sites being dated with ^{14}C. Another method which could really be of use is analyses of iron artefacts, more precisely of the slag inclusions in the objects. This can show the providence of the ore used in the production process (Buchwald 2005, p. 202). This, in turn, could on a larger level perhaps point to areas where the production has been of a larger scale, big enough so that that the finished iron has been transported to other regions.

The idea of affiliation networks proposed in the theoretical discussion has not been dealt with in any larger depth in this thesis. Preliminary, it can be said that finding links consisting of other material culture between the sites in the limited area handled in this study would be hard. However, if a study like this is applied on a larger regional level or interregional level, this might be an approach that could yield interesting results.

5.0 Conclusions

Several interesting observations have been made in this study, showing both the capabilities of least cost analysis when applied to the material in question and showing movement in the landscape when viewed in a larger context as well as showing the many interesting possibilities in the material of iron production sites. Further, the study has shown that there is a real advantage in choosing to travel through the rivers, streams and the many lakes present in the Iron Age landscape even when no load is included in the calculations. Choosing to travel over land is associated with a much higher cost even though the total distance is shorter. However, several interesting things have been spotted connected to the land-based paths that were calculated, indicating that the calculated terrestrial paths show areas where movement has occurred. On many occasions, these trails pass close to or sometimes directly through known places of production, or areas where slag has been found, both undated sites and those securely dated to Iron Age. Furthermore, the terrestrial paths also pass in the vicinity of areas where there is documented sunken pathways. This does not only indicate that this is indeed areas where movement has occurred and thus, these areas are more prone to contain unknown sites, but also that there really is a strong connection between the calculated LCP in the landscape and the actual historical movements that people of the past have undertaken. However, what is hard to determine when it comes to these observations, is the timeframe for the movement. The areas where the land-based tracks pass through dated Iron Age production sites can possibly be said to indicate movement along these tracks specifically during the Iron Age. The sunken pathways are, as have been stated before, hard to date and therefore it cannot be said that movement occurred here at one particular time, but perhaps that the area is culturally and topographically keen to allow movement. And therefore also making it possible that people moved here during the Iron Age. The same could be said about the areas where the path goes through, or close to, undated production sites.

The terrestrial least cost paths therefore, I believe, might very well contribute to new knowledge which can help us find new areas of interest and maybe also evidence of paths in the landscape. I also believe that the results relating to the waterways can help us highlight an area of iron-related research that has not been given much attention in the past as a clear connection between less energy expenditure and waterways can be shown. And it has to be remembered that transport does not only involve the movement of people but also of goods. Iron is heavy, and if you have to move, for example, 100 kg of iron, you are most likely going to choose the method which involves the least amount of risk and energy loss. This in conjunction with the results showing the savings of water-based routes as opposed to land-based options, I think, is a strong incentive for that boats would have been used for transporting iron during the Iron Age and later periods. The routes allowing transport via the waterways are, however, a little harder to use in the process of locating unknown sites as the movement is more restricted to the waterways themselves. An exception to this would be, as previously stated, the presence of now gone lakes. When talking about the streams I believe it is the movement to and from the production site and the stream that has the possibility to shed light on unknown sites.

6.0 Summary

In this thesis project, the method of Least Cost Path Analysis has been used in order to improve our knowledge concerning the transport of iron in the landscape during the latter part of the Iron Age. The questions asked were: How was the iron transported? Which routes were used? and Can the knowledge of these routes in extension help us trace new sites of iron production or other actions connected to these activities? Upon reviewing the first question it can be said that there is much to be gained by utilising the waterways. And following the idea of PLE, outlined by Zipf in 1949, this would suggest that the waterways might have been utilised more than previously argued. It is my own opinion that the waterways should be seen as important in the Scanian Iron Age landscape not least because two big Iron Age regional centres are located along the coastal areas of the larger rivers of Lagan and Helge å. Concerning the second question, the generated LCPs show the least costly routes through the landscape indicating that the waterways are less costly than the terrestrial paths. Following the idea of PLE this means that the waterways would be more attractive for the transport of goods. However, the land-based paths show clear signs of going through areas of movement and activity on many occasions indicating the possibility that these paths also might have been utilised, but perhaps for lighter or shorter transportation as heavier transportation with wagons would most likely have required labour intensive activities to make the ground more suitable for wagons. The last question cannot be completely answered at the present moment as this require fieldwork to see if the possibilities outlined in this thesis can help us find new sites. Several possible areas have been presented in the discussion above.

As an initial study into the use of LCP analysis to highlight aspects of transportation and networks in the archaeological material of iron production sites dated to Iron Age and Early Medieval times, the work conducted here has to be deemed successful. The study has shown that transport in Scania via the rivers Lagan and Helge å are the most viable and cost-effective choices, and even though the terrestrial paths seem to point towards areas which saw more movement it is likely that these areas indicate movement or transport over shorter distances. These areas also seem to be well suited for the searching for unknown sites. Future studies will hopefully shed more light on the subject of this thesis as well as questions derived thereof.

7.0 References

7.1 Literature

Appadurai, A. (2010) How Histories Make Geographies: Circulation and Context in a Global Perspective. *Transcultural Studies.* Vol. 1. Pages 4-13.

Arturosson, M. (2001) En korsning I tid och rum. Ett vägsystem från yngre järnåldern-folkvandringstid på en boplats vid Saxån, Skåne. In Larsson, L. (Ed.) *Kommunikation I tid och rum*. University of Lund, Institute of Archaeology. Lund: Institute of Archaeology.

Backhouse, P. (2006) Drowning in data? Digital data in a British contracting unit. In Evans, T. L. and Daly, P. (Eds.) *Digital archaeology, Bridging method and theory*. New York: Routledge Taylor & Francis Group.

Berglund, B. E. (1991a) Palaeoecology. In Berglund, B. E. (Ed.) *The cultural landscape during 6000 years in sothern Sweden- the Ystad project*. Ecological Bulletins. Copenhagen: Munksgaard

Berglund, B. E. (1991b) The Roman Iron Age landscape. In Berglund, B. E. (Ed.) *The cultural landscape during 6000 years in sothern Sweden- the Ystad project*. Ecological Bulletins. Copenhagen: Munksgaard.

Berglund, B. E. (1991c) The Viking Age landscape. In Berglund, B. E. (Ed.) *The cultural landscape during 6000 years in sothern Sweden- the Ystad project*. Ecological Bulletins. Copenhagen: Munksgaard.

Berglund, B. E. (1991d) The Köpinge area. In Berglund, B. E. (Ed.) *The cultural landscape during 6000 years in sothern Sweden- the Ystad project*. Ecological Bulletins. Copenhagen: Munksgaard.

Berglund, B. E. (1991e) The Krageholm area. In Berglund, B. E. (Ed.) *The cultural landscape during 6000 years in sothern Sweden- the Ystad project*. Ecological Bulletins. Copenhagen: Munksgaard.

Binford, L.R. (1964) A Consideration of Archaeological Research Design. *American Antiquity*. Vol. 29(4). Pages 425-441.

Binford, L. R. (1980) Willow smoke and dogs' tails: hunter-gatherer settlement systems and archaeological site formation. *American Antiquity*. Vol. 45(1). Pages 4-20.

Björk, T. (2009) Vems var järnet? Om järn och makt i skånsk järnålder. In Helgesson, B. (Ed.) *Järnets roll, Skånelands och södra Smålands järnframställning under förhistorisk och historisk tid*. Kristianstad: Regionsmuseet/Landsantikvarien i Skåne.

Blake, E. (2013) Social networks, path dependence, and the rise of ethnic groups in pre-Roman Italy. In Knappet, C. (Ed.) *Network Analysis in Archaeology: New Approaches to Regional Interaction*. Oxford: Oxford University Press.

Bonde, N. & Christensen, A. (1993) Dendrochronological dating of the Viking Age ship burials at Oseberg, Gokstad and Tune, Norway. *Antiquity*, 67(256). Pages 575-583.

Bradley, R. (1984) *The social foundations of prehistoric Britain, themes and variations in the archaeology of power.* London: Longman Ltd.

Brøgger, A. W. & Shetelig, H. (1971) *The Viking ships; their ancestry and evolution*. Oslo: Twayne Publishers.

Buchwald, V. F. (2005) *Iron and steel in ancient times*. Historiske-filosofiske Skrifter 29. København: Det Konglige Danske Videnskabernes Selskabe.

Callmer, J. (1991a) Platser med anknytning till handel och hantverk i yngre järnålder, Exempel från södra Sverige. In Mortensen, P. and Rasmussen, B. M. (Eds.) *Fra Stamme til Stat 2*. Højbjerg: Jysk Arkæologisk Selskab.

Callmer, J. (1991b) Territory and Domination in the Late Iron Age in Southern Scandinavia. In Jennbert, K., Larsson, L., Petré, R. and Wyszomirska-Werbart, B. (Eds.) *Regions and reflections, In honour of Märta Strömberg*. Acta Archaeologica Lundensia. Series IN 8º Nº 20. Stockholm: Almqvist & Wiksell International.

Callmer, J. (1998) Handelsplatser och kustplatser och deras förhållande till lokala politiska system, Ett bidrag till strukturen i den yngre järnålderns samhälle. In Larsson, L. and Hårdh, B. (Eds.) *Centrala platser centrala frågor, Samhällsstrukturen under Järnåldern*. Acta Archaeologica Lundensia. Series IN 8º Nº 28. Stockholm: Almqvist & Wiksell International.

Carlie, L. (2001) Hålvägar och landskap. Äldre kommunikationsleder utmed Nissans dalgång, Halland. In Larsson, L. (Ed.) *Kommunikation i tid och rum*. University of Lund, Institute of Archaeology. Lund: Institute of Archaeology.

Carlie, A. & Artursson, M. (2005) Böndernas gårdar. In Carlie, A. (Ed.) *Järnålder vid Öresund. Band 1. Specialstudier och syntes. Skånska spår- Arkeologi längs Västkustbanan*. Stockholm: Riksantikvariämetet.

Chapman, H. (2006) *Landscape Archaeology and GIS*. Stroud: The History Press.

Christophersen, A. (1989) Kjøpe, selge, bytte, gi. Vareutveksling og byoppkomst i Norge ca 800–1100 – En modell. In Andrén, A. (Ed.) *Medeltidens födelse. Symposier på Krapperups borg 1.* Lund: Wallin & Dalholm.

Clark, G. (1978) Spatial Analysis in Archaeology by Ian Hodder; Clive Orton. *American Antiquity*. Vol. 43(1). Pages 132-135.

Conolloy, J. & Lake, M. (2006) *Geographical Information Systems in Archaeology*. Cambridge: Cambridge University Press.

Daly, P. & Evans, T. L. (2006) Introduction, Archaeological theory and digital pasts. In Evans, T. L. and Daly, P. (Eds.) *Digital archaeology, Bridging method and theory*. New York: Routledge Taylor & Francis Group.

Englund, L. E. (2002) *Blästbruk, myrjärnshanteringens förändringar i ett långtidsperspektiv.* Doctoral dissertation. Stockholm: Jernkontoret.

Etherington, T.R. & Penelope Holland, E. (2013) Least-cost path length versus accumulated-cost as connectivity measures. *Landscape Ecology*. Vol 28(7). Springer. Pages 1223–1229.

Evans, T. L. (2006) You, me and it, The application of simple quantitative techniques in the examination of gender, identity and social reproduction in the Early to Middle Iron Age of north-eastern France. In Evans, T. L. and Daly, P. (Eds.) *Digital archaeology, Bridging method and theory*. New York: Routledge Taylor & Francis Group.

Gibb, A. (1977) Spatial Analysis in Archaeology. By Ian Hodder and Clive Orton. *Archaeological Journal*. Vol. 134(1). Pages 448-449.

Gould, R. A. (2011) *Archaeology and the social history of ships*. Cambridge: Cambridge University Press. 2nd edition.

Harding, A. F. (1998) North-south Exchanges of Raw Materials. *Gods and Heroes of the Bronze Age.* 25th Council of Europe Art Exhibition. Copenhagen: National Museum of Denmark.

Harding, A. (2013) World Systems, Cores, and Peripheries in Prehistoric Europe. *European Journal of Archaeology.* Vol. 16(3). Pages 378-400.

Helgesson B. (2002) *Järnålderns Skåne, samhälle, centra och region.* Acta Archaeologica Lundnsia, series in 8°. no. 38. Stockholm : Almqvist & Wiksell International

Herzog, I. (2014) A review of case studies in archaeological least-cost analysis. *Archeologia e Calcolatori*. Vol. 25. Pages 223-239.

Hjärthner-Holdar, E., Grandin, L., Sköld, K. & Svensson, A. (2018) By Who, for Whom? Landscape, Process and Economy in the Bloomery Iron Production AD 400-1000. *Journal of Archaeology and Ancient History*, Vol. 21. Pages 1-50.

Hjärthner-Holdar, E., Lindahl, A., & Kresten, P. (1993) *Järnets och järnmetallurgins introduktion i Sverige*. Uppsala: Societas archaeologica Upsaliensis. Uppsala Universitet.

Hodder, I. & Orton, C. (1976) *Spatial analysis in archaeology*. Cambridge: Cambridge University Press.

Horn, B.K.P. (1981) Hill shading and the reflectance map. *Proceedings of the IEEE*. vol.69, no.1. Pages 14-47.

Jörgensen, M. S. (1982) To jyske bronzealderveje-og en ny metode til arkeologisk opmåling. *Nationalmuseets Arbejdmark*. 1982. København.

Jörgensen, M. S. (1996) Oldtidens veje i Danmark, Nogle aspekter af den forhistoriske landfærdsel. In Vellev, J. (Ed.) *Braut: Nordiske Vejhistoriske Studier.1*. København: Danmarks vejmuseum i samarbejde med Finlands vägmuseum, Norsk vegmuseum, Vägverkets museum, Sverige.

Jörgensen, M. S. (1997) Looking in to the Landscape. In Christiansen, C. and Knudsen, N. T. (Eds.) *Aarhus Geoscience*. Vol. 7. Aarhus: Department of Earth Sciences, Aarhus University.

Jörgensen, M. S. (2001) Förhistoriske veje. Nogle problemer og perspektiver med udgangspunkt I dansk materiale. In Larsson, L. (Ed.) *Kommunikation I tid och rum*. University of Lund, Institute of Archaeology. Lund: Institute of Archaeology.

Karlén, W. (1988) Scandinavian glacial and climatic fluctuations during the Holocene. *Quaternary Science Reviews*. Vol. 7. Pages 199-209.

Knappett, C. (2008) The Neglected Networks of Material Agency: Artefacts, Pictures and Texts. In Knappett, C. and Malafouris, L. (Eds.) *Material Agency: Towards a Non-Anthropocentric Approach*. New York: Springer.

Knappett, C. (2011) *An Archaeology of Interaction. Network Perspectives on Material Culture and Society*. Oxford: Oxford University Press.

Larsson, A-C. (2004) *Järnframställningsplats vid Ulvaryd*. Archaeological report, RAÄ 69 Ulvaryd 6:1, Markaryd socken, Kronobergs län, Småland. Smålands museum, Rapport 2004:12. Växjö: Smålands museum.

Livingood, P. (2012) No Crows Made Mounds, Do Cost-Distance of Travel Time Improve Our Understanding of Southern Appalachian Polity Size?. In White D. A. and Surface -Evans S. L. (Eds.) *Least Cost Analysis of Social Landscapes, Archaeological Case Studies*. Salt Lake City: The university of Utha press.

Lock, G. and Pouncett, J. (2010) Walking the Ridgeway Revisited: The Methodological and Theoretical Implications of Scale Dependency for the Derivation of Slope and the Calculation of Least-Cost Pathways. In Frischer, B., Webb Crawford, J. and Koller, D. (Eds.) *Making History Interactive. Computer Applications and Quantitative Methods in Archaeology (CAA)*. Proceedings of the 37th International Conference, Williamsburg, Virginia, United States of America, March 22-26 (BAR International Series S2079). Oxford: Archaeopress.

Lucy, S. (2005) Ethnic and cultural identities. In Díaz-Andreu, M. (Ed.) *Archaeology of Identity: approaches to gender, age, status, ethnicity and religion.* Vol. 86. London; New York: Routledge.

Lundqvist, L. (1998) Centralplatser och centralområden i Västsverige. In Larsson, L. and Hårdh, B. (Eds.) *Centrala platser centrala frågor, samhällsstrukturen under järnåldern*. Acta Archaeologica Lundensia, series in 8°, N°. 28. Stockholm : Almqvist & Wiksell International.

McGrail, S. (2001) *Boats of the World: From the Stone Age to Medieval Times*. Oxford: Oxford University Press.

Mogren, M. (2008) Riksgränsen. In Anglert, M. (Ed.) *Landskap bortom traditionen. Historisk arkeologi I nordvästra Skåne*. Stockholm: Riksantikvarieämbetet.

Mohen, J.-P. (1998) Adventures, Artisans and Travellers. *Gods and Heroes of the Bronze Age.* 25th Council of Europe Art Exhibition. Copenhagen: National Museum of Denmark.

Montello, D. (1997) The perception and Cognition of Environmental Distance: Direct Sources of Information. In *Spatial Information Theory: A Theoretical Basis for GIS*. Berlin: Springer.

Naum, M. (2010) Re-emerging Frontiers: Postcolonial Theory and Historical Archaeology of the Borderlands. *Journal of Archaeological Method and Theory* Vol. 17(2). Pages 101-131.

Nihlén, J. (1932) *Studier rörande äldre svensk järnhantering med särskild hänsyn till Småland*. Jernkontorets Bergshistoriska Skrifter Nr 2. Stockholm: Jernkontoret.

Nihlén, J. (1939) *Äldre järntillverkning i Sydsverige: Studier rörande den primitiva järnhanteringen i Halland och Skåne*. Stockholm: Jernkontorets Bergshistoriska Skrifter Nr 9. Stockholm: Jernkontoret.

Nordin, S. (1991) Vägmätningar för milstolpar. *Fornvännen* 86. Pages 11-14.

Nylén, E. & Schönbäck, B. (1994a) *Tuna i Badelunda – Guld kvinnor båtar*. Vol. 1. Västerås kulturnämnds skriftserie 27. Västerås: Kulturnämnden.

Nylén, E. & Schönbäck, B. (1994b) *Tuna i Badelunda – Guld kvinnor båtar*. Vol. 2. Västerås kulturnämnds skriftserie 30. Västerås: Kulturnämnden.

Näsman, U. (1988) Den folkvandringstida krisen. In Näsman, U. and Lund, J. (Eds.) *Folkvandringstiden i norden, en krisetid mellan ældre og yngre jernalder*. Aarhus: Universitetsforlag.

Påsse, T. (2001) *An empirical model of glacio-isostatic movements and shore-level displacement in Fennoscandia*. Svensk Kärnbränslehantering AB. SKB R-01-41, Stockholm.

Rissetto, J. D. (2012) Using Least Cost Path Analysis to Reinterpret Late Upper Paleolithic Hunter-Gatherer Procurement Zones in Northern Spain. In White, D. A. and Surface -Evans, S. L. (Eds.) *Least Cost Analysis of Social Landscapes, Archaeological Case Studies.* Salt Lake City: The university of Utha press.

Räf, E. & Norr, L. (Ed.) (2009) *Järnstad. Järnframställning och boplats.* Linköping: Östergötlands länsmuseum. Avdelningen för arkeologi.

Sadalla Edward, K. & Staplin Lorin, J. (1980) The Perception of traversed distance: Intersections. *Environment and Behaviour* 12(2). Pages 167-182.

Sindbaek, S. (2013) Broken links and black boxes: material affiliations and contextual network synthesis in the Viking world. In Knappet, C. (Ed.) *Network Analysis in Archaeology: New Approaches to Regional Interaction.* Oxford: Oxford University Press.

Skoglund, P. (2001) Vagnfyndet från Skirsnäs mosse, Småland. In Larsson, L. (Ed.) *Kommunikation I tid och rum*. University of Lund, Institute of Archaeology. Lund: Institute of Archaeology.

Stjernquist, B. (1963) Om Göingebygdens bronsålder. In Ulfstrand, S. (Ed.) *Skånes Natur, Skånes Naturskyddsförenings Årsskrift.* Vol. 50.

Strömberg, B. (2005) Järnåldersbygder I bronsålderns landskapsrum. In Carlie, A. (Ed.) *Järnålder vid Öresund. Band 1. Specialstudier och syntes. Skånska spår- Arkeologi längs Västkustbanan*. Lund: Riksantikvarieämbetet.

Strömberg, B. (2008) *Det förlorade järnet, dansk protoindustriell järnhantering*. Stockholm: Riksantikvarieämbetet.

Surface- Evans, S. L. & White, D. A. (2012) An Itroduction to the Least Cost Analysis of Social Landscapes. In White D. A. and Surface -Evans S. L. (Eds.) *Least Cost Analysis of Social Landscapes, Archaeological Case Studies*. Salt Lake City: The university of Utha press.

Svanberg, F., Söderberg, B., Andersson, E., & Brorsson, T. (2000) *Porten till Skåne: Löddeköpinge under järnålder och medeltid*. Lund: Avdelningen för arkeologiska undersökningar, Riksantikvarieämbetet.

Söderpalm, K. (1967) Skånska Milstolpar. In Thun, E. (Ed.) *Skånsk väg*. Lund: Skånes hembygdsförbund.

Tang, J. & Pilesjö, P. (2011) Estimating slope from raster data: a test of eight different algorithms in flat, undulating and steep terrain. *WIT Transactions on Ecology and the Environment*, Vol. 146. Pages 143-154.

Westerdahl. C. (1985) Sewn boats of the north*. The International Journal of Nautical Archaeology and Underwater Exploration*. Vol. 14(1). Pages 33-62.

Westerdahl. C. (2008) Boats Apart. Building and Equipping an Iron-Age and Early-Medieval Ship in Northern Europe. *The International Journal of Nautical Archaeology*. Vol. 37(1). Pages 17–31.

Winkler, M. (2001) Vägen till Södra Sallerup. In Larsson, L. (Ed.) *Kommunikation I tid och rum.* University of Lund, Institute of Archaeology. Lund: Institute of Archaeology.

Witcher, R. E. (1999) GIS and landscapes of perception. In Gillings M., Mattingly, D.J. and van Dalen, J. (Eds.) *Geographical information systems and landscape archaeology, Mediterranean landscape archaeology 3*. Oxford: Oxbow Books.

Zagal-Mach Wolfe, U. I. (2013) *Grasping Technology, Assessing Craft. Developing Research Method for the Study of Craft-Tradition*. Acta Archaeologica Lundensia Series In 8^{o}, No. 63. Lund: Lund University.

Zipf, K. G. (1949) *Human Behavior and the Principle of Least Effort*. Harvard University. Cambridge, Massachusetts: Addison- Wesley Press, inc.

Zubrow. E. B. W. (1990) Contemplating space: a commentary on theory. In Allen K. M. S., Green S. W. and. Zubrow E. B. W (Eds.). *Interpreting Space: GIS and archaeology*. London: Tayler and Francis.

Zubrow, E. B.W. (2006) Digital archaeology, A historical context. In Evans, T. L. and Daly, P. (Eds.) *Digital archaeology, Bridging method and theory*. New York: Routledge Taylor & Francis Group.

Ödman, A. (2001) *Vittsjö, En socken i dansk järnbruksbyggd*. Norra Skånes medeltid 2. Lund: University of Lund, Institute of Archaeology.

Ödman A. (2005) *Skeingeborg, borgen som Saxo glömde*. Norra Skånes medeltid 4. Lund: University of Lund, Institute of Archaeology.

Ödman A. (2009) Introduktion till skånsk järnforskning och en tur i den nordskånska skogsbygden. In Helgesson, B. (Ed.) *Järnets roll*, *Skånelands och södra Smålands järnframställning under förhistorisk och historisk tid.* Kristianstad: Regionsmuseet. Landsantikvarien i Skåne.

7.2 Online sources

ArcGIS 10.5 online desktop help:

http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-distance.htm 07-04-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/understanding-cost-distance-analysis.htm 08-04-2018

http://desktop.arcgis.com/en/arcmap/10.5/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm 30-03-2018

http://desktop.arcgis.com/en/arcmap/10.5/extensions/spatial-analyst/map-algebra/a-quick-tour-of-using-map-algebra.htm#ESRI_SECTION1_9E69B85807144B748B05C93CC106C83C 24-04-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/data-management-toolbox/mosaic-to-new-raster.htm 24-04-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/data-management-toolbox/raster-catalog-to-raster-dataset.htm 25-04-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/maximum-likelihood-classification.htm 20-03-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/environments/cell-size.htm 20-03-2018

http://pro.arcgis.com/en/pro-app/help/mapping/layer-properties/data-classification-methods.htm#ESRI_SECTION1_A0FBB74753CA4B4089D6B38F078F5017 20-03-2018 http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-raster-calculator-works.htm 15-05-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-distance.htm 15-05-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-back-link.htm 16-05-2018

http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/cost-path.htm 18-05-2018

http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-path.htm 18-05-2018

GRASS GIS 7.4.0 Online Reference Manual:

file:///C:/OSGEO4~1/apps/grass/grass-7.4.0/docs/html/r.walk.html#move 14-04-2018

Online data resources:

https://zeus.slu.se/get/?drop

http://dwtkns.com/srtm30m/

https://earthexplorer.usgs.gov/

https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/Historiska-kartor/

http://www.fmis.raa.se/cocoon/fornsok/search.html

https://ext-geodatakatalog.lansstyrelsen.se/GeodataKatalogen/

External tools:

https://rapidlasso.com/lastools/

Other online sources:

SGU: https://www.sgu.se/om-geologi/ 23-03-2018

http://www.fotevikensmuseum.se/sewnboat/tunaboat/asp.html 10-03-2018

7.3 Figures

Fig. 1. Original image downloaded from Wikimedia Commons. It consists of an SRTM-image showing the topography of Hokushin Five Mountains in Japan. Modification made by Simon Rosborg.

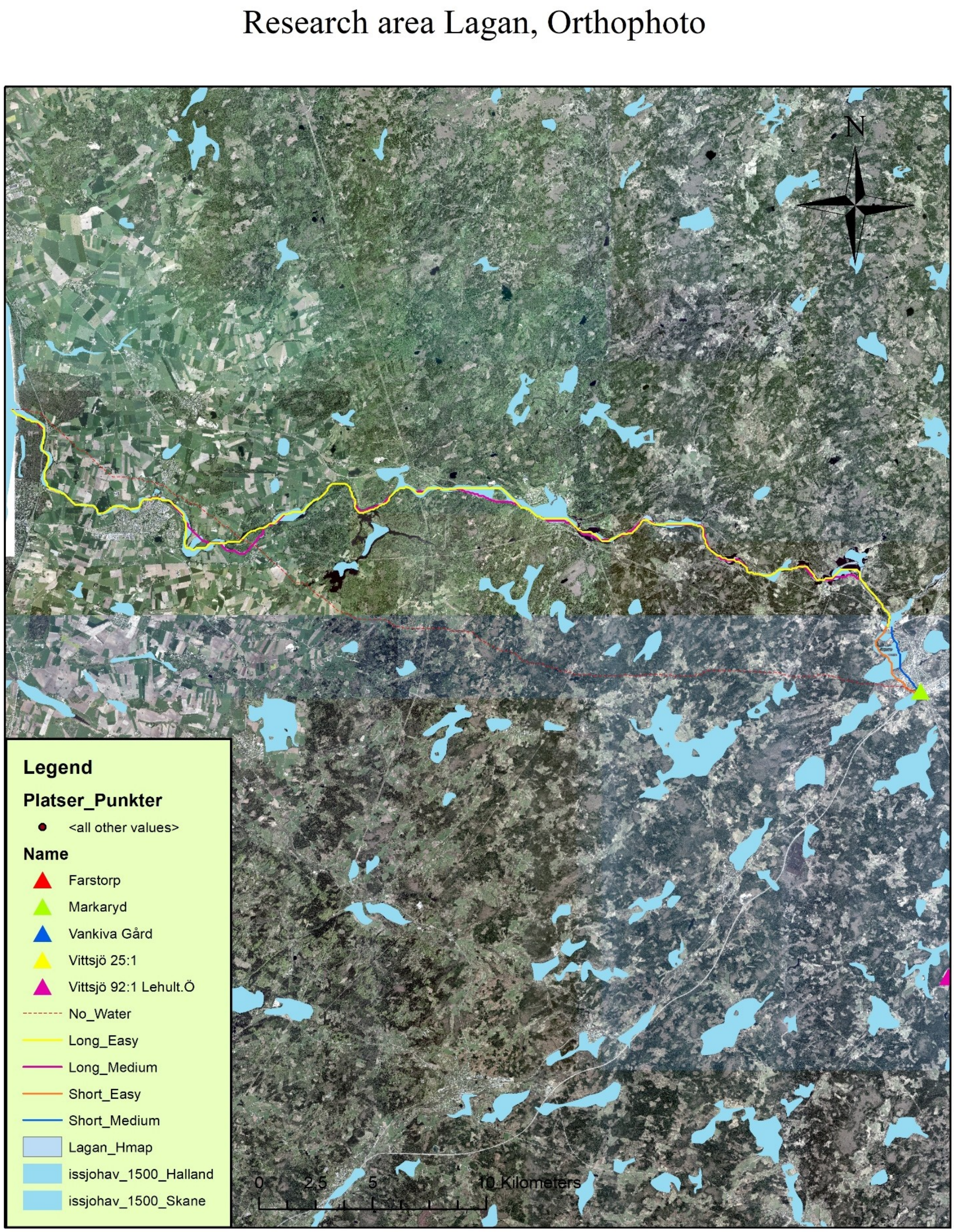
Fig. 2. Table of sites used in the study. Made by Simon Rosborg, using Microsoft Excel.

8.0 Appendix

8.1 Maps

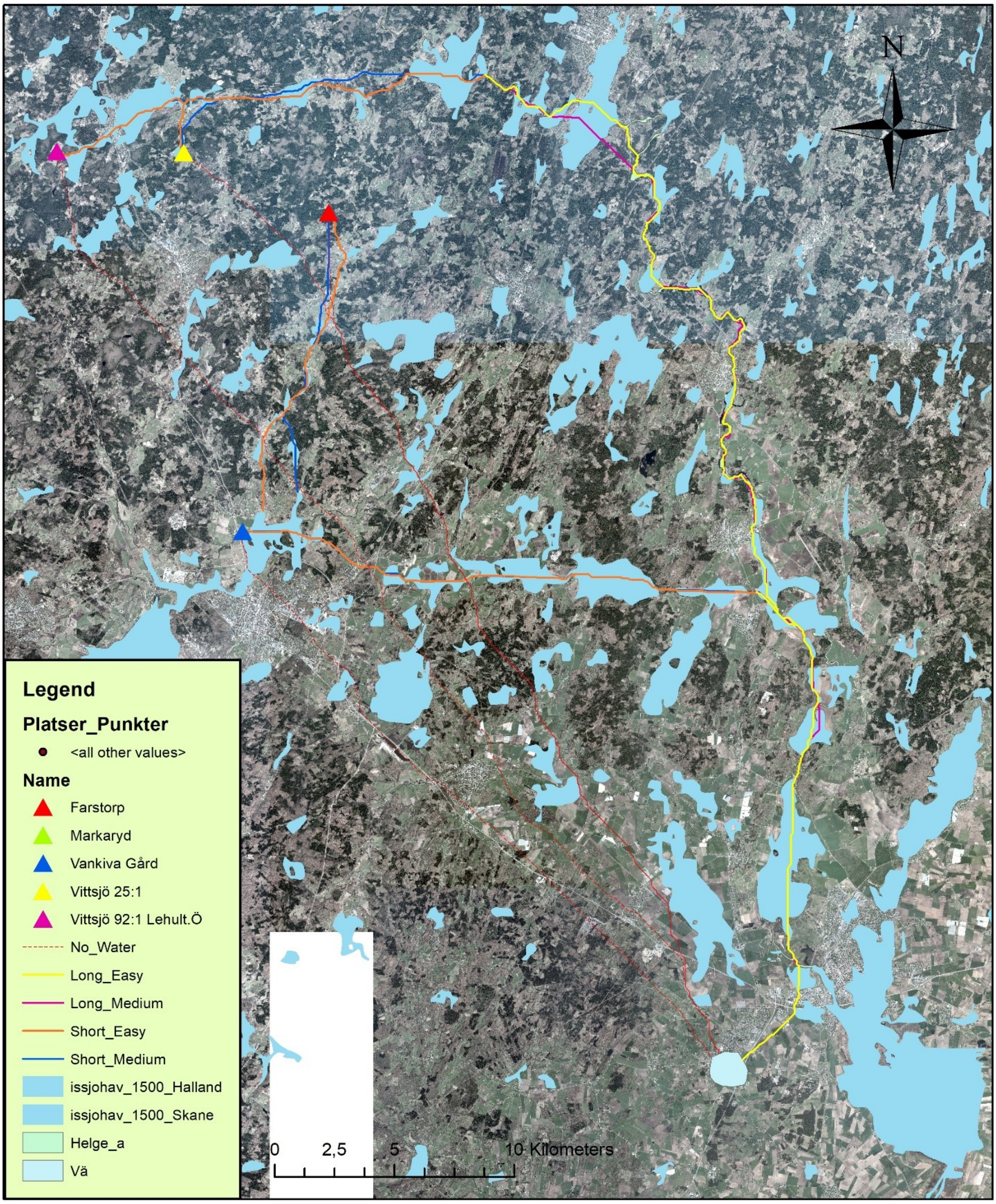
All maps were made in ArcGIS by Simon Rosborg.

Map. 1


Research area Lagan, Orthophoto
N
Legend
Platser_Punkter
<all other values>
Name
Farstorp
Markaryd
Vankiva Gård
Vittsjö 25:1
Vittsjö 92:1 Lehult.Ö
No_Water
Long_Easy
Long_Medium
Short_Easy
Short_Medium
Lagan_Hmap
issjohav_1500_Halland
issjohav_1500_Skane
0 2,5 5 10 Kilometers

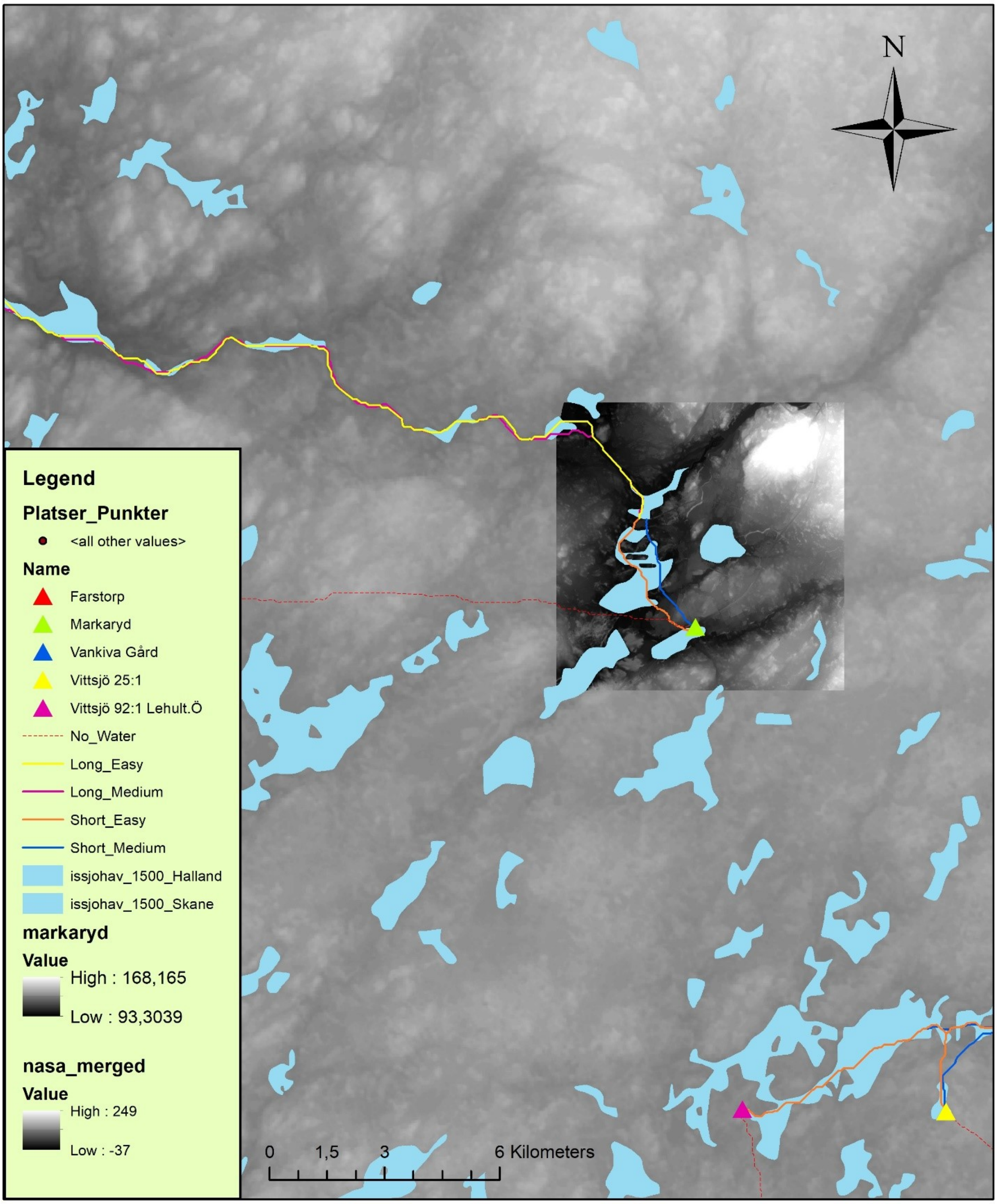
Map. 2

Research area Helge å, Orthophoto

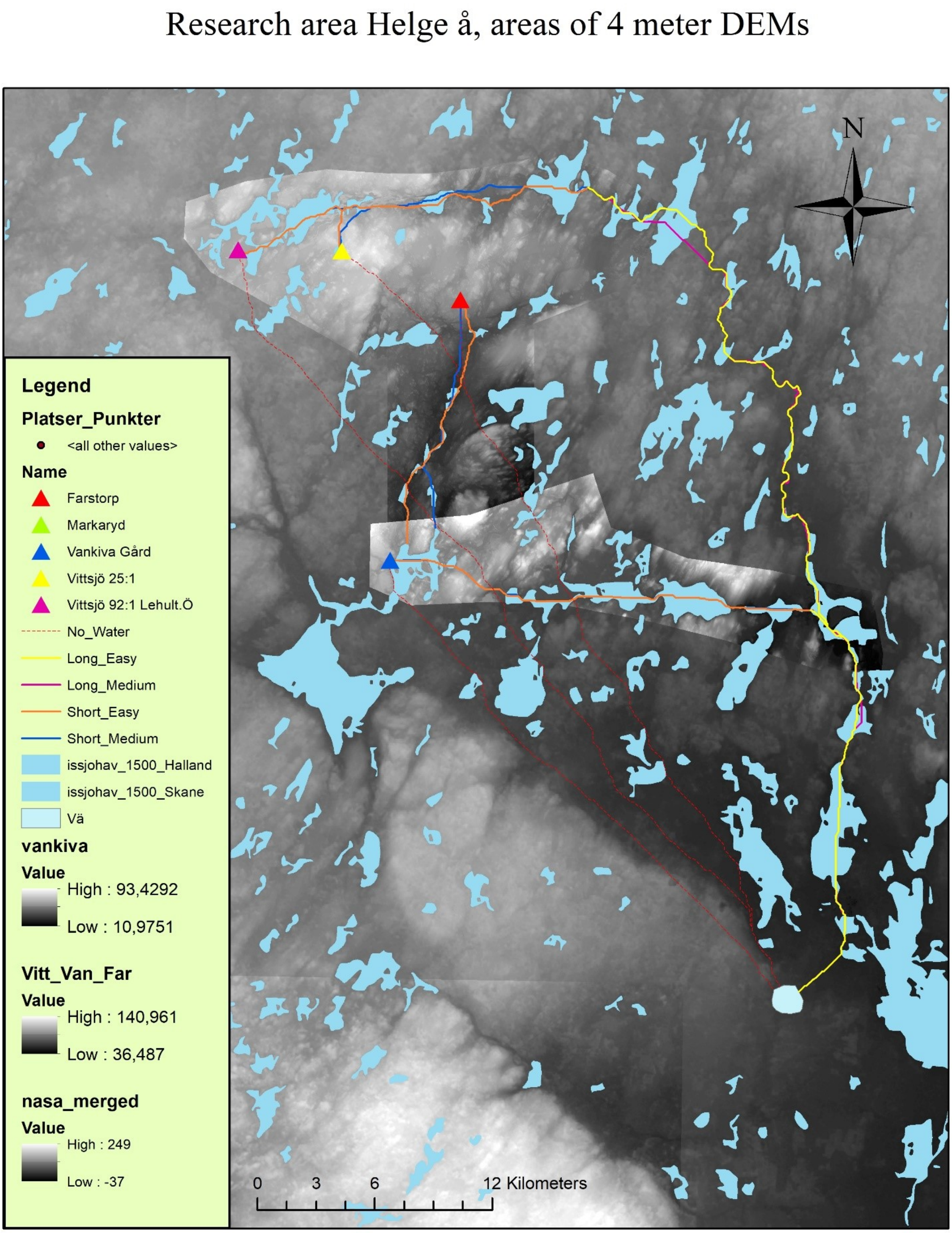


Map. 3

Research area Lagan, areas of 4 meter DEMs

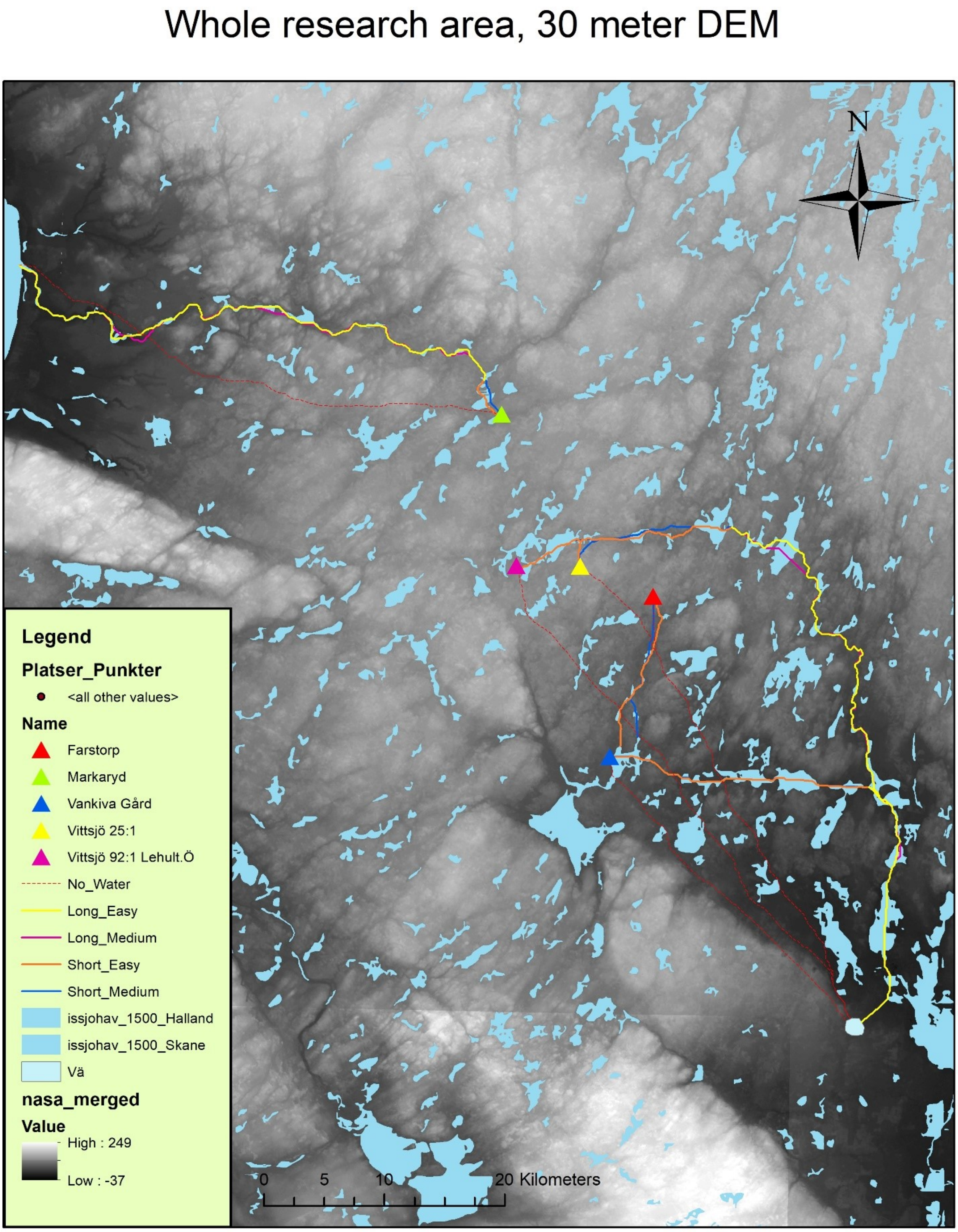


Map. 4



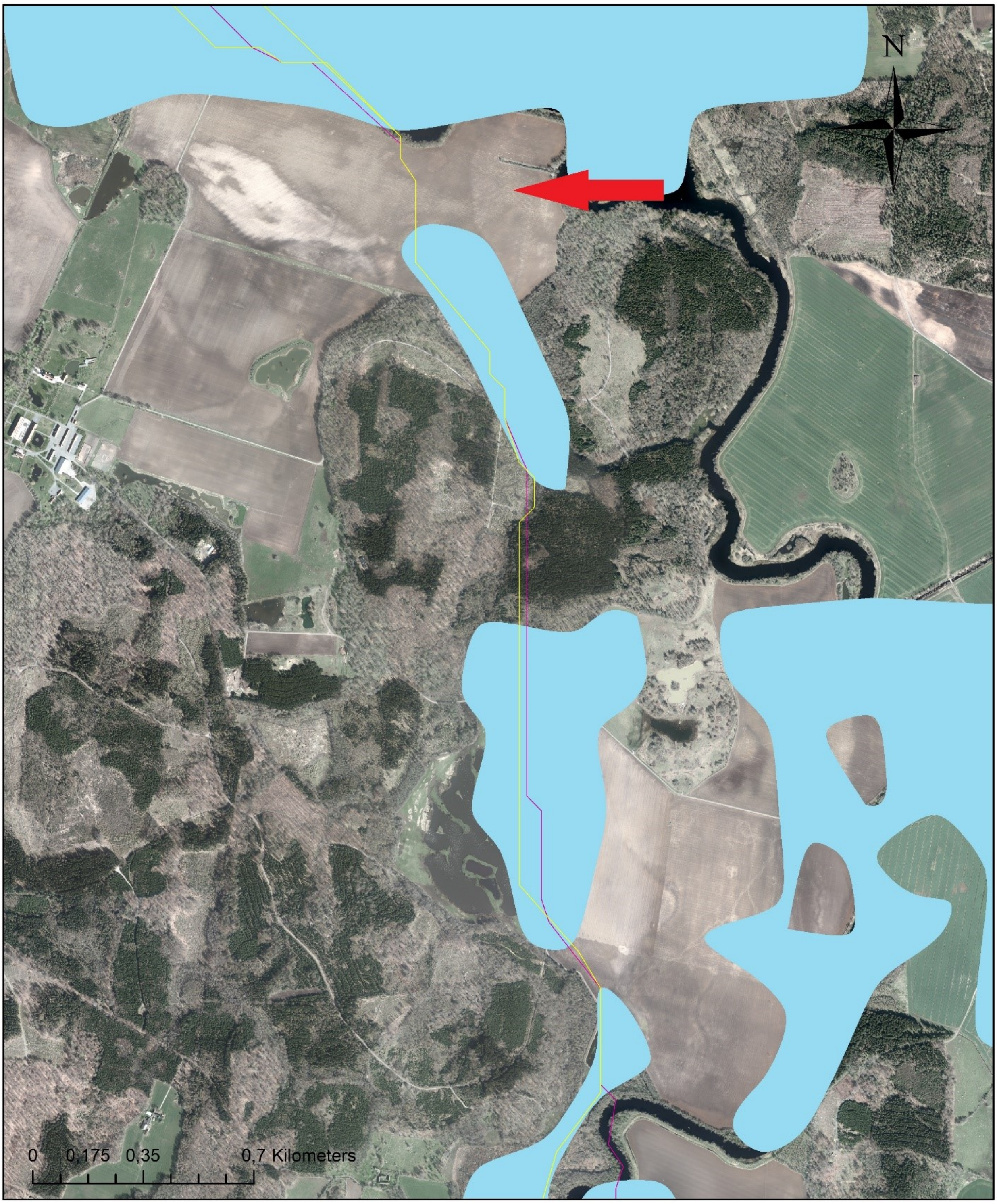
Research area Helge å, areas of 4 meter DEMs
N
Legend
Platser_Punkter
<all other values>
Name
Farstorp
Markaryd
Vankiva Gård
Vittsjö 25:1
Vittsjö 92:1 Lehult.Ö
No_Water
Long_Easy
Long_Medium
Short_Easy
Short_Medium
issjohav_1500_Halland
issjohav_1500_Skane
Vä
vankiva
Value
High : 93,4292
Low : 10,9751
Vitt_Van_Far
Value
High : 140,961
Low : 36,487
nasa_merged
Value
High : 249
Low : -37
0 3 6 12 Kilometers

Map. 5

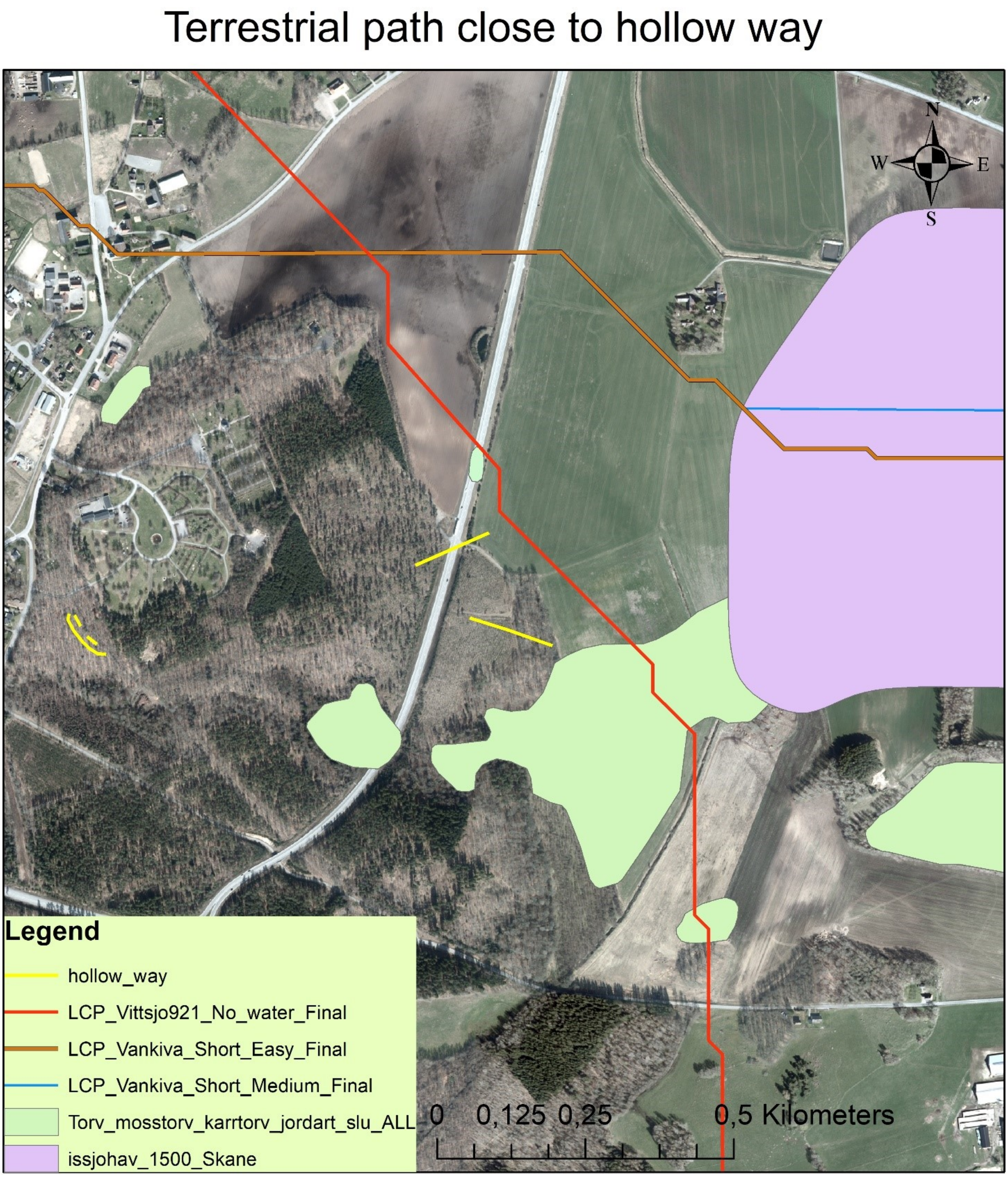

Whole research area, 30 meter DEM
N
Legend
Platser_Punkter
<all other values>
Name
Farstorp
Markaryd
Vankiva Gård
Vittsjö 25:1
Vittsjö 92:1 Lehult.Ö
No_Water
Long_Easy
Long_Medium
Short_Easy
Short_Medium
issjohav_1500_Halland
issjohav_1500_Skane
Vä
nasa_merged
Value
High : 249
Low : -37
0 5 10 20 Kilometers

Map. 6

Possible old connection between to historical lakes

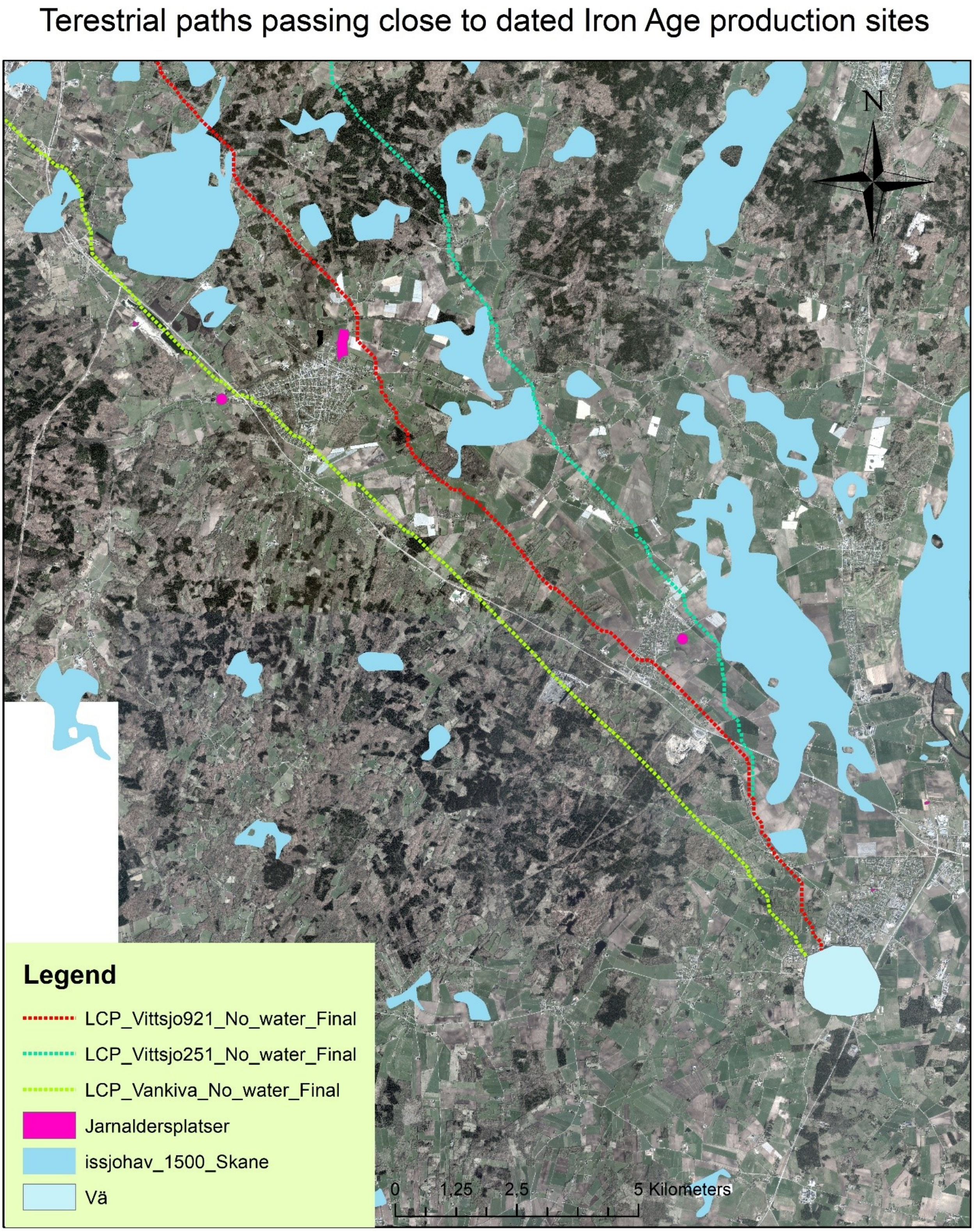


Map. 7

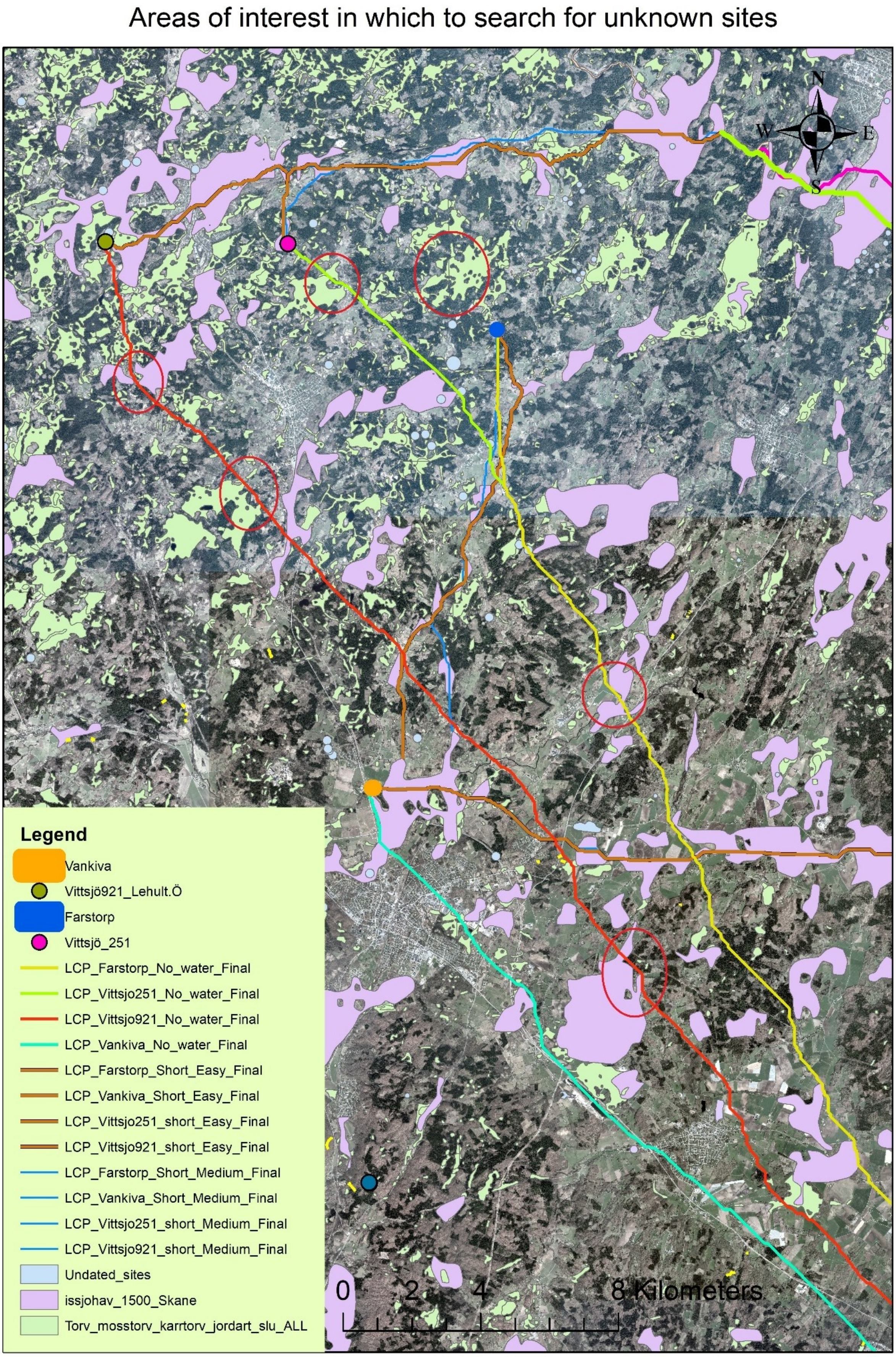


Terrestrial path close to hollow way
N
W
E
S
Legend
hollow_way
LCP_Vittsjo921_No_water_Final
LCP_Vankiva_Short_Easy_Final
LCP_Vankiva_Short_Medium_Final
Torv_mosstorv_karrtorv_jordart_slu_ALL
issjohav_1500_Skane
0 0,125 0,25 0,5 Kilometers

Map. 8

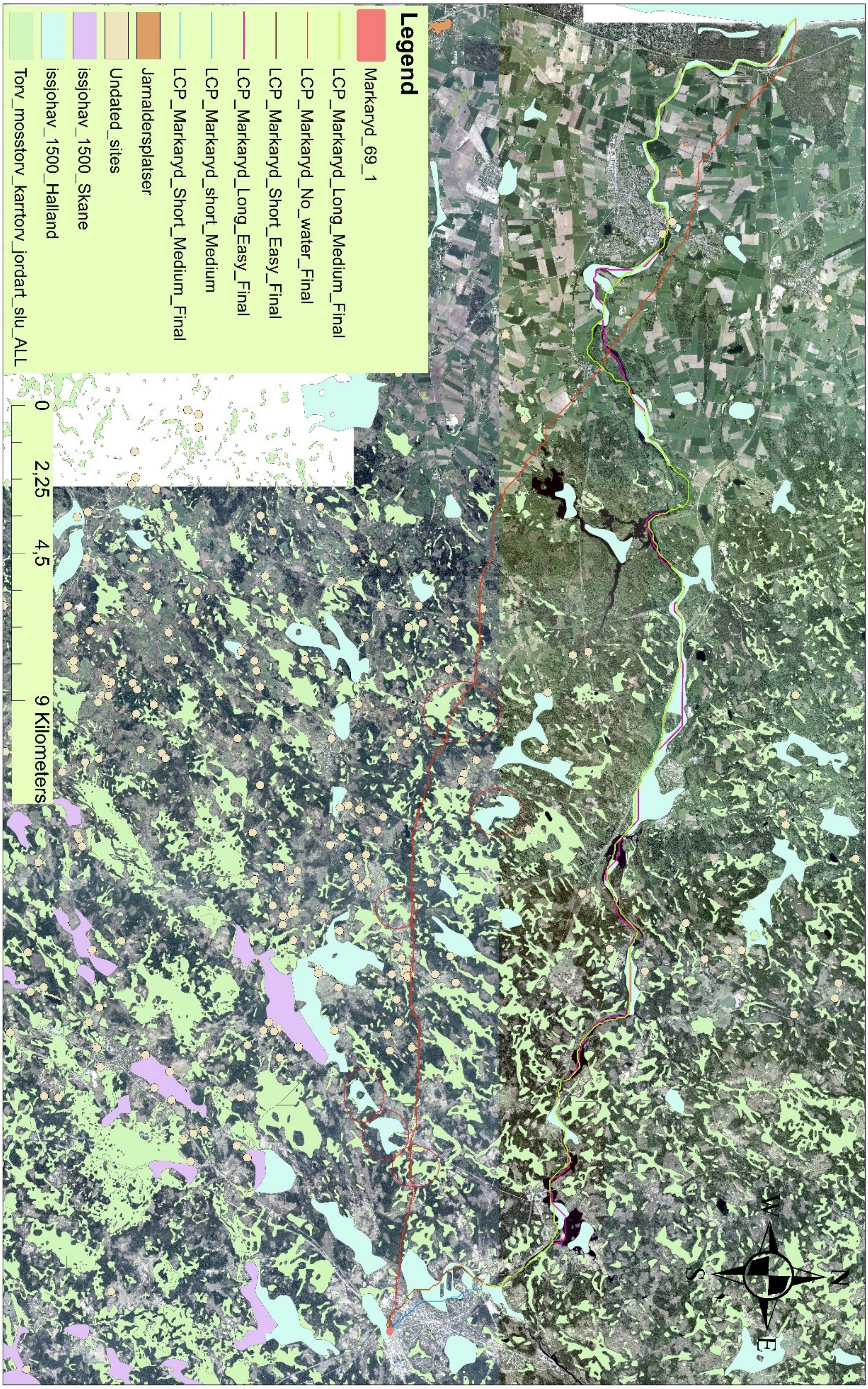

Terestrial paths passing close to dated Iron Age production sites
N
Legend
LCP_Vittsjo921_No_water_Final
LCP_Vittsjo251_No_water_Final
LCP_Vankiva_No_water_Final
Jarnaldersplatser
issjohav_1500_Skane
Vä
0 1,25 2,5 5 Kilometers

Map. 9



Areas of interest in which to search for unknown sites
N
W
E
S
Legend
Vankiva
Vittsjö921_Lehult.Ö
Farstorp
Vittsjö_251
LCP_Farstorp_No_water_Final
LCP_Vittsjo251_No_water_Final
LCP_Vittsjo921_No_water_Final
LCP_Vankiva_No_water_Final
LCP_Farstorp_Short_Easy_Final
LCP_Vankiva_Short_Easy_Final
LCP_Vittsjo251_short_Easy_Final
LCP_Vittsjo921_short_Easy_Final
LCP_Farstorp_Short_Medium_Final
LCP_Vankiva_Short_Medium_Final
LCP_Vittsjo251_short_Medium_Final
LCP_Vittsjo921_short_Medium_Final
Undated_sites
issjohav_1500_Skane
Torv_mosstorv_karrtorv_jordart_slu_ALL
0 2 4 8 Kilometers

Map. 10


Legend
Markaryd_69_1
LCP_Markaryd_Long_Medium_Final
LCP_Markaryd_No_water_Final
LCP_Markaryd_Short_Easy_Final
LCP_Markaryd_Long_Easy_Final
LCP_Markaryd_short_Medium
LCP_Markaryd_Short_Medium_Final
Jarnaldersplatser
Undated_sites
issjohav_1500_Skane
issjohav_1500_Halland
Torv_mosstorv_karrtorv_jordart_slu_ALL
0
2,25
4,5
9 Kilometers
N
S
E
W

8.2 Testing the data, LIDAR and SRTM, and learning the tools

For the purposes of this test, or trail LCP if you will, I am going to calculate a LCP from a randomly picked production site to a destination point. In the analysis, I will also be calculating paths with an intermediate point which served as a sort of restraint for the path. However, for this particular test this will not be included as it does not bring more to the evaluation of the data itself, rather it served as a step in evaluating a strategy for the workflow and how to best reflect a possible reality. It should be said though, that if an intermediate point would not be used the path would most likely go completely cross-country without any logic what so ever, and as suggested by Lock and Pouncett, people would have used intermediate points in the landscape to navigate (Lock & Pouncett 2010).

In theory this is what the test is supposed to consist of: creating the DEMs using the tool "LAS to Multipoint" turning the laser points in to multipoint files, create TINs (triangulated irregular networks) from the multipoint files using the tool "Create TIN" and from the TIN files create the raster DEMs using the tool "TIN to Raster", all available in the 3D Analyst toolbox. To see if the point spacing of the DEMs makes a difference to the resulting LCPs, I create three different DEMs. The point spacing of the original data is 0,5-1 point/m^2, I run the data with an "average point spacing" of 1, 4 and 30 meters, thus displaying, first every point, then every fourth point and lastly I use the data provided by NASA through their Shuttle Radar Topography Mission (http://dwtkns.com/srtm30m/). This data, as stated in the chapter Material, has a resolution of 30 meters and is downloaded in big squares of about 62x111 kilometres. The data for the higher resolution DEMs arrives as LAS-files and has to go through the process outlined above, making sure that each tile of DEM gets the right cell size corresponding to the point spacing. For the reason that the computer used did not have enough power to run the whole dataset per resolution in one go, the finished patches of DEMs have to be merged into two final DEMs with two different resolutions, 1 and 4 meters. The NASA DEMs also has to be merged, but as there are only four large tiles, this is an easy job. After this, the creation of the LCP can begin. I run the model, created in Model Builder (what Model Builder is and how it is used is explained at the beginning of the Analysis chapter), three times with the three different point spacing in order to be able to compare the results and to see if the path deviates from each other. The dataset chosen for the areas where higher resolution is going to be used will also be run in the program QGIS which uses a series of different algorithm than ArcGIS to calculate LCP. When calculating the slope raster, which is one of the cost raster's used in calculating the LCP, two different algorithms are used. In ArcGIS, the algorithm used for calculating slope is the Neighbourhood Slope Angle Algorithm, developed by P. A. Burrough and R. A. Mcdonell in 1998, which is the standard for many GIS programs, among then ArcGIS. In QGIS several different algorithms can be used depending on which tool is utilised, but for this test, Horns algorithm developed by Berthold K. P. Horn in 1981, was used (Horn 1981). To calculate the cost of moving from point A to point B the Cost Distance tool is used in ArcGIS and the GRASS r.Walk tool in QGIS. The output of these two tools is a raster map showing the least cumulative cost of moving between the two points. For the Cost Distance tool, this is expressed in distance and for the r.Walk tool it is expressed in time. The second output is a direction raster map, or backlink raster, which shows the movement direction to the next cell in the raster map to achieve the lowest cost (file:///C:/OSGEO4~1/apps/grass/grass-7.4.0/docs/html/r.walk.html#move & http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/cost-distance.htm). The Cost Distance tool calculates movement in an isotropic fashion, meaning that it can only move in 8 directions from the source cell. The r-Walk tool, on the other hand, calculates movement in an anisotropic fashion making it possible to move in 24 directions from the start cell (Herzog 2014, p. 235 & file:///C:/OSGEO4~1/apps/grass/grass-7.4.0/docs/html/r.walk.html#move & http://desktop.arcgis.com/en/arcmap/10.5/tools/spatial-analyst-toolbox/understanding-cost-distance-analysis.htm).

The resolution and quality of the DEMs used have been shown to have an effect on the results of calculated slope, just as the algorithm used also effects the results (Tang & Pilesjö 2011 p. 143f). As this is the case, testing both resolutions used, as well as different algorithms, seem to be a good idea.

For the tests, I do not use any land cover maps, which is used to let the algorithm know what type of vegetation and terrain the area has. The reason for this is that I do not need to test this data in the same way as it is at a fixed resolution of 30 meters, thus it will be included first when the actual analysis commences.

8.2.1 Problems and Solutions, Test

Several problems emerged through this process of tests and a lot of new things was learned along the way. The biggest problem that was encountered was the sheer size of the data that needed to be processed to create the DEMs. In part, this was because the downloaded data did not need to have the large coverage it had, as at the time of the downloading the points of source and destination had not been fully decided on. But also the way in which you choose the geographical extent of the data at the SLU site (https://zeus.slu.se/get/?drop=), in effect making the chosen area much larger than needed. This problem was solved by using the external toolset of LAStools, created by Martin Isenburg (https://rapidlasso.com/lastools/). The lasclipPro tool was used to clip or filter the LAS files in order to only contain points within a pre-defined area in the input format of a polygon. The result was a much smaller data set which could be processed faster through all the steps described above to create the DEMs. The advantage of this process as compared to the "Clip tool" integrated into ArcGIS, which needs an input of at least multipoint files, is that you do not have to do any processes other than calculating statistics for the LAS files prior to clipping the data. What is important here is to use the LAStools version of statistics calculation (lasindex) as it outputs lax-files rather than lasx-files which are only compatible with ArcGIS own tools.

The second problem relates to the first one as it has to do with the computational power of the machine used. As mentioned above, because of this lack of power, the result of the process of turning the LAS data into DEMs, resulted in several patches of DEMs that had to be merged. Luckily this is an easy job in ArcMap using the "Mosaic to New Raster" in the toolbox ArcToolbox > Data Management". This tool not only merge the rasters of your choice in to one "mosaic raster dataset" it also reduces the size of the resulting dataset as it removes overlaps as well as have a higher degree of success in removing seems between the individual rasters (http://desktop.arcgis.com/en/arcmap/10.5/tools/data-management-toolbox/mosaic-to-new-raster.htm & http://desktop.arcgis.com/en/arcmap/10.5/tools/data-management-toolbox/raster-catalog-to-raster-dataset.htm). At this point I decided to save the merged data in a Geodatabase as I am going to import all the resulting and final files in to a geodatabase anyway, thus saving myself a tiny bit of work as well as space.

A third problem appeared when was I revising the final DEM from the first run with point-spacing 4. Unfortunately, there were several places in between the original raster DEMs that for some reason contained no data at all. This might be a result of bad swath alignment during the original LIDAR-accession but become apparent first now. Having areas of "no data" is of course not a good thing and must be fixed. One way to do this is to use the Image Analysis function in ArcGis and through a series of steps interpolate new data into the NoData value of the problem area. This new data will consist of approximations of the surrounding data and given that the NoData area is not too big (a maximum of a few pixels wide) the area can be repaired and the DEM will function without problem.

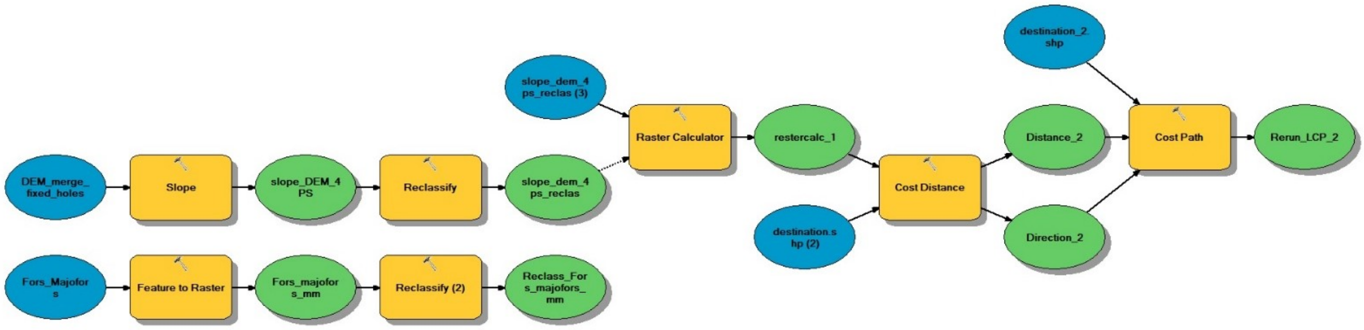
A fourth problem emerged when running the second DEM with point-spacing 1, something made the merging process function incorrectly and an error message was the result of every single try. The solution to this proved to be a way to do the same thing but in fewer steps. Using the process of creating a new Mosaic Dataset in your Geodatabase, add the rasters you want to merge in the dataset and then run the tool Mosaic to New Raster with that dataset as input. This will give you a seem free merged raster DEM. Interestingly enough the problems with NoData areas previously experienced, which were also present before running the tool Mosaic to New Raster on the second collection of DEMs with point-spacing 1, were nowhere to be seen this time after the merging.

A fifth problem is the modern interference in the landscape. This consists of all human-made structures that are not filtered away in the initial choice of which returns the DEM is going to be built from; canopy, buildings or ground. The interference can be visible obvious like dams, airfields, cities or the like and they can be more subtle like roads, traces of buildings not completely filtered out, modern earthworks and flattening of the topography. This is not an easy issue to overcome as it will always be reflected in the high data of the DEMs thus making the removal or remodelling hard as the real historical high data is not known. Whether a modern feature will turn up or not also depends largely on the resolution of the dataset as a DEM with points every 30 meters might miss features captured with a DEM with points every fourth meter. This highlights another reason why testing your data first is an important part of this type of analysis, to see which resolutions are most suited for that specific type of landscape. The problem can be partly overcome by using polygons with the shape of the modern feature. These shapefiles are then turned in to rasters to tell the algorithm where it can and cannot go, thus providing the algorithm with additional data to be considered along with the information provided by the DEM for those specific areas. Alternatively, it can also be used to tell the algorithm where it is easier to go, more on this below.

8.2.2 Results of the tests

The first of the tests involved running the LPC model with point spacing 4 as this was the first DEM raster dataset I created. After this, a LCP was generated using the 30 meter DEM, after this the 1 meter DEM and lastly LCP was generated in QGIS using the 4 meter DEM.

The model used in ArcGIS for the running of the tests



The test in QGIS was run using separate tools. First using the SAGA tool “Slope, Aspect, Curvature” to create the slope, then using GRASS tool “r.walk” with the 4 meter DEM as elevation and the obtained slop raster as friction as well as my source, converted from vector to raster format, as the starting point. The output of this is a raster showing the anisotropic cost of moving based on the friction provided by the slope (QGIS). In order to give my source point coordinates, the tool “Add Coordinates to points” was run. Last but not

Test of the data

least the LCP was generated using the SAGA tool “Least Cost Path”. The raster from the “r.walk” tool was used as Accumulated cost and my destination point as Source Points.

The tests showed that when using the 4 meter DEM there was for most of the distance no larger deviance between the algorithm incorporated in ArcGIS and that incorporated in the SAGA tool used in QGIS. However, when entering areas where the landscape becomes more intricate, the path generated with QGIS performed better. This can be seen in an area where all paths, except the one generated with the 1 meter DEM, was following a stream. When the paths entered a less obvious portion of the topography, the path generated with QGIS continued following the stream as the other paths diverged from it. Even though the general direction was largely the same in all four paths. From this, it can be said that if using the QGIS software instead of ArcGIS the results could be more detailed and provide a different result. Further testing of the QGIS software using different resolutions and other areas and more incorporated information of the terrain could also provide a clearer picture. But for this project ArcGIS is continually going to be used as the timeframe for this project is not large enough to learn a new software environment. It should also be said that the ArcGIS environment is much more user-friendly (ArcMap 10.5.1) than the QGIS (QGIS 3.0) environment, probably lending to ArcGIS higher popularity.

When running the different resolutions in ArcGIS the path stays largely the same when using the 4 meter DEM and the 30 meter DEM. When using the 1 meter DEM, on the other hand, the path deviates quite a lot from the three other. Instead of following the stream the path takes off to the east and travels over flat land to the larger stream and enters it above the rest of the generated paths. This is seen as a less likely scenario as it is the only one taking off in that direction and completely abandons the natural structures visible in the DEMs.

Evaluating these results, it was decided that the DEM with the resolution of 4 meters was the one performing best in line with what could be considered logic in the landscape. For the smaller areas where higher resolution is going to be used the 4 meter DEM will thus be used. Concerning the use of the ArcGIS algorithm and SAGA algorithm used in QGIS the conclusion can be drawn that the tests run in QGIS show a higher degree of detail, following the stream even more closely than the 4 meter DEM run in ArcGIS. However, as the different generated paths by large follow the same features, the divergence for the end result arguably would not be large. This in combination with ArcGIS’s higher user-friendliness makes the process easier and more time effective means that the scale pan tips in favour for ArcGIS. Thus ArcGIS is going to be used for the analysis in this project.