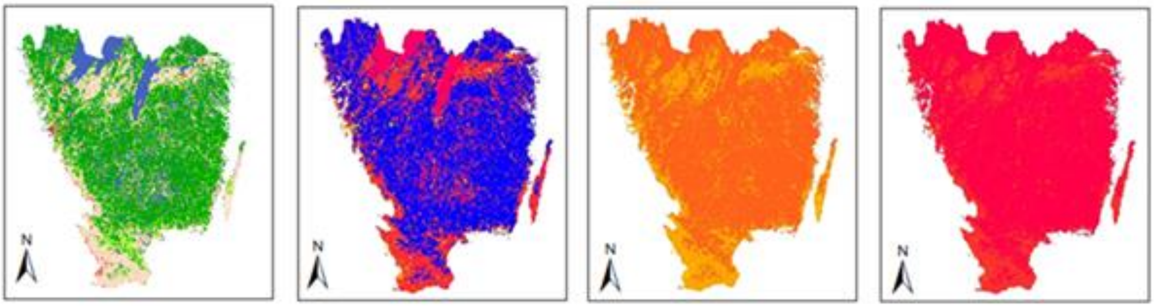
Master Thesis in Geographical Information Science nr 109

Land cover changes in Southern Sweden from the mid-Holocene to present day: Insights for ecosystem service assessments



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Master thesis, 30 credits, in Geographical Information Science

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Abstract

Climate change and human impact play a huge role in the sustainability and development of ecosystems and the services they offer to societies over temporal and spatial scales. Fossil pollen-based estimates provide unique information on past land cover change, but to date there are not many methods able to create spatially continuous maps and have a fine scale of land cover changes inferred from pollen information. No spatially continuous maps of this type exist for southern Sweden.

This studies aim was to evaluate these spatial changes in land cover in Götaland, through a long-term perspective and the related ecosystem services (ES), to determine how land cover may change here going forward and what ES can be expected for society, and how best to manage that land cover to get the most ES for the benefit of future societies.

First CORINE land cover data (2012) was mapped in ArcMap 10 representing the present, showing that Götaland is currently 63% forested, 19% arable land and 11% water bodies.

Next the Landscape Reconstruction Algorithm (LRA) based on pollen estimates, including pollen records from 41 sites in Götaland covering 25 plant taxa, was used to create land cover maps of the past. To determine the best interpolation method to use with the LRA, 17 methods were assessed in ArcMap for the reconstruction of land cover for five land cover types: conifer forest, broad-leaved forest, shrubs, open land, and arable land, for a period in the past closest to 2012. This involved cross-validation and visual comparison with the CORINE data. Simple kriging with cokriging with an arcsine transformation was determined to be the most suitable method.

Spatially continuous maps of land cover were created in ArcMap for 15 time windows in 6 periods: the Mesolithic, Neolithic, Bronze Age, Iron Age, medieval period, and the modern period. These maps were split into 5 counties: Blekinge, Halland, Jönköping, Kronoberg and Skåne for further analysis.

The maps showed good concurrence with historical data and other studies from the Holocene for the study site in terms of land cover patterns, with much finer spatial resolution than many other studies. Major land cover patterns were: a decrease in forest cover over the Holocene with an increase in open land and arable land. Intervening periods were somewhat stable with a patch work of land cover types. Forest cover returned in modern times to high levels all over the study site and arable land was concentrated in areas along the coasts.

The regional map of Götaland and the more local ones considering the five counties were then discussed in terms of changes of ES through time based on the knowledge obtained from an ES assessment matrix for the present. Forests were the main source of ES in the early periods with this decreasing over time with human activities, until modern times where it increases again. ES from open land and arable land become more and more available over the Holocene as technology advances. In intervening periods these improvements in agricultural practices greatly influenced land cover with expansion and contraction of this land cover type and its ES's due to changes in climate, favourable or not, and other negative impacts on human civilization.

The data produced in this Master thesis have a great potential to be further used to assess the respective long-term influences of land-use and climate on the major ES in Götaland. They would therefore be of great interest for effective land management strategies, using for example past disturbance regimes, to face the ongoing and future climate changes.

Key words: Geography, Geographical Information Systems, GIS, Physical Geography, Götaland, Landscape Reconstruction Algorithm, Fossil Pollen, Ecosystem Services.

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List of Acronyms

ET	Ecosystem Type
ES	Ecosystem Service
LRA	Landscape Reconstruction Algorithm
LCT	Land Cover Type
TW	Time Window
RMSE	Root Mean Square Error
RSAP	Relevant Source Area of Pollen

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1. Introduction

Climate change and human impact play an important role in the sustainability and development of ecosystems over temporal and spatial scales (MEA, 2005). Climate changes have been the major drivers of changes in ecosystems through centuries, millennia and millions of years. Climate was the main major driver of change until ca. 4500 BP when human activities and population growth start to have a large influence on vegetation changes at regional and sub-continental scales of Europe (Marquer et al., 2014, 2017). Today the climate is mainly changing due to human activities, and so many uncertainties arise. In particular, human-induced changes in climate conditions, temperature and precipitation might affect the biogeographic distribution of species, and thereby influence ecosystem functioning (IPCC, 2014). Ecosystems and their related services are dependent on human activities via land-use. Land-use changes influence the natural variability of ecosystem changes (Kareiva et al., 2017).

Ecosystems provide goods to human societies. The term ecosystem services has been created to provide a starting point for defining, monitoring and valuing such services (Science for Environment Policy, 2015). The ongoing climate changes affecting ecosystems have therefore an impact on ecosystem services, with subsequent societal effects. With the proper use of ecosystems we can obtain a number of services which benefit people. These services can be broken down into different categories: i) provisioning services such as food, water, timber and genetic resources, ii) supporting services such as soil formation and primary production, iii) regulating services such as air quality regulation, and waste treatment, and iv) cultural services such as spiritual and religious values, and recreation and tourism (EEA, 2013).

In order to reduce any negative impacts of land-use on ecosystems and in turn the services they provide to us, sustainability is needed. The concept of sustainability refers to a good compromise between nature and society. To be sustainable we must stay within the limits of the natural environment to allow it to continue to function properly (de Groot, 2006), and provide enough goods to societies. The outcomes of the ongoing climate change may affect how societies interact with nature, and therefore the sustainable use of resources by humans. However, some outcomes of climate change could also be a benefit to society. For example, a few degrees warmer in northern latitudes can increase agricultural productivity and thereby give new land-use opportunities. Therefore, a better understanding of how climate change will affect ecosystems will provide a better view on how to act and so mitigate the influence of changes (Dietz et al., 2016). Most studies only focus on the short-term impacts on ecosystems, over a few decades or the last century. There needs to be a longer-term perspective (several centuries and millennia) rather than a few decades, to extract the natural variability of changes from the ones caused by human activities (Berglund et al., 2008). How societies have been flexible in the past and how vegetation has responded to climate and human influences of changes is of critical interest.

In recent years new ways of mapping ecosystem services have been developed (Burkhard et al., 2009, 2012; Campagne & Roche 2018; Bordt & Saner, 2019). Many focus on subcontinental scale assessments, which provide valuable information but don't aid in local or regional decision making due to the lack of appropriate data to quantify ecosystem goods and services at this level. Burkhard et al. (2009) created an assessment matrix to assess different land cover types to provide ecosystem services. While a very useful tool, the long-term perspective was missing from their study.

Prior to the 20th century sources of past land cover data were mostly drawn maps. Sweden's national archives have 12,000 digitized geometric maps from 1630-1655, and 5000 geometric maps from 1680-1700 (Riksarkivet (2019)). The land surveying database, Landmäteriet, have one of the world's largest digital map databases, yet the oldest for Sweden only goes back to 1628 (Landmäteriet (2019)). A digital platform called Alvin contains Swedish texts with maps of land cover. However, the oldest texts on file also only go back to the 1600's (Alvin (2019)). All the maps in these archives are drawn by hand, and are in many cases generalized and don't convey the land cover in any great detail, or if they do they only focus on certain areas and not entire regions. Land cover for the thousands of years humans inhabited Sweden and before this time is also missing.

In 1916 a Swedish scientist, Lennart von Post championed a pollen analysis method which he used to create the first pollen diagrams (Manten, A., 1966; Twiddle, C. L., 2012). Paleoecology, the study of past ecosystems using e.g. fossil pollen-based estimates followed on from this work. Using this type of data provides unique information on vegetation composition, land cover, and plant diversity changes at Holocene-time scale, our interglacial period. Substantial climate and vegetation changes have been recorded during the last millennia and centuries. From regional to local scales, impacts of human activities on vegetation cover are recorded at different rates and extents, and this needs to be explored.

Many of the studies reconstructing the landscape of the past only consider one or two sites and don't produce continuous cover maps for large areas. They also don't contain local scale level detail, which is of interest for environmental policies and for stakeholders. Local scales have more meaning to people living around a region than global ones. To date there is only one study mapping land cover based on pollen for southern Sweden (Lindbladh et al., 2000). The techniques they used to produce these maps use models that don't incorporate pollen dispersal, deposition, and production characteristics, and so do not correspond to any spatial scales. As a result the maps are low resolution and quite blocky. Also the number of pollen sites available since then have increased (Fyfe et al., 2009; Giesecke et al., 2014). Studies using a REVEALS model (Regional Estimates of VEgetation Abundance from Large Sites) use fossil pollen data to create maps of past land cover at regional or subcontinental scale (Nielsen et al., 2012, Pirzamanbein et al. 2014, Zanon et al. 2018). These studies are of better resolution than that done by Lindbladh et al., (2000). However, they still do not consider the local scale details. Additionally, the study by Nielsen et al., (2012) only used one interpolation method to recreate past land cover. For accuracy purposes a number interpolation methods need to be compared.

In order to achieve quantitative reconstruction of vegetation cover at local scales, background pollen should be quantified and subtracted from the relevant source area pollen. Using the Landscape Reconstruction Algorithm (LRA), which incorporates a LOVE (LOcal Vegetation Estimates) model can do this (Sugita, S., 2007b). Currently there are no maps based on LOVE estimates for Sweden and elsewhere. Recreation of land cover at this scale can also help us gain a better understanding of the long-term variability of change in ecosystems and the directions they are going (Berglund et al., 2008).

Dependent on the outcomes of the ongoing climate change, in the future, ecosystems at the northern latitudes may be strongly impacted by the related land cover changes. Sweden has a gradient of ecosystems from Nemoral in the south, to Northern Boreal vegetation zones. Götaland (southern Sweden) is characterized by heavily human-modified landscapes resulting from long land-use history (Björkman, 1999). Land-use and climate influences on ecosystems and their services are difficult to distinguish there and it is critical for the understanding of land management strategies. Götaland is therefore a key region to study the climate-versus anthropogenic-impacts on vegetation changes and ecosystem services from regional to local scales, the scales that are of interest for local environmental policies.

1.1 Aims

The present study aims at evaluating spatial changes in land cover in Götaland, through a long-term perspective (millennia) and the related ecosystem services, to determine how land cover may change in the study site going forward and what ecosystem services can be expected for society, and how best to manage that land cover to get the most ecosystem services for the benefit of future societies. For this purpose a conceptual framework approach has been developed (Fig. 1).

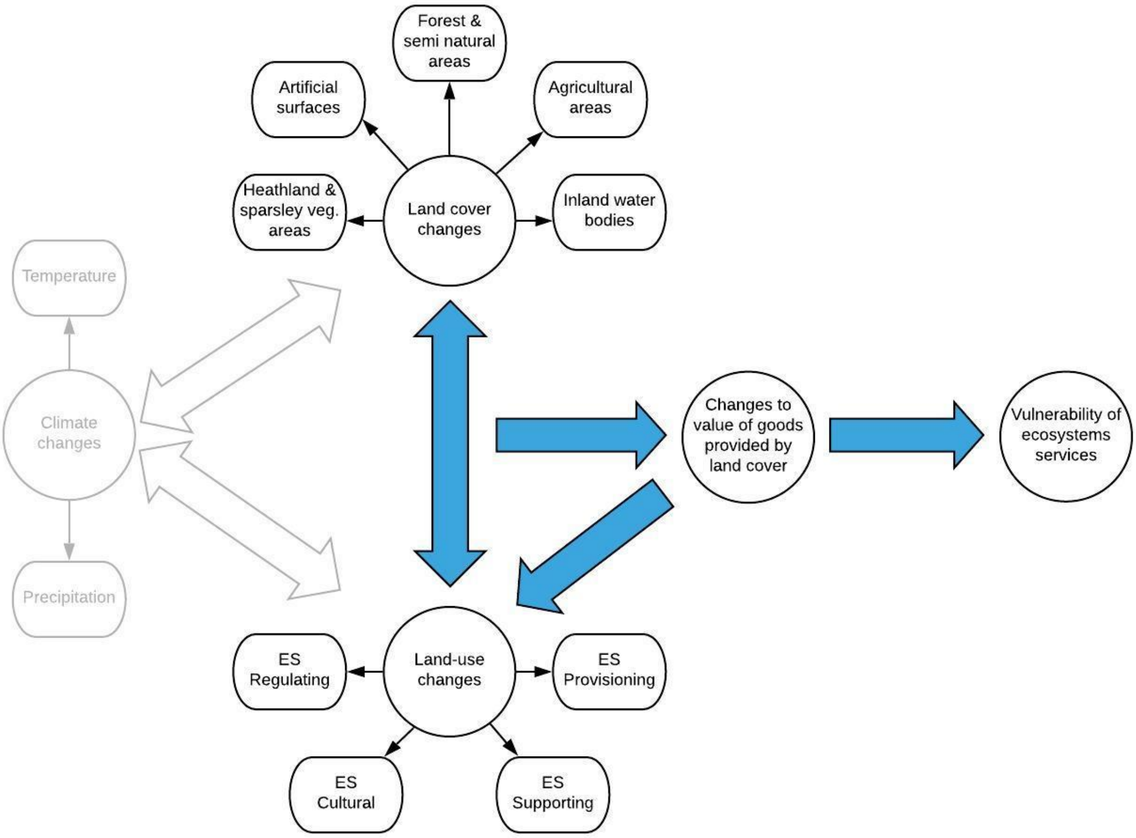


Figure 1. *Conceptual diagram of the different components included in this study. Climate changes (grey) are not factored into the analysis part of this thesis. Land-use changes, such as from forestry to agriculture, have an effect on land cover, and land cover changes such as from heathland to forest cover, have an effect on how the land can be used. The interaction between land-use and land cover then impacts the values of goods provided by land cover, and in turn on the vulnerability of ecosystem services. Additionally, the value of goods change over time, such as using rapeseed oil as a source of biofuel, which can have a major impact on land-use.*

With these interactions in mind, the main research questions that this study will attempt to answer are as follows:

1) What is the current land cover in Götaland?

Götaland is a heavily human modified area and as such diverse land cover is expected.

2) What is the most appropriate interpolation method for recreating past land cover with fossil pollen data converted into vegetation estimates with the Landscape Reconstruction Algorithm (LRA)?

Geostatistical methods should give better interpolation of past land cover than deterministic methods due to incorporation of spatial autocorrelation and statistically optimizing the weights when combining regional data points. Cokriging is expected to produce the lowest variance in the estimation error due to using the spatial cross-correlation between the primary variable and the auxiliary variable.

3) How much have plant resources (land cover) changed through time and location in the study site?

It is expected that forest cover will dominate earlier in the Holocene as no or few humans are present. This will give way to open land and arable land as humans settle and expand their domain. However, due to climate changes and other extenuating factors, human transformation of the landscape from forest to open land over time will not be in a linear manner.

4) How much have temporal and spatial changes in plant resources (land cover) affected the services offered to societies, including the ES found today in the study site?

People will use what they have readily available to them, reducing resources (type of land cover) as their populations grow. Fluctuations in one land cover type due to natural forces will also open up other land cover types for exploitation, or limit human growth. By answering this question it should be possible to provide a long term perspective on drivers of land use changes and altered provision of ecosystem services as a function of changes in climate, technology and population growth.

5) How is aim 4 important for today’s ecosystem service management?

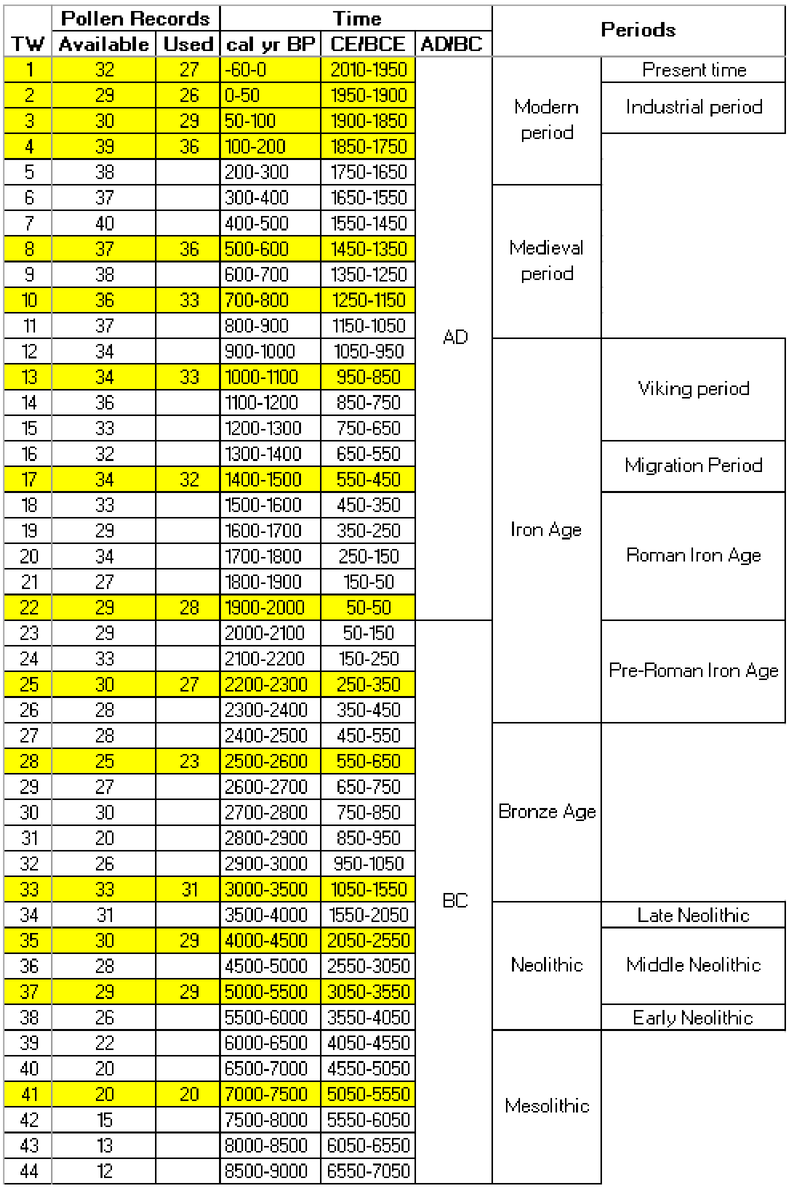
Proper archaeological or historical data is not part of this study, nor available from the deep past. As such, literature sources that are available i.e. research publications, are referred to. However, by combining aims 3 and 4, a discussion can be made on how land cover may change in the study site going forward and what ecosystem services can be expected for society / how best to manage that land cover to get the most ecosystem services for the benefit of future societies.

2. Research background

2.1 Historical landscape perspectives in Southern Sweden

Swedish vegetation and floristic diversity have changed over the Holocene due to migration of species, climate change, ecological succession of species, and more recently human activities (Berglund et al., 1991, 2008; Björkman, 1999; Lindbladh et al., 1999, 2008; Cui et al., 2014; Hultberg et al., 2015; Mazier et al., 2015; Fredh et al., 2012, 2017; Hannon et al., 2018). A number of key periods in human history occur in the Holocene which affected the Swedish landscape (Table 1).

Table 1. *Correspondence between 1- number of pollen records available, 2- number of pollen records used in the analyses, 3- time windows (TWs) with estimates of pollen-based land cover reconstruction (LRA estimates) available (Marquer et al., in prep), 4- time windows selected for this study (yellow), and 5- cultural periods of Swedish history. Time windows are given in cal yr BP as well as CE/BCE and AD/BC*



	Pollen Records		Time			Periods	
TW	Available	Used	cal yr BP	CE/BCE	AD/BC		
1	32	27	-60-0	2010-1950	AD	Modern period	Present time
2	29	26	0-50	1950-1900			Industrial period
3	30	29	50-100	1900-1850			
4	39	36	100-200	1850-1750			
5	38		200-300	1750-1650			
6	37		300-400	1650-1550		Medieval period	
7	40		400-500	1550-1450			
8	37	36	500-600	1450-1350			
9	38		600-700	1350-1250			
10	36	33	700-800	1250-1150			
11	37		800-900	1150-1050			
12	34		900-1000	1050-950		Iron Age	Viking period
13	34	33	1000-1100	950-850			
14	36		1100-1200	850-750			
15	33		1200-1300	750-650			
16	32		1300-1400	650-550			Migration Period
17	34	32	1400-1500	550-450			
18	33		1500-1600	450-350			Roman Iron Age
19	29		1600-1700	350-250			
20	34		1700-1800	250-150			
21	27		1800-1900	150-50			
22	29	28	1900-2000	50-50			
23	29		2000-2100	50-150	BC		Pre-Roman Iron Age
24	33		2100-2200	150-250			
25	30	27	2200-2300	250-350			
26	28		2300-2400	350-450			
27	28		2400-2500	450-550		Bronze Age	
28	25	23	2500-2600	550-650			
29	27		2600-2700	650-750			
30	30		2700-2800	750-850			
31	20		2800-2900	850-950			
32	26		2900-3000	950-1050			
33	33	31	3000-3500	1050-1550			
34	31		3500-4000	1550-2050		Neolithic	Late Neolithic
35	30	29	4000-4500	2050-2550			Middle Neolithic
36	28		4500-5000	2550-3050			
37	29	29	5000-5500	3050-3550			
38	26		5500-6000	3550-4050			Early Neolithic
39	22		6000-6500	4050-4550		Mesolithic	
40	20		6500-7000	4550-5050			
41	20	20	7000-7500	5050-5550			
42	15		7500-8000	5550-6050			
43	13		8000-8500	6050-6550			
44	12		8500-9000	6550-7050			

The lengths of these periods have been sourced here from: Berglund et al. 1988, 2003, 2008 and 2014. Based on these periods of significant events in human history and climate changes, a series of time windows (TWs) have been selected (Table 1). General patterns of land cover changes in southern Sweden classified into cultural periods (including selected TWs) are the following:

Mesolithic Period

7500-7000BP Late Mesolithic (TW41)

Forest cover dominated the landscape. This was part of the warmest period of the Holocene (Holocene climate optimum) in Northern Europe (8000-5500BP) that is characterized by a maximum extent of forest cover (e.g. Fyfe et al. 2015; Marquer et al, 2017). It was a time of low human impact and population density around the Baltic catchment (Kuosmanen et al., 2018). This phase follows the initial pioneer vegetation cover that developed at the beginning of the Holocene in cooler times*; Juniperus* (juniper), *Pinus* (pine), *Betula* (birch) and *Gramineae* (grasses) are progressively replaced at a sub-continental scale by deciduous trees such as *Tilia* (lime), *Ulmus* (elm), *Alnus* (alder), *Corylus* (hazel), *Fraxinus* (ash) and *Quercus* (oak) (e.g. Giesecke et al., 2017; Marquer et al. 2014, 2017).

Neolithic Period

5500-5000BP Early – middle Neolithic (TW37)

At this time there was a slight reduction in forest cover around the coasts and some arable land cover on the coastal areas. After 5500BP there was a cooling trend due to declining summer insolation (Imbrie et al., 1992). At the same time agricultural land spreads over Northern Europe, Scandinavia, as well as Southern Sweden, and this period corresponds to a starting point of records of human-induced vegetation changes and expansion of the open landscape (Eriksson & Cousins, 2014). Both events led to fluctuations in plant populations (Marquer et al., 2014). Although other factors such as diseases may have affected vegetation composition changes, i.e. Elm decline is possibly caused by some elm diseases that occurred ca. 5000 BP (Berglund et al., 1991). Overall landscape use change occurred earlier on the fertile coastal plains (Berglund et al. 2014).

4500-4000BP Middle to late Neolithic (TW35)

There was also a slight reduction in forest cover around the coasts and some arable land cover on the coastal areas during this period. Climate is wet and cool during this period that is characterized by lake levels rise and expansion of agriculture, herb, and grasslands. Mainly coastal areas utilized still at this stage (Berglund, 2003). Slash-and-burn cultivation coincides with a slight increase in *Calluna* pollen (heathers), indicating grazing pressure around 4000 BP (Hannon et al., 2018). Out-fields dominated by dense and natural forest (Lindbladh, 1999).

Bronze Age

3500-3000BP Early Bronze Age (TW33)

Massive reduction in forest cover and expansion of arable land during this time. Climate changed from more continental to oceanic with lake levels rising further. Expanding agricultural settlement (permanent crops) occurs also affecting the inland (Berglund, 2003). Forest structure and composition over much of South-West Sweden impacted largely by Bronze Age activity (Hannon et al., 2018). Around ca. 3000 BP forest cover was estimated as below 40% (Eriksson & Cousins, 2014). Woodlands still dominate the inner hummocky zone. Wooded and semi-natural vegetation and cultivated fields are mostly found in outer hummocky and coastal zones (Berglund, 1988). Forests are initially opened up to improve grazing with cultivation then becoming more important (Lindbladh, 1999).

2600-2500BP Late Bronze Age (TW28)

Continued expansion of arable land. Around ca. 2500 BP manure from livestock was used to fertilize fields to increase crop yields. These crops would have then outcompeted wild plants (Eriksson & Cousins, 2014). Mixed deciduous forest still dominant forest type (Björkman and Bradshaw, 1996).

Iron Age

2300-2200BP Pre-Roman Iron Age (TW25)

Mosaic of open land, arable land and semi-open forest cover. Stabling of livestock starts. It is an efficient way to collect manure. Hay-making develops to overwinter livestock. The landscape is now a mosaic of fields, meadows, pastures and managed semi-open woodlands (Eriksson & Cousins, 2014).

2000-1900BP Roman Iron Age (TW22)

Open land cover high in the south, with low forest cover here. At this time grasslands are mostly used as hay-meadows for livestock. Woodlands in the south cover limited areas. Burning is used to open up and keep the landscape open (Eriksson & Cousins, 2014).

1500-1400BP Migration Period (TW17)

Reduction in open land and arable land and expansion of forest cover. This is a period of rapid cooling. The Roman Empire collapses AD 480 (1470 BP). Agriculture retreats, such as pasturing and cultivation of crops, leading to reforestation of large areas (Berglund, 2003).

1100-1000BP Viking Period (TW13)

Reduction in forest cover and re-expansion of arable land. The climate is now warmer and drier (Medieval Warm Epoch, Northwest Europe) than in the previous periods, with high treelines and glacial retreat. Around this time new areas are cleared for colonization and expanding of settlements and agriculture, with permanently cultivated land areas (Berglund, 2003).

Medieval Period

800-700BP Early Medieval Period (TW10)

Increased reduction in forest cover, mainly broad-leaved forest cleared, with continued expansion of arable land. This is the end of the previous warm period, with a change to a cool/moist climate. Broad-leaf trees start to be cleared in Sweden. The forests are mixed deciduous with increasing presence of *Fagus sylvatica* (European Beech) (Björkman & Bradshaw, 1996). Agriculture intensifies on the in-fields, most importantly for cereal cultivation. Out-fields used for forest grazing and slash-and-burn agriculture (Lindbladh, 1999; Fredh et al., 2017).

600-500BP Middle - Late Medieval Period (TW8)

Massive reduction in arable land then a stable landscape of shrubs and patchy forest cover. Cold conditions prevail now with a severe effect on agriculture (mid-Medieval agrarian crisis) (Berglund, 2003). Pastures and meadows decline by 40-50% between 600 and 300 BP. This may correspond with the Black Death pandemic that first struck Sweden in 600 BP, and again between 600 and 500 BP. 60-70% of all farms in the uplands of Southern Sweden were abandoned because of this (Fredh et al., 2017). The structure and composition of the landscape and vegetation is fairly stable with heathland, grassland and patchy woodland from here until the 18th century (Eriksson & Cousins, 2014).

Modern Period

200-100BP Start of Modern Period (TW4)

Massive expansion of arable land, forest cover reducing. This is the time of the agricultural revolution. There is an increase in science and technology. An increasing demand for food leads to massive expansion of agriculture. Forests are increasingly cleared, and lakes and wetlands drained. Crop rotation and fertilizers are introduced. Semi natural grasslands are used for crop production and forests are less used for grazing. Machines run on oil replace horses (Eriksson & Cousins, 2014). The largely constant agricultural land cover feeds more people due to more efficient nutrient supply to the arable land, land divisions, more efficient manuring, irrigation and marling (Fredh et al., 2017). In out-land areas deciduous forest is replaced by dense coniferous forest (Lindbladh, 1999).

100-50BP Industrial Period (TW3)

Higher shrub cover than in other periods and highest open land cover. Grasslands start to decline around this time. Grasslands on clay and silty soils are drained and turned into crops. Conservation of nature and culture become fashionable. In Sweden this means the cultural landscape (Eriksson & Cousins, 2014). The heathland reaches its maximum areal extent (Björkman, 1997). It is a period of highest landscape openness, with tree cover around 34% in parts of Southern Sweden (Mazier et al., 2015).

50-0BP Industrial Period (TW2)

Reduction in open land and arable land and increased forest cover, especially conifer forest. Forest grazing is banned in 1928 (22 BP), so as to produce more timber in Sweden. Further declines in grassland take place (Eriksson & Cousins, 2014). Spruce plantations become increasingly common in Southern Sweden, and in particular the province of Småland, from the beginning of this TW (Cui, et al., 2014). Small scale agriculture gives way to modern land-use, focusing on commercial forestry and crop cultivation. As a result, the rural population drops. The introduction of artificial fertilizers means it is unnecessary to keep animals for nutrient supply to the fields with a consequent general reduction in meadows and pastures (Fredh et al., 2017).

Present Time

0-(-) 60BP (TW1)

High forest cover, greatly reduced open land and arable land cover. After the Second World War farmers were instructed to plant low productive areas with forest. At the same time due to change in legislation many small farm owners had to sell up. This all leads to a decline in grasslands and an increase in forest cover. A program for maintaining remaining semi-natural grasslands is initiated during the 1980s in Sweden (Eriksson & Cousins, 2014). Forest cover increased to around 70% and wetland covered decreased to 8% (Mazier et al., 2015).

2.2 The European Pollen Database

Since the 1960s large sets of pollen data have been acquired and have been increasing over the last number of decades. Towards the end of the 1980s EU research programs involved in palaeoclimatology needed improved maps of late Quaternary palaeovegetation based on these data sets. A pollen database thus evolved from this need and was called The European Pollen Database (EPD) (Fyfe et al., 2009; Giesecke et al., 2014). It was developed in the early 1990s to provide a structure to archive, exchange and analyse Quaternary pollen data from Europe. As of January 2009, the EPD archived 1,032 fossil pollen sequences from all over Europe (Fig. 2), 668 of which have age-depth models allowing chronological comparison (Fyfe et al., 2009). While much work has gone into the content of the database, the data still carries a number of uncertainties especially to do with aging the samples. Also, many of the pollen taxa have various taxonomic levels. However, maps created from the pollen database represent the major aspects of European vegetation history, and while spatial distribution of the sites is currently quite uneven, the database is constantly updated to include new sites (Brewer et al., 2017). Pollen records from the EPD covering southern Sweden will be used in this study.

Figure 2. *European Pollen Database pollen sites (Brewer et al., 2017)*

2.3 Pollen-based quantitative estimates of past vegetation

Pollen estimates of past vegetation are critical to assess a long-term perspective of change. However, until recently pollen data did not take into account crucial parameters of pollen production from the plant (species-specific pollen production), pollen dispersal (species-specific pollen dispersal) and deposition in a sedimentary basin (bogs or lakes of different sizes). New approaches (e.g. Landscape Reconstruction Algorithm, LRA) have been developed over the last decade to integrate production, dispersal and deposition mechanisms to express pollen-based vegetation estimates in terms of quantitative values of land cover (Sugita, 2007a, 2007b). Semi-quantitative methods have also been developed e.g. pseudobiomization method (PBM) to transform pollen proportions to land cover classes including land-use categories (Woodbridge et al., 2014; Fyfe et al., 2015), and biomization method to assess biome changes at a continental scale (e.g. Guiot et al., 1996; Prentice & Jolly, 2000; Williams et al., 2008; Davis et al., 2015), and Modern Analog Technique (MAT) to estimate changes in tree cover (e.g. Williams, 2002; Williams and Jackson, 2003; Williams et al., 2011; Zanon et al., 2018). LRA quantitative approaches provide the most accurate estimates of land cover in terms of plant taxa at specific spatial resolution (from regional, 50-100km around the site where pollen deposited) to local scale (a few meters or kilometres around the site). Quantitative estimates also provide the assessment of the rate of vegetation change as well as diversity indices (Marquer et al., 2014, 2017). Those are of high interests to explore the relations between land cover and ecosystem services in the past, and thereby assess the missing long-term perspective.

The LRA (Sugita, 2007a, 2007b) is currently the most advanced algorithm for working with pollen estimates to get quantitative estimates of local land cover changes at a known spatial scale (Fig. 3). It works by first using pollen recorded from sites at large lakes (>50 ha) to estimate regional vegetation coverage with the REVEALS model (Marquer et al., 2014, 2017; Trondman et al., 2015). Once the influence of regional vegetation is defined, purely local signals from smaller sites, lakes and bogs, (<50 ha) are obtained with another model called LOVE. This allows background pollen to be subtracted and only the relevant source area of pollen to be used for a quantitative reconstruction of local vegetation (Sugita, 2007b). Local vegetation means here less than 4km around each pollen site. For past vegetation reconstruction in southern Sweden the LRA has so far only been applied to a small number of fossil pollen sites (Cui et al., 2014; Mazier et al., 2015; Fredh et al., 2012,2013, 2018). The difference for this study is that the LRA was run with for all current fossil pollen sites in southern Sweden.

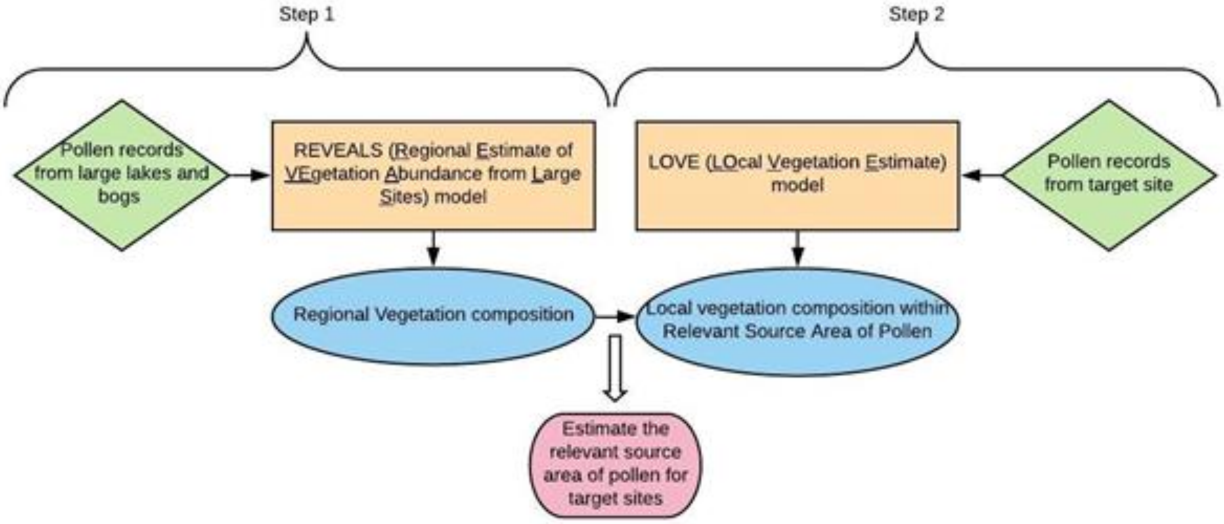


Figure 3. *The Landscape Reconstruction Algorithm (LRA). Step one the REVEALS model is used to calculate regional vegetation compositions with pollen records from large lakes and bogs. Step two the LOVE model is used to calculate the local vegetation composition with pollen records from the target. Subtracting the two gives the estimate of the relevant source area of pollen for target sites. (Modified from Sugita, 2007 a, b).*

While palaeoecology provides important information on past vegetation and land cover using fossil pollen, spatial continuous maps based on such data are still difficult to assess, i.e. paleo records are considered as point estimates with gaps between them. Maps based on quantitative and semi-quantitative pollen modelling have already been created at continental and sub-continental scales (e.g. Nielsen et al., 2012; Pirzamanbein et al. 2014; Trondman et al., 2015; Zanon et al., 2018). However, maps at local scales are poorly developed. Nielsen et al. (2012) used a REVEALS method to model land cover for Northern Germany and Denmark using pollen data properly, and the maps are better resolution than Lindbladh et al. (2000), but this model only focuses on regional land cover and not local cover. They also only use one interpolation method for the work rather than Pirzamanbein et al. 2014 and Zanon et al. 2018

2.4 Spatial interpolation to fill the gaps between points estimates (pollen records)

Spatial interpolation is a means of using a limited number of sample points with known values to estimate the value at unknown points. This can be extended over large areas (ArcGIS Desktop help, 2017). ArcMap 10, and in particular the geostatistical analyst tool, has a number of interpolation methods to choose from (ArcGIS Desktop help, 2017). These methods allow one to construct models of reality. In the case of this study, modelling land cover and land cover change over time. However, for any model to work well, the phenomenon should be understood, as well as how the samples were collected and what the models represent, or are expected to provide (ArcGIS Desktop help, 2017). Deterministic methods create surfaces from the measured points, based on the degree of smoothing or extent of similarity. Geostatistical methods use the statistical properties of the measured points, i.e. quantifying spatial autocorrelation and accounting for the spatial configuration of the points around the predicted location. Four deterministic methods and the seven geostatistical methods were evaluated in this study. Each method has its own set of parameters which means it can be customized for different datasets and also the requirements for the generated outputs.

There are many studies comparing the performance of spatial interpolation methods for different purposes, such as modelling precipitation (Javari, 2017) or sea level pressure (Besselaar et al., 2011). IDW, kriging and cokriging are the most commonly used interpolation methods. Kriging generally has the lowest prediction bias compared to other methods, that is why it is often used (Mirzaei & Sakizadeh, 2016). However, few studies combine spatial interpolation and modelled pollen data to create spatially continuous land cover maps, and even fewer of local level detail. For those that do, the determination of the best interpolation method is not made (e.g. see Nielsen et al., (2012)). This study uses the geospatial analyst tool in ArcMap to trial 11 interpolation methods, with a focus on kriging, to construct spatially continuous maps of areas in Götaland, covering time periods in the Holocene using pollen estimates modelled by the LRA giving local level detail. Additionally, cokriging, which is using a supporting data set as a source of additional information (in this case elevation), was also trialled with disjunctive, indictor, ordinary, probability, simple and universal kriging. This added 6 more methods, giving a total of 17 methods trialled, greatly improving the accuracy of the maps, and recreating past land cover for southern Sweden never recreated before in such detail and range. Allowing an unrivalled assessment of the ecosystem services available at different periods over the Holocene for this part of Sweden.

2.5 Ecosystem Service Assessment Matrices

Matrices are important tools for ecosystem services (ES) mapping and assessment. They link ecosystem types (ET) or land cover types (LCT) to ES by giving a score to ES capacity, demand or supply (Campagne & Roche, 2018).

Various methods for assessing ES have been used in different studies. According to Bordt & Saner (2018), there is a lack of an internationally-accepted, fully comprehensive classification system for which ecosystems provide which services. Having such a system they say would improve the aggregation of local studies into national and international ecosystem accounts. To create this system, or superset as they call it, Bordt & Saner (2018) compared 9 ecosystem service assessment systems. These ranged from meta-analytical studies (meta-analysis of a large number of local scale studies), to global assessments such as The Millennium Ecosystem Assessment (MA, (2005)) and The Economics of Ecosystem and Biodiversity (TEEB), and also local and national assessments such as The United Kingdom National Ecosystem Assessment (UK EA), which is based on the MA (2005) system. They were able to come to somewhat of a consensus for some ecosystems but not all. However, their approach is useful for integrating information at different scales. Campagne & Roche (2018) state that any list of ES can be used in an assessment matrix, but that they recommend using a standard list as reference and adapting it to meet the assessment goal and be relevant for local stakeholders. Ecosystem types, they mention are just the ecosystem or LCT found in the case-study area. According to Campagne & Roche (2018) the main scoring scheme used in the literature for ES assessment matrixes is based on Burkard et al (2009). This system ranges from 0 to 5. With 0 being no relevant capacity of an ET to provide ES, to 5, a very high relevant capacity to provide ES. Some authors use ranking such as 0-100 and others 0-2. With larger scales taking more time for experts to score (Campagne & Roche, 2018).

The supply of ES depends on the conditions of the ecosystems themselves, and changes in land cover over space and time due to human land cover changes, land-use, and climate changes. Human activities can be directly measured through spatial patterns of land cover and land cover changes over large regions. The mapping of distributions and changes over time of ES can provide complex information in the support of landscape sustainability assessments for decision makers (Burkhard et al., 2012).

3. Methodology

3.1. Data for present time

3.1.1 Study region

This study focused on southern Sweden, in particular the land cover of Götaland (Fig. 4).

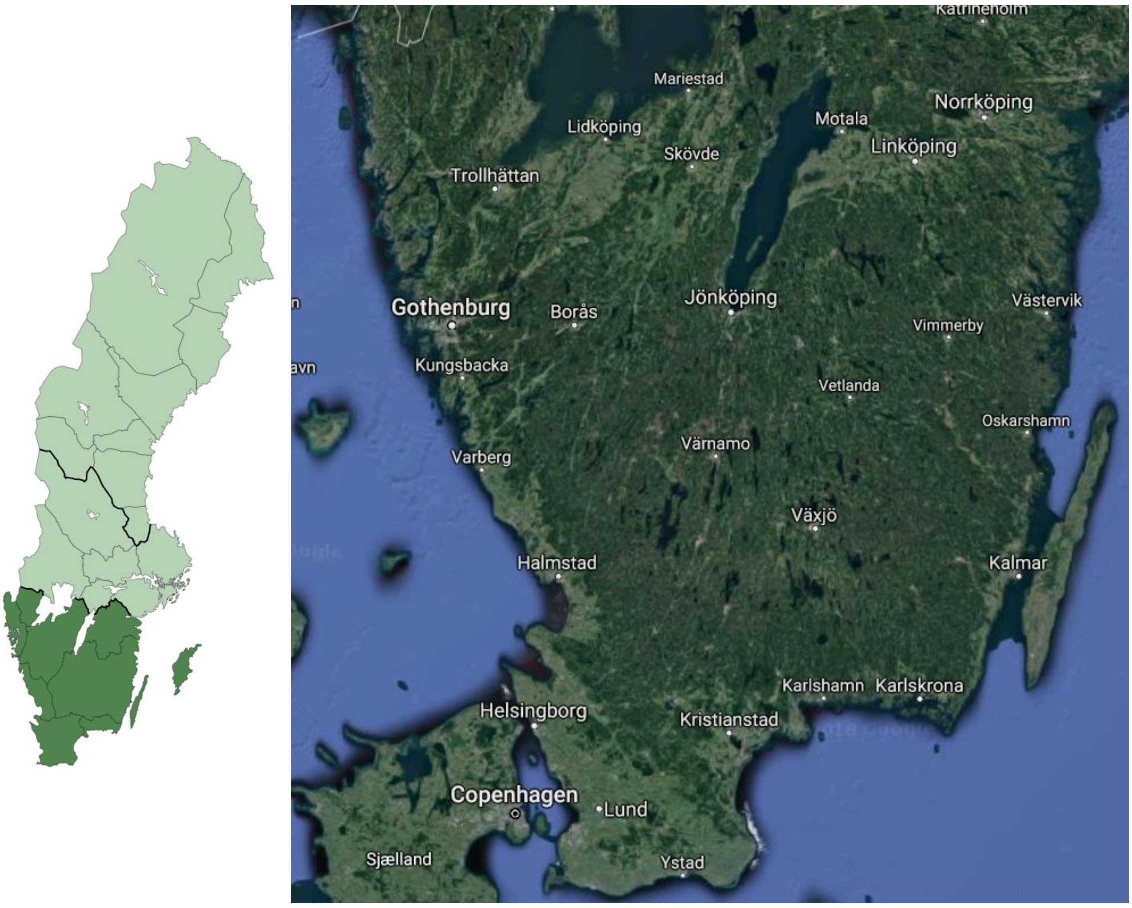


Figure 4. *The study region Götaland in southern Sweden. Open land / agricultural areas (light green) on the island of Öland to the south east, and around the coast and south of the map in Skåne. Parts of the north beside the lakes also have this land cover. More central inland areas consist mainly of forested regions (dark green). Image from Google Earth.*

3.1.2 CORINE land cover dataset

For present day land cover the European Union provides easily available data through the CORINE database. Up to date CORINE land cover data (2012) in vector format from the European Environment Agency database was downloaded at the following link: http://www.eea.europa.eu/publications/COR0-landcover. Administrative boundary layers of Sweden were downloaded from the DIVA-GIS website: http://www.diva-gis.org/Data and used to cut out the study area from the CORINE land cover dataset. The CORINE programs aim is to compile information on the state of the environment. CORINE data covers 44 land cover classes that were converted for the purpose of this study to five groups representing the major land cover types of Europe and to match the format of pollen estimates: artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands, and water bodies. 34 out of the 44 land cover types were used for this study as they were what are found today in Götaland (Fig. 5). Four sets of land cover types with different degrees of generalization were used in this study, as the pollen data did not support an analysis of all present-day land cover types. Some of these land cover types (LCT hereafter) did not exist back thousands of years ago. The first alternative was a map of present time Götaland with all the available data (34

LCTs) to visualize the real patterns (Table 2). The other three alternatives (13, 11 & 7 LCTs) were combinations of LCTs to have a look at the effect of increasing generalization in LCTs at present, and thus how this can affect the simplified LCTs that are used for the past periods (Table 2).

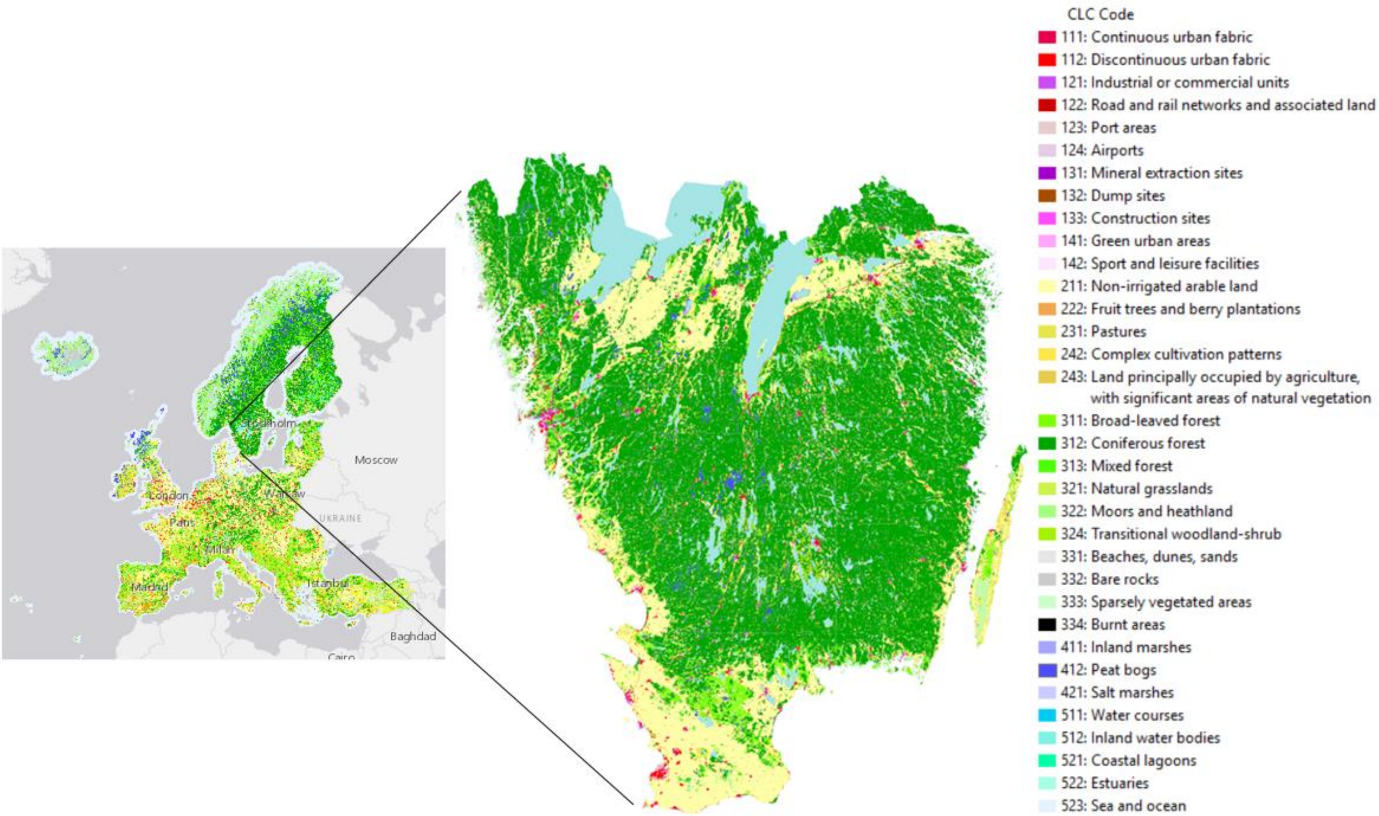


Figure 5. *CORINE land cover for Europe (smaller map) and Götaland (expanded map), with CORINE land cover (CLC) codes for land cover types.*

3.2 Data analysis and maps for Götaland for the present time

The first alternative based on the 34 specific CORINE data land-cover types (see section 3.1.2) was mapped for Götaland using ArcMap 10 by clipping the administration boundary for Götaland from the CORINE map of Europe. Next maps of Götaland with the three new alternatives were created. This was done by making new fields in the attribute table and subcategorizing the LCTS down to 13, 11 and 7 LCTs for alternative 2, 3 and 4. The percentage of each land cover type in hectares for Götaland, was then depicted in piecharts. The LCT Sea and ocean was left out as it was disproportionally shown when included.

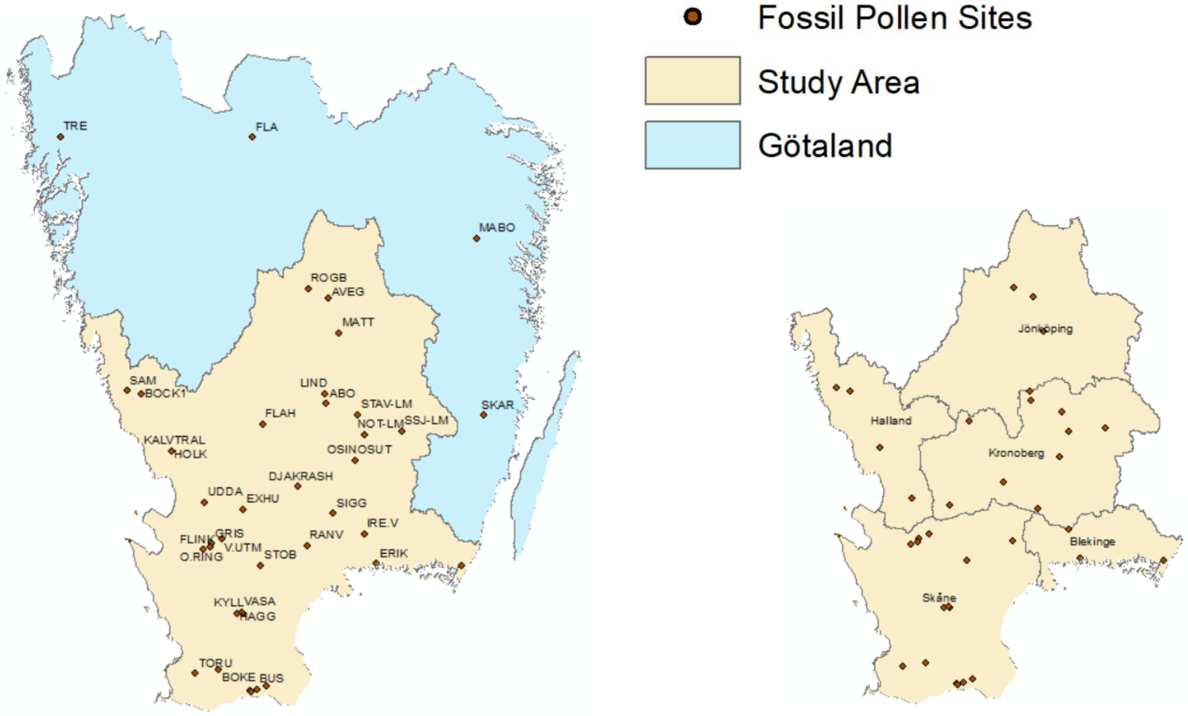
Table 2. *Separation of Götaland into land cover type categories and subcategories using four alternatives. Colouring used to show where alternative 1 LCTs end up in other alternatives. CLC_CODE = CORINE land cover class code.*

Surface	CLC_CODE	Name of CORINE data classes	LCTs Alternative 1	LCTs Alternative 2	LCTs Alternative 3	LCTs Alternative 4
Artifical surfaces	111	Continuous urban fabric	Continuous urban fabric	Urban areas	Urban areas	
	112	Discontinuous urban fabric	Discontinuous urban fabric			
	121	Industrial or commercial units	Industrial or commercial units			
	122	Road and rail networks and associated land	Road and rail networks and associated land			
	123	Port areas	Port areas			
	124	Airports	Airports			
	131	Mineral extraction sites	Mineral extraction sites			
	132	Dump sites	Dump sites			
	133	Construction sites	Construction sites			
	141	Green urban areas	Green urban areas			
	142	Sport and leisure facilities	Sport and leisure facilities			
Agricultural areas	211	Non-irrigated arable land	Non-irrigated arable land	Arable land	Arable land	Arable land
	222	Fruit trees and berry plantations	Fruit trees and berry plantations	Permanent crops		
	231	Pastures	Pastures	Pastures	Grassland	Open land
	242	Complex cultivation patterns	Complex cultivation patterns	Arable land	Arable land	Arable land
	243	Land principally occupied by agriculture, with significant areas of natural vegetation	Land principally occupied by agriculture, with significant areas of natural vegetation			
Forest and semi natural areas	311	Broad-leaved forest	Broad-leaved forest	Broad-leaved forest	Broad-leaved forest	Broad-leaved forest
	312	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest
	313	Mixed forest	Mixed forest	Mixed forest	Mixed forest	Mixed forest
	321	Natural grasslands	Natural grasslands	Natural grasslands	Grassland	Open land
	322	Moors and heathland	Moors and heathland	Moors and heathland	Moors and heathland	Shrubs
	324	Transitional woodland-shrub	Transitional woodland-shrub	Transitional woodland-shrub	Transitional woodland-shrub	
	331	Beaches, dunes, sands	Beaches, dunes, sands	Little or no vegetation	Little or no vegetation	Open land
	332	Bare rocks	Bare rocks			
	333	Sparsely vegetated areas	Sparsely vegetated areas			
	334	Burnt areas	Burnt areas			
Wetlands	411	Inland marshes	Inland marshes	Wetlands	Wetlands	Wetlands
	412	Peat bogs	Peat bogs			
	421	Salt marshes	Salt marshes			
Water bodies	511	Water courses	Water courses	Water bodies	Water bodies	
	512	Inland water bodies	Inland water bodies			
	521	Coastal lagoons	Coastal lagoons			
	522	Estuaries	Estuaries			
	523	Sea and ocean	Sea and ocean			

3.3 Data for Past Periods

3.3.1 Study Region

The original data set (Trondman et al., 2016; Marquer et al., in prep) included 45 fossil pollen sites in Götaland (Fig. 6a). Note that four of the fossil pollen sites (TRE, FLA, MABO and SKAR) were quite spread out. To create more accurate land cover maps, it was decided to exclude the four ‘’outlier’’ sites and therefore reduce the study region to the five counties containing more closely spaced fossil pollen sites: Blekinge, Halland, Jönköping, Kronoberg and Skåne, leaving 41 fossil pollen sites (Fig. 6b).



a) ***b)***

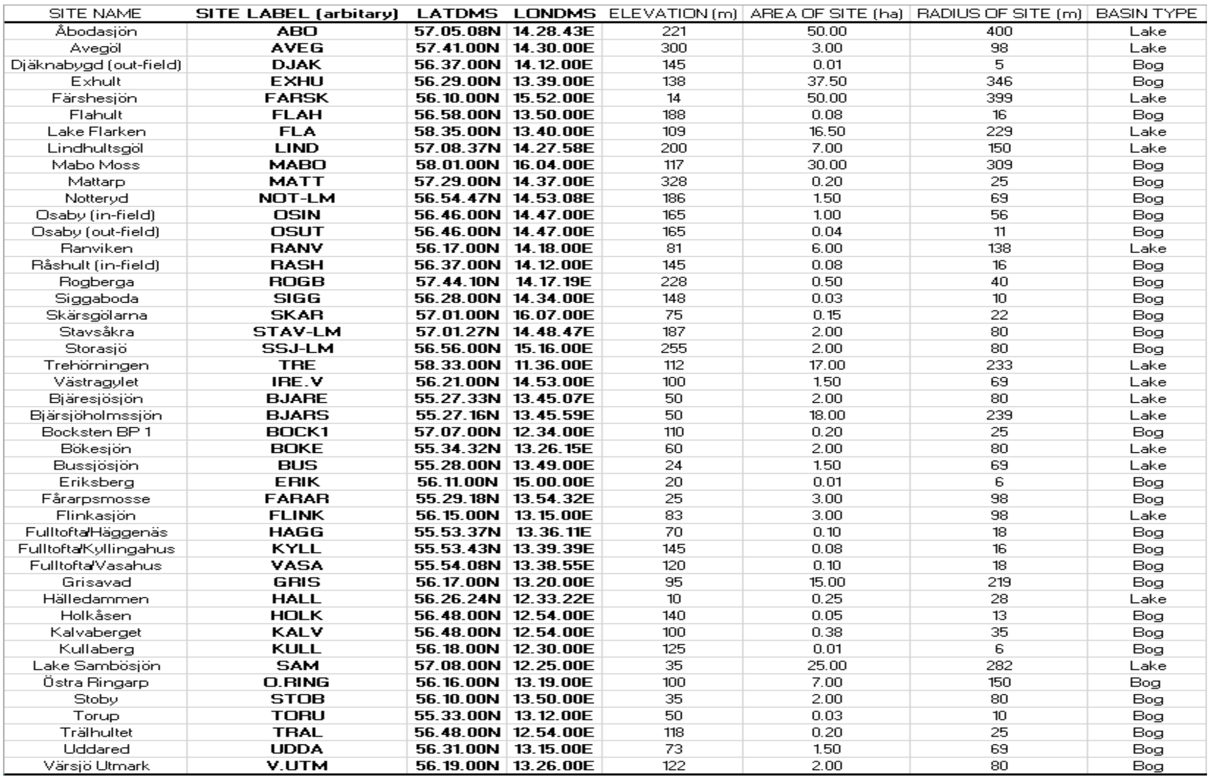
Figure 6. a) *Study region Götaland in Southern Sweden. The fossil pollen records used to estimate local vegetation cover based on the Landscape Reconstruction Algorithm (LRA) are shown (data from Marquer et al., in prep). Pollen records correspond to lake and bog sediment cores. The correspondence between labels and the pollen records is given in Table 3.* ***b)*** *Study area split into five counties.*

3.3.2 Fossil pollen-based quantitative vegetation estimates

All the 41 fossil pollen records in the study contained point estimates of local vegetation for 44 time windows (TW’s) i.e. the smallest time windows that can provide relevant results based on the LRA and these 41 pollen records (high pollen counts and reasonable standard errors), throughout the Holocene. The algorithms for the two models used in the LRA approach, REVEALS and LOVE, were found in the appendices of Sugita, S., (2007a, 2007b). The LOVE model was applied to fossil pollen data for the above mentioned 45 pollen sites (section 3.3.1) which is freely available from the LANDCLIM dataset (Trondman et al., 2015, 2016; Marquer et al., 2017) the European Pollen Database (EPD) network: http://www.europeanpollendatabase.net/index.php and from researchers, to obtain these point estimates of local vegetation. Four large lake sites were used for the REVEALS model: Fiolen, Kansjön and Trummen in Småland and Krageholmssjön in Skåne. Profiles for two of these sites can be seen in figure A7 (arable land contains pollen species from open land so it is more than 100% that is actually represented). Laurent Marquer previously ran the LRA model to get the inputs for the maps used in this study. The output of which consisted of one large excel file with 44 tabs, each tab represented a TW containing the coordinates of each of the 41 fossil pollen sites (Table 3) and the 25 taxa found at those sites (Table 4), with the standard errors of each taxa. These TW’s spanned 50 year periods from present time (1950) back to 100 BP, then 100 year periods from 100 BP back to 3000 BP, and 500 year periods from 3000 BP back to 9000 BP. The point estimates for local vegetation provided by Laurent Marquer represented the land cover of an area (Relevant source area of pollen, RSAP) between 100m to 3500m radius around each pollen site. While RSAP could have been used in the interpolation method IDW (see next section) it was not used in this study for interpolation purposes.

Based on the plant species present in a type of land cover (Table 4) the coverage estimates for LCT were also provided. Six LCT's were used in this study to best fit alternative 4 (See table 2 for alt. 4); Conifer forest, Broad-leaved forest, Shrubs, Open land, Arable land and Wetland. Several pollen species were overlapping between open land, arable land and wet land. Each LCT was considered individually and not as relative to each other. But related in a way. An example from one pollen site, Avegöl can be seen in figure A6. Arable land and wet land are not shown separately as they consisted of pollen estimates for species already represented in the LCT open land. Including them would have given coverage over 100% in that chart.

Table 3. *Metadata of the 45 fossil pollen records spread over Götaland by location (site name), with site label, coordinates, area of site, radius of site, and source of pollen core (basin type) (Trondman et al., 2016; Marquer et al., 2017, in prep).*



SITE NAME	SITE LABEL (arbitary)	LATDMS	LONDMS	ELEVATION (m)	AREA OF SITE (ha)	RADIUS OF SITE (m)	BASIN TYPE
Åbodasjön	**ABO**	**57.05.08N**	**14.28.43E**	221	50.00	400	Lake
Avegöl	**AVEG**	**57.41.00N**	**14.30.00E**	300	3.00	98	Lake
Djäknabygd (out-field)	**DJAK**	**56.37.00N**	**14.12.00E**	145	0.01	5	Bog
Exhult	**EXHU**	**56.29.00N**	**13.39.00E**	138	37.50	346	Bog
Färshesjön	**FARSK**	**56.10.00N**	**15.52.00E**	14	50.00	399	Lake
Flahult	**FLAH**	**56.58.00N**	**13.50.00E**	188	0.08	16	Bog
Lake Flarken	**FLA**	**58.35.00N**	**13.40.00E**	109	16.50	229	Lake
Lindhultsgöl	**LIND**	**57.08.37N**	**14.27.58E**	200	7.00	150	Lake
Mabo Moss	**MABO**	**58.01.00N**	**16.04.00E**	117	30.00	309	Bog
Mattarp	**MATT**	**57.29.00N**	**14.37.00E**	328	0.20	25	Bog
Notteryd	**NOT-LM**	**56.54.47N**	**14.53.08E**	186	1.50	69	Bog
Osaby (in-field)	**OSIN**	**56.46.00N**	**14.47.00E**	165	1.00	56	Bog
Osaby (out-field)	**OSUT**	**56.46.00N**	**14.47.00E**	165	0.04	11	Bog
Ranviken	**RANV**	**56.17.00N**	**14.18.00E**	81	6.00	138	Lake
Råshult (in-field)	**RASH**	**56.37.00N**	**14.12.00E**	145	0.08	16	Bog
Rogberga	**ROGB**	**57.44.10N**	**14.17.19E**	228	0.50	40	Bog
Siggaboda	**SIGG**	**56.28.00N**	**14.34.00E**	148	0.03	10	Bog
Skärsgölarna	**SKAR**	**57.01.00N**	**16.07.00E**	75	0.15	22	Bog
Stavsåkra	**STAV-LM**	**57.01.27N**	**14.48.47E**	187	2.00	80	Bog
Storasjö	**SSJ-LM**	**56.56.00N**	**15.16.00E**	255	2.00	80	Bog
Trehörningen	**TRE**	**58.33.00N**	**11.36.00E**	112	17.00	233	Lake
Västragylet	**IRE.V**	**56.21.00N**	**14.53.00E**	100	1.50	69	Lake
Bjäresjösjön	**BJARE**	**55.27.33N**	**13.45.07E**	50	2.00	80	Lake
Bjärsjöholmssjön	**BJARS**	**55.27.16N**	**13.45.59E**	50	18.00	239	Lake
Bocksten BP 1	**BOCK1**	**57.07.00N**	**12.34.00E**	110	0.20	25	Bog
Bökesjön	**BOKE**	**55.34.32N**	**13.26.15E**	60	2.00	80	Lake
Bussjösjön	**BUS**	**55.28.00N**	**13.49.00E**	24	1.50	69	Lake
Eriksberg	**ERIK**	**56.11.00N**	**15.00.00E**	20	0.01	6	Bog
Fårarpsmosse	**FARAR**	**55.29.18N**	**13.54.32E**	25	3.00	98	Bog
Flinkasjön	**FLINK**	**56.15.00N**	**13.15.00E**	83	3.00	98	Lake
Fulltofta/Häggenäs	**HAGG**	**55.53.37N**	**13.36.11E**	70	0.10	18	Bog
Fulltofta/Kyllingahus	**KYLL**	**55.53.43N**	**13.39.39E**	145	0.08	16	Bog
Fulltofta/Vasahus	**VASA**	**55.54.08N**	**13.38.55E**	120	0.10	18	Bog
Grisavad	**GRIS**	**56.17.00N**	**13.20.00E**	95	15.00	219	Bog
Hälledammen	**HALL**	**56.26.24N**	**12.33.22E**	10	0.25	28	Lake
Holkåsen	**HOLK**	**56.48.00N**	**12.54.00E**	140	0.05	13	Bog
Kalvaberget	**KALV**	**56.48.00N**	**12.54.00E**	100	0.38	35	Bog
Kullaberg	**KULL**	**56.18.00N**	**12.30.00E**	125	0.01	6	Bog
Lake Sambösjön	**SAM**	**57.08.00N**	**12.25.00E**	35	25.00	282	Lake
Östra Ringarp	**O.RING**	**56.16.00N**	**13.19.00E**	100	7.00	150	Bog
Stoby	**STOB**	**56.10.00N**	**13.50.00E**	35	2.00	80	Bog
Torup	**TORU**	**55.33.00N**	**13.12.00E**	50	0.03	10	Bog
Trälhultet	**TRAL**	**56.48.00N**	**12.54.00E**	118	0.20	25	Bog
Uddared	**UDDA**	**56.31.00N**	**13.15.00E**	73	1.50	69	Bog
Värsjö Utmark	**V.UTM**	**56.19.00N**	**13.26.00E**	122	2.00	80	Bog

Table 4. *The 25 plant taxa/pollen types used for the pollen-based land cover modelling, sorted into 6 land cover types.*

Conifer forest	Broad-leaved forest	Shrubs	Open land	Arable land	Wet land
Abies	*Alnus*	*Juniperus*	*Artemisia*		
Picea	*Betula*	*Salix*	*Calluna Vulgaris*		*Calluna Vulgaris*
Pinus	*Carpinus*		*Cerealia-t*	*Cerealia-t*	
	Corylus		*Cyperaceae*		*Cyperaceae*
	Fagus		*Filipendula*		
	Fraxinus		*Graminea*		
	Quercus		*Plantago lanceolata*		
	Tilia		*Plantago media*		
	Ulmus		*Plantago montana*		
			Rumex acetosa-t		
			Secale cereale	*Secale cereale*	

3.4 Data analysis and maps for past periods

3.4.1 Selection of past time periods.

The point estimates for the 44 TW's containing the 25 plant taxa sorted into 6 LCTs (Table 4) were copied into 44 individual excel files named for each TW. They then had their coordinates converted into decimal degrees and were saved as 44 tab delimited files. These were then added to ArcMap 10 and converted into shapefiles. Using all 44 TWs in this study would have been too time consuming and not suitable for the time allowed for a master's thesis. Also, the data for a number of TWs, especially those further back in time were of poor quality (few pollen records and therefore few point estimates for creating maps) and could not be used. For the 44 TWs, out of 45 pollen records, anywhere between 12 and 40 records had data recorded at the pollen site (Table 1). Finally out of the 44 TWs, 15 of the best quality TWs were selected for this study to cover the most important steps of land use and society developments throughout the Holocene (the last 11,700 years): the Mesolithic period, the Neolithic period, the Bronze Age, the Iron Age, the medieval period and the modern period (Table 1).

3.4.2 Interpolation methods

41 pollen record sites were used in this study covering a large area. ArcMap 10 was used to create a surface with estimates for the whole study area i.e. spatially continuous maps for each of the 15 TWs. As TW 1 was the closest TW to the 2012 CORINE land cover data for comparison purposes, the fossil pollen estimates shapefile from this TW was used to determine the best interpolation method to recreate land cover for all 15 TWs.

Initially 17 interpolation methods from the geostatistical analyst tool were trialled as potential methods to create past land cover maps for the TW's using TW 1 shapefile data (Table 5). This number was reduced later based on accuracy and representation of present-day land cover. A description of how each method was run in ArcMap is found in table A1. For cokriging, an elevation layer of Sweden downloaded at the following link: http://www.diva-gis.org/Data was clipped to the study area and used as dataset 2 for disjunctive, indictor, ordinary, probability, simple and universal kriging, and the same steps repeated for these interpolation methods as per table A1.

Table 5. *The 17 interpolation methods that were tested in the present study, sorted into deterministic methods and geostatistical methods. All geostatistical methods except EBK were also run with cokriging.*

	Method abbreviation		Method name
		cokriging	
Deterministic methods	GPI		Global polynomial interpolation
	LPI		Local polynomial interpolation
	IDW		Inverse distance weighted
	RBF		Radial basis functions
Geostatistical methods	EBK		Empirical bayesian kriging
	DK	DKC	Disjunctive kriging
	IK	IKC	Indicator kriging
	OK	OKC	Ordinary kriging
	PK	PKC	Probability kriging
	SK	SKC	Simple kriging
	UK	UKC	Universal kriging

3.4.3 Cross-validation

To determine if a method was appropriate to produce the final surface it was needed to know how well the model predicted the values at unknown locations. Cross-validation in ArcMap showed this. It worked by a process of removing each point one by one and then making a predication for those points. The root mean square error (RMSE) obtained after performing an interpolation indicated how well the model predicted values at unknown locations. The lower the RMSE value the better, >0.5 related to a bad predictive model. For this study TW 1 was chosen for interpolation method validation purposes as it was closest to the 2012 CORINE land cover data in terms of time. Comparisons between the two could be used to judge any interpolation method used for the other 14 TW's. The 17 interpolation methods in table 5 were judged good for predictive purposes if the RMSE was less than 0.45, just under the 0.5 limit for bad models. Additionally, optional parameters in the interpolation methods were adjusted to try to reduce the RMSE values further. Only the arcsin transformation, which can be used for data that is in the form of proportions or percentages (which the fossil pollen data was), improved the RMSE values, and only for certain interpolation methods.

3.4.4 Visualization of interpolated data with raster maps for best method selection

A pilot test using combined LCT maps from interpolated surfaces of TW1 for all 6 LCTS was not successful as a method validation tool due to plant species issues (the *betula sp.* pollen estimates were masking all other species). It was then decided to create individually interpolated surfaces for each of the 6 LCT's using the narrowed down interpolated methods. These were then compared visually with the 2012 CORINE data. TW1 covered the years 1950-2010. For the CORINE data to be useful as a validation tool it should really also have spanned these years. However, CORINE datasets were only available for the years 1990, 2000, 2006, and 2012 (soon a 2018 dataset will be released), see link: https://land.copernicus.eu/pan-european/corine-land-cover. Unfortunately the 1990 dataset did not contain land cover for Sweden. As its only 12 years in the difference and the 2012 CORINE dataset was already formatted in this study to represent present time land cover, it was decided to stick with this dataset for validation purposes of the interpolation methods. Raster's were chosen instead of vectors here as they gave an average value for each cell, which, when compared to vector data when using pollen estimates was much more suitable in terms of calculating areas. Vectors gave a range for each polygon which was harder to work with statistically. The interpolated surfaces (section 3.4.2) were converted to raster's by right clicking the layer, then data, and convert to raster. The best interpolation method was that with a low RMSE and close visual match to the 2012 CORINE land cover data maps.

3.4.5 Creating interpolated surfaces of land cover with fossil pollen data

Based on the best method selection (see previous section) the SKC method with arcsin transformation was selected (see results section) and applied to the LCT's (Conifer forest, Broad-leaved forest, Shrubs, Open land and Arable land) and the 15 TW's.

Vegetation coverage for fossil pollen data ranged between 0-1.0. 0 being not present at all. 1.0 being 100% coverage. Most of the study area in this project had a mix of LCTs, and so for a LCT interpolated surface its raster cells did not contain vegetation coverage of 1.0, but could have been 0. Some cells were <0, as ArcMap extrapolates beyond the dataset using this interpolation method. All interpolated LCT surfaces were converted to raster layers and reclassified according to the broad coverage range in table 6b and shown as classes 0-20. This coverage range was suitable for three of the LCT's: conifer forest, broad-leaved forest and open land. However, shrubs and arable land required reclassifying further to the finer coverage range in table 6a. For these two LCTs the coverage did not go above 0.2. Having a finer scale enabled changes in vegetation coverage over time to be visualized that would have been missed with the broad scale. Additionally, a number of classes were merged to better see the differences in coverage i.e. more contrast in colour between classes.

Table 6a *Fine range pollen cover. Pollen cover classes reclassified into finer cove ranges.*

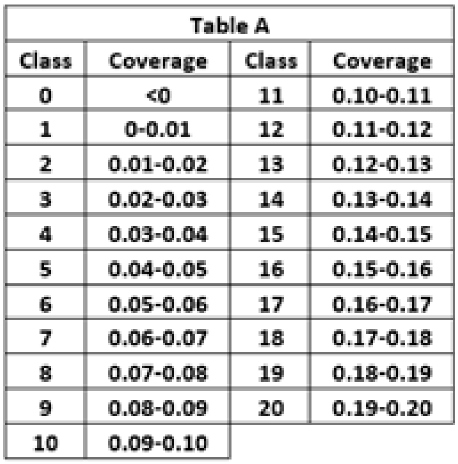


Table A			
Class	Coverage	Class	Coverage
0	<0	11	0.10-0.11
1	0-0.01	12	0.11-0.12
2	0.01-0.02	13	0.12-0.13
3	0.02-0.03	14	0.13-0.14
4	0.03-0.04	15	0.14-0.15
5	0.04-0.05	16	0.15-0.16
6	0.05-0.06	17	0.16-0.17
7	0.06-0.07	18	0.17-0.18
8	0.07-0.08	19	0.18-0.19
9	0.08-0.09	20	0.19-0.20
10	0.09-0.10		

Table 6b. *Broad range pollen cover. Pollen cover classes reclassified into broad ranges.*

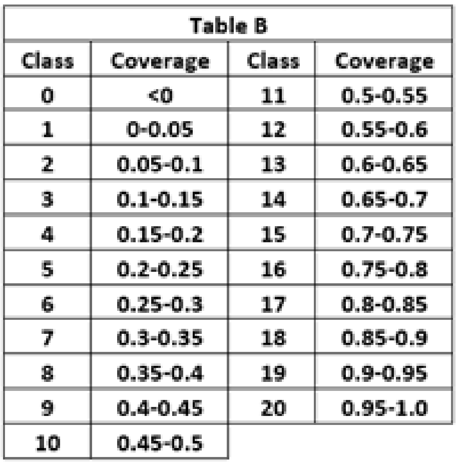


Table B			
Class	Coverage	Class	Coverage
0	<0	11	0.5-0.55
1	0-0.05	12	0.55-0.6
2	0.05-0.1	13	0.6-0.65
3	0.1-0.15	14	0.65-0.7
4	0.15-0.2	15	0.7-0.75
5	0.2-0.25	16	0.75-0.8
6	0.25-0.3	17	0.8-0.85
7	0.3-0.35	18	0.85-0.9
8	0.35-0.4	19	0.9-0.95
9	0.4-0.45	20	0.95-1.0
10	0.45-0.5		

3.4.6 County-by-county analysis

After the above reclassifications in ArcMap, the study area was split into the five county boundaries: Blekinge, Halland, Jönköping, Kronoberg and Skåne (Fig. 6b). The coverage ranges for each class were then exported to excel for further analysis using the table to excel tool (see results section).

3.5 Ecosystem Services

3.5.1 Assessment of present time ecosystem services

As the assessment matrix used in Burkhard et al. (2009) was the gold standard most studies use for assessing ecosystem services, it was also used in this study to assess the capacity of land cover types for all four alternatives to support a particular ecosystem service (Table 8). The matrix used by Burkhard et al. (2009) combined meta-analytical study assessment systems such as by Costanza et al. (1997), and global assessment systems (MA, 2005). Some minor changes were made to the choice of ES in the matrix for this study: Biotic water flows, metabolic efficiency and storage capacity (SOM) were removed from the supporting services section. Additional categories: genetic resources, carbon sequestration and storage, moderation of extreme events, recreation and tourism, and aesthetic appreciation and inspiration for culture, art and design, were added in order to provide a more complete picture of ES provided in this region. These were from The Millennium Ecosystem Assessment (MA), The Economics of Ecosystems and Biodiversity (TEEB) and The Common International Classification of Ecosystem Services (CICES) systems, (EEA, 2013). Like the matrix in Burkard et al. (2009), the 34 land cover types taken from the CORINE 2012 data set that were present in Götaland (Fig. 5, Table 2) were placed on the y-axis, and the ES on the x-axis. The ES were further divided into four categories: supporting, provisioning, regulating and cultural services. It was decided to keep the matrix relatively simple and use a low ranking scale. This was as it was only going to be used for the present time ES and not the majority of the study. A value of 0 was given to a land cover type that had no relevant capacity to provide a particular ecosystem service. A value of 1 was given to a land cover type that had a capacity to provide a particular ecosystem service. Adding up the 1's for a land cover type gave its ecosystem service number. This represented alternative 1 LCTs. Additionally, these values were graded from 1 to 15 based on the lowest to highest ecosystem service number as an alternative grading system to see if this provided more information. The whole procedure was repeated to create a second assessment matrix for alternatives 2-4 (Table A3).

3.5.2 Maps of the ecosystem service number for land cover types in the present

The land cover map for Götaland (3.2) for alternative 1 was reclassified in ArcGIS 10 into the ecosystem service number for each land cover type to visualize which areas had higher or lower ES number and how this compared to LCT (data not shown). This procedure was similar to creating land cover maps for the other 3 alternatives in 3.2: An extra field was added to the layers attribute table in ArcMap. The ES number from the assessment matrix for each LCT was added in the ES number field for each particular LCT. The symbology for the layer was then changed to the ES number field, and a colour scheme selected. This was also done for ecosystem service grade and for provisioning, regulating, supporting and cultural service. Alternative 2-4 land cover maps were not reclassified into ecosystem numbers.

3.5.3 Estimation of ecosystem services provided by past land cover

Major documents used and information sources about land cover in the past and the relative goods they provided to societies were obtained from Berglund et al. (1988, 1991, 2003, 2008, 2014), Björkman et al. (1996, 1997, 1999), Eriksson & Cousins (2014), Fredh et al. (2012), Lindbladh et al, (1999, 2008), Mazier et al. (2015) and Lagerås et al. (1995, 2000, 2003). This information was mainly used for the background section and when discussing the past ecosystem services. For the past TWs, out of the four categories of ecosystem services (section 3.5.1) only provisioning services were taken into account when assessing past ecosystem services provided by past land cover. This was because from the literature it is possible to know what the different land cover was used for in terms of provisional services such as timber, fresh water, crops etc. But for the other categories it was more abstract or not known at all. The types of provisional services available at the time for each TW in different locations on the study site were then attributed to the type of land cover and the percentage cover for a given location e.g. more broad-leaved forest cover at a location meant more timber available at that location.

4. Results

4.1 Spatial and quantitative extents of the 6 major land cover types for the present time

Conifer forest

The Spatial extent for conifer forest in Götaland (Fig. 7 & 9b) covered most of the map for all 4 alternatives, excluding the southernmost area, along the coasts, and some of the northern parts around the lakes. Götaland as a whole (Fig. 8) was characterized by no changes in the quantitative extent of conifer forest between alternatives 1, 2 and 3 (56.23%), and a lower percentage for alternative 4 (42.71%). Conifer forest was the largest LCT for all 4 alternatives.

Broad-leaved forest

The Spatial extent for broad-leaved forest in Götaland (Fig. 7 & 9c) was a scattering over the whole map for all 4 alternatives, with no cover on the coasts or around the lakes, and a dense cover in the south. Götaland as a whole (Fig. 8) was characterized by no changes in the quantitative extent of broad-leaved forest between alternatives 1, 2 and 3 (4%), and a much higher percentage for alternative 4 (10.13%). This is the fourth largest LCT for alternatives 1 to 3 and the third largest LCT for alternative 4.

Shrubs

The Spatial extent for shrubs in Götaland (Fig. 7 & 9d) was a broad scattering over the whole map for all 4 alternatives with a concentration of cover in the middle. Götaland as a whole (Fig. 8) was characterized by no changes in the quantitative extent of shrubs between alternatives 1, 2 and 3 (1.78%), and a higher percentage for alternative 4 (5.8%). This was the 8th largest LCT by area for alternatives 1 to 3 and the 5th largest for alternative 4.

Open land

The Spatial extent for open land in Götaland (Fig. 7 & 9e) was a thin scattering of cover inland and the same on the west coast for all 4 alternatives, with the densest cover in the south. Götaland as a whole (Fig. 8) was characterized by no changes in the quantitative extent of open land between alternatives 1, 2 and 3 (2.06%), and a higher percentage for alternative 4 (5.31%). For alternatives 1 to 3 this was the 7th largest LCT. For alternative 4 it was the 6th largest LCT.

Arable land

The Spatial extent for arable land in Götaland (Fig. 7 & 9f) was for the most part in the south and along the coasts for all 4 alternatives, with a scattering in inland areas and the north. Götaland as a whole (Fig. 8) was characterized by more or less no changes in the quantitative extent of open land between alternatives 1, 2 and 3 (18.65-18.66%), and half that for alternative 4 (9.24%). Arable land was the third largest LCT in alternative 1 to 3, and the second largest LCT in alternative 4. Non-irrigated arable land made up 4.38% of the 8.33% in alternative 1.

Wetlands

The Spatial extent for wetlands in Götaland (Fig. 7) was limited to small patches throughout the inland parts of the map for all 4 alternatives. Götaland as a whole (Fig. 8) was characterized by no changes in the quantitative extent of wetlands between alternatives 1, 2 and 3 (1.09%), and a higher percentage for alternative 4 (2.2%). For alternative 1 it was the 10th largest LCT by area. For alternatives 2 and 3 it is the 9th. For alternative 4 it was the 7th.

Water bodies

The Spatial extent for water bodies in Götaland (Fig. 7) was in two large lakes in the north and some smaller patches south of the lakes in inland areas for alternatives 1 to 3. Water bodies were not included in alternative 4. Götaland as a whole (Fig. 8) was characterized by no changes in the quantitative extent of water bodies between alternatives 1, 2 and 3 (11.21%). Inland water bodies made up 11.1% of this LCT in alternative 1 and is merged into the LCT water bodies in alternatives 2 and 3. This was the third largest LCT by area for all three alternatives.

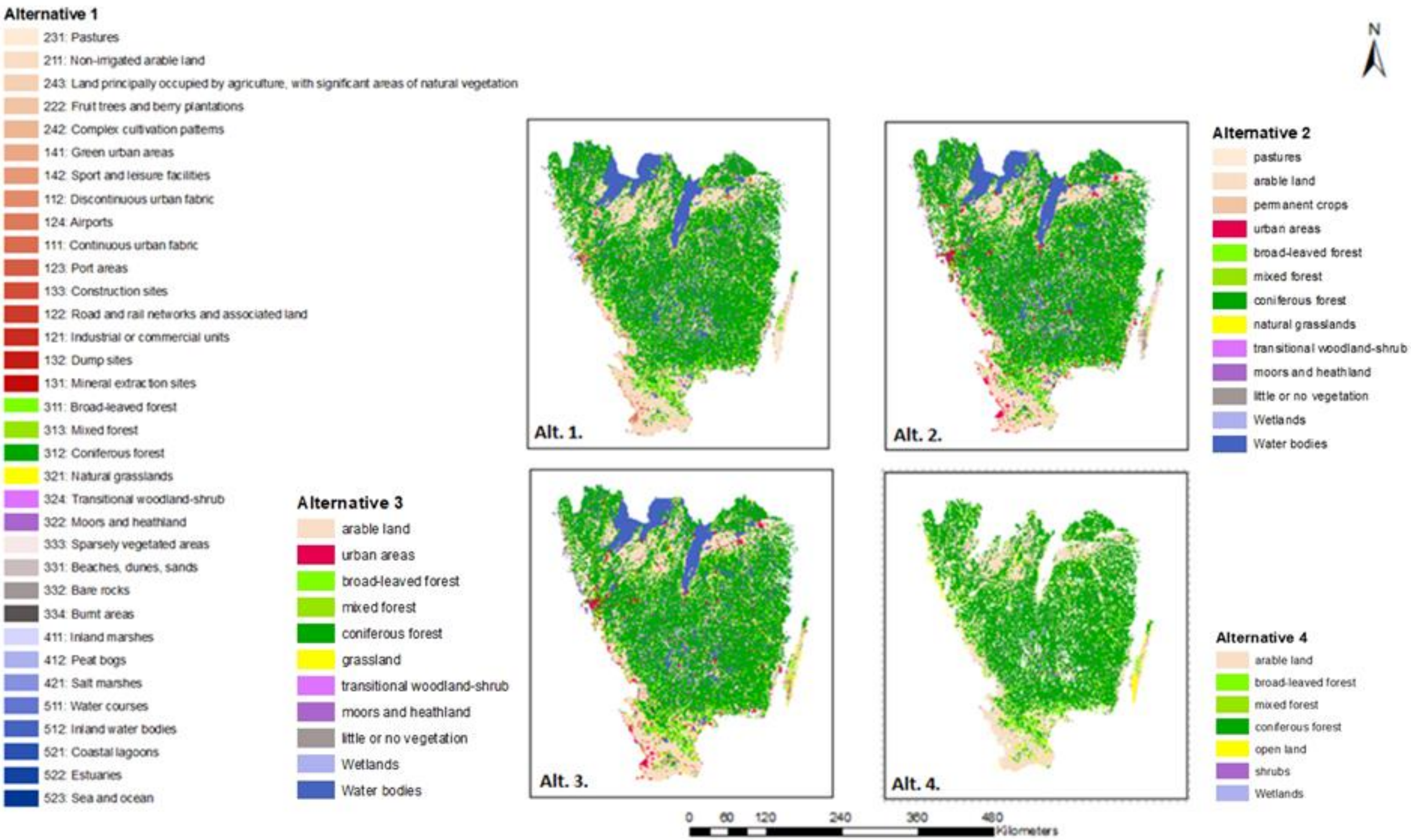


Figure 7. *Spatial extent of the different land cover types (LCTs) for the four alternatives of LCTs (see table 2) based on CORINE land cover data, i.e. present time. Shades of red/pink are agricultural areas. Shades of green are forested areas. Yellow is natural grasslands. Shades of purple are areas of heathland. Shades of black, grey and white are bare land areas. Shades of blue are water areas.*

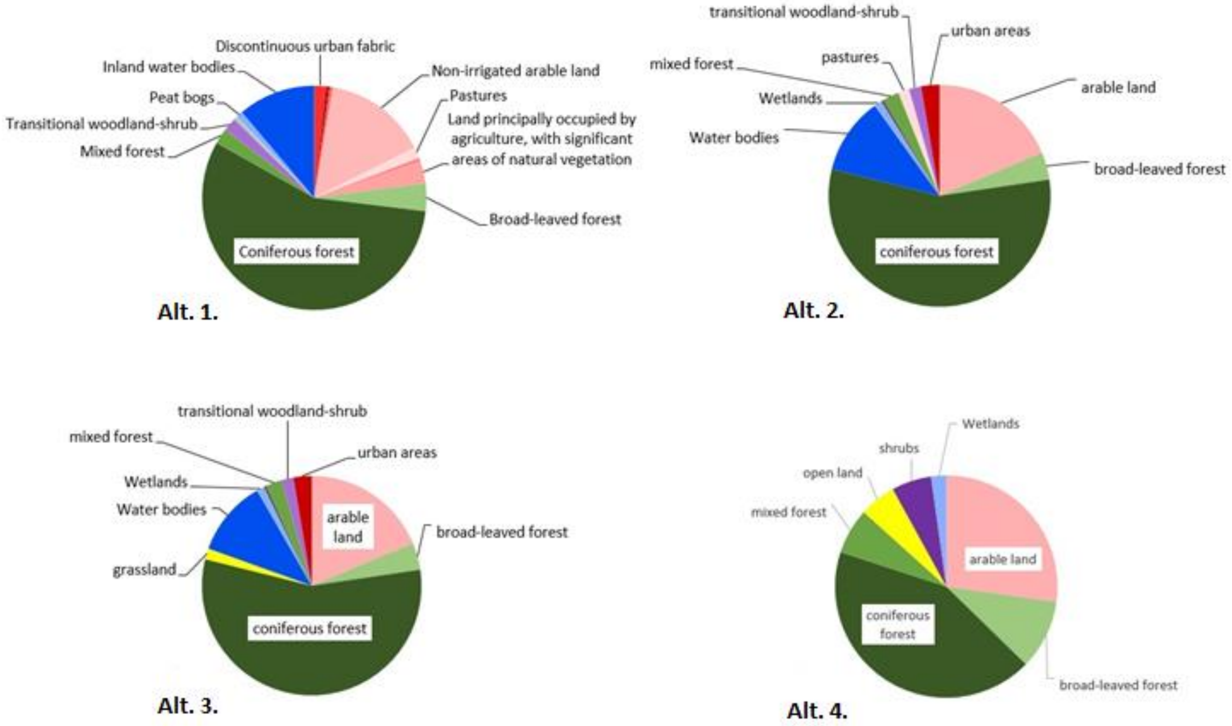


Figure 8. *Piechart of the area (in hectares expressed here as %) of land cover types in Götaland as a whole for the four alternatives in table 2. Alternative 1, 34 LCTs; alternative 2, 13 LCTs; alternative 3, 11 LCTs; alternative 4, 7 LCTs. Shades of red/pink are agricultural areas. Shades of green are forested areas. Yellow is natural grasslands. Shades of purple are areas of heathland. Shades of black, grey and white are bare land areas. Shades of blue are water areas.*

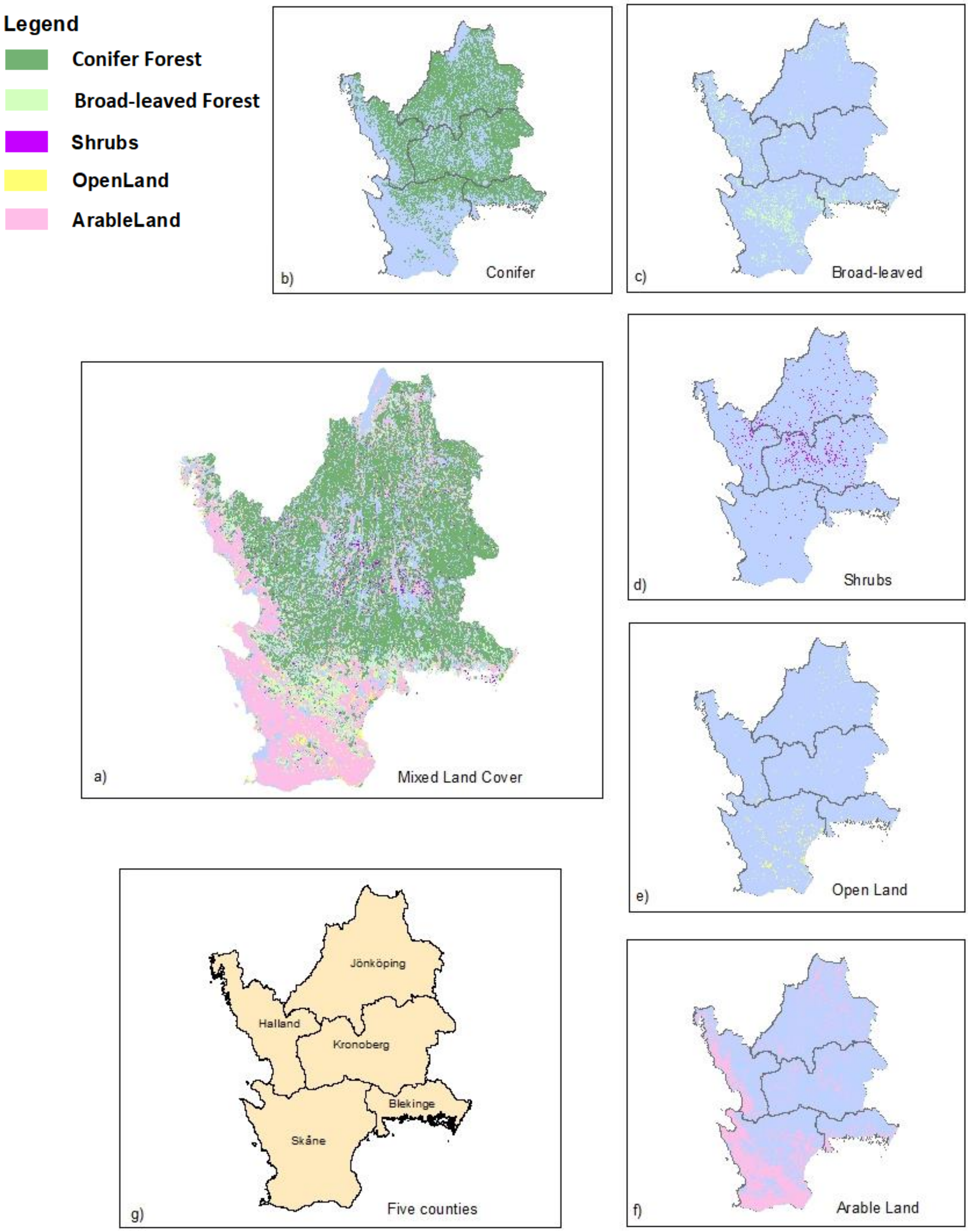


Figure 9. *Land cover in five county area of southern Götaland for alternative four (34 LCTs). Dark green = conifer forest, light green = broad-leaved forest, purple = shrubs, yellow = open land, pink = arable land. 2012 CORINE land cover data was separated into each of the 5 LCTs in ArcMap and displayed one by one.*

4.2 Past time windows

4.2.1 Cross-validation analysis to evaluate the spatial modelling approaches

Table 7 shows the RMSE outputs for all 17 evaluated interpolation methods using TW1 data. Any interpolation method producing a surface with a RMSE value ≥ 0.45 was taken as producing bad predictive models and was not looked at further. This left 13 methods with RMSE values less than 0.45 covering all 6 LCTs. SKC was the top performing method, being the best method for conifer forest, arable land and wet land. It was the fourth best for shrubs, the ninth best for broad-leaved forest and the 12th best for open land. SK was the best performing method for shrubs and open land. SK was the third best performing method for conifer forest and wet land. OK was the best method for broad-leaved forest. OK was the third best performing method for open land and arable land. DKC was the second best performing method for conifer forest, arable land and wetland. It was the third best for shrubs. UK was the second best performing method for broad-leaved forest. DK was the second best for shrubs and open land. IDW was the third best performing method for broad-leaved forest.

Table 7. *RMSE values for the 17 interpolation methods after running each method in with the geostatistical tool in ArcMap. NA = Not Applicable. Grey section = cut off limit for RMSE value ≥ 0.45.*

Interpolation Method		RMSE Rank					
		Conifer forest	Broad-leaved forest	Shrubs	Open Land	Arable Land	Wet Land
Deterministic	GPI	0.25	0.34	0.08	0.26	0.04	0.08
	LPI	0.25	0.3	0.07	0.22	0.04	0.09
	IDW	0.27	0.27	0.07	0.18	0.04	0.09
	RBF	0.26	0.27	0.07	0.18	0.04	0.08
Geostatistical	EBK	0.25	0.28	0.07	0.19	0.04	0.08
	DK	0.24	0.28	0.06	0.17	0.04	0.08
	IK	0.5	0.52	0.5	0.46	0.45	0.53
	OK	0.25	0.25	0.07	0.17	0.04	0.08
	PK	0.5	0.52	0.51	0.46	0.45	0.53
	SK	0.24	0.28	0.06	0.17	0.04	0.08
	UK	0.25	0.25	0.07	0.17	0.04	0.08
	DKC	0.23	0.31	0.06	0.23	0.04	0.08
	IKC	0.5	0.52	0.51	0.46	0.45	0.52
	OKC	0.25	0.33	0.07	0.23	0.04	0.08
	PKC	0.52	0.52	0.51	0.52	0.48	0.52
	SKC	0.23	0.31	0.06	0.23	0.03	0.08
	UKC	0.25	0.33	0.07	0.23	0.04	0.08

4.2.2 Visualization of interpolated data with raster surfaces for best method selection

In order to evaluate the performance of the best method selection based on the RMSE results (see previous section), all the LCT maps for each ‘’best method’’ were compared visually, and with the CORINE data (Fig. 10).

Deterministic methods

Global polynomial interpolation (GPI) produced a series of horizontal lines for each LCT (Fig. 10). They have a very rough indication of where the highest coverage is (high to low) for each LCT when compared to the CORINE data. Local polynomial interpolation (LPI) produced a series of curved gradients of high to low coverage (Fig. 10). Slightly better representation of the CORINE data but still not very close to it. Inverse distance weighting (IDW) produced a number of circular areas of different coverage for each LCT (Fig. 10). It was a more detailed surface, with the best being broad-leaved forest, open land and arable land. It did not compare in general very well with the CORINE data. Radial basis functions (RBF) also produced circular coverage patterns (Fig. 10), with the best also being broad-leaved forest, open land and arable land when compared with the CORINE data.

Geostatistical methods

Empirical bayesian kriging (EBK) produced surfaces with a pattern that were a mix of local polynomial interpolation and radial basis functions i.e. curved lines and circular patterns (Fig. 10). The closest to the CORINE data was conifer forest, broad-leaved forest and open land. Disjunctive kriging (DK) produced circular and elongated patterns of coverage, except for open land and wetland (Fig. 10). Open land was a series of small circles of varying coverage. Wet land was a uniform low coverage surface. The closest to the CORINE data was broad-leaved forest. Disjunctive kriging with cokringing (DKC) produced much more realistic surfaces with the coverage following the elevation (Fig. 10). Conifer forest, broad-leaved forest and arable land were quite close to the CORINE data. Shrubs, open and wet land were not at all close to the CORINE data set. Ordinary kriging (OK) and universal kriging (UK) produced the exact same surfaces (Fig. 10), and had the same RMSE values. For conifer forest and broad-leaved forest it was a pattern of circles and elongated shapes not very like the CORINE data. For the other 4 LCTS the pattern was a mostly smooth background with lots of circles in the inner part also not very like the CORINE data set.

Ordinary kriging and universal kriging with cokriging (OKC & UKC) produced a series of curved lines similar to local polynomial interpolation (Fig. 10), with the exception being for wetland. This looked more like an elevation surface. Conifer forest and arable land being the closet to the CORINE data set byt not very close. Simple kriging (SK) produced a pattern of circles and elongated shapes for all LCTs except open land and wetland (Fig. 10). Open land was a low coverage background with smalle circle in the middle of high and low coverage. Wet land was a monotone low coverage surface. The closest LCTs to the CORINE data being broad-leaved forest and arable land. Shrubs and open land had the lowest RMSE with this method but visually were not close to the CORINE data. Simple kriging with cokriging (SKC) produced the second most realistic surfaces for conifer forest, broad-leaved forest and arable land when compared to the CORINE data (Fig. 10). The lowest RMSE values were for conifer forest, arable land and wet land with this method. Shrubs and wet land were not at all close looking to the CORINE data.

Simple kriging with cokriging (SKC) using the arcsin transformation produced the most realistic surfaces for conifer forest, broad-leaved forest and arable land when compared to the CORINE data (Fig. 10). The RMSE values for conifer forest and wetland were improved further than simple kriging with cokriging. Shrubs and wetland were not at all close looking to the CORINE data. This method appears to be the most reliable for interpolation, and for that reason it has been chosen as the approach for creating maps for past TWs (see below). Note that the differences between CORINE map for present and TW1 based on pollen-based land cover reconstruction might further have been caused by the difference in the length of the time periods, i.e. CORINE is a map for 2012 when pollen data represent an average of land cover over 50 years.

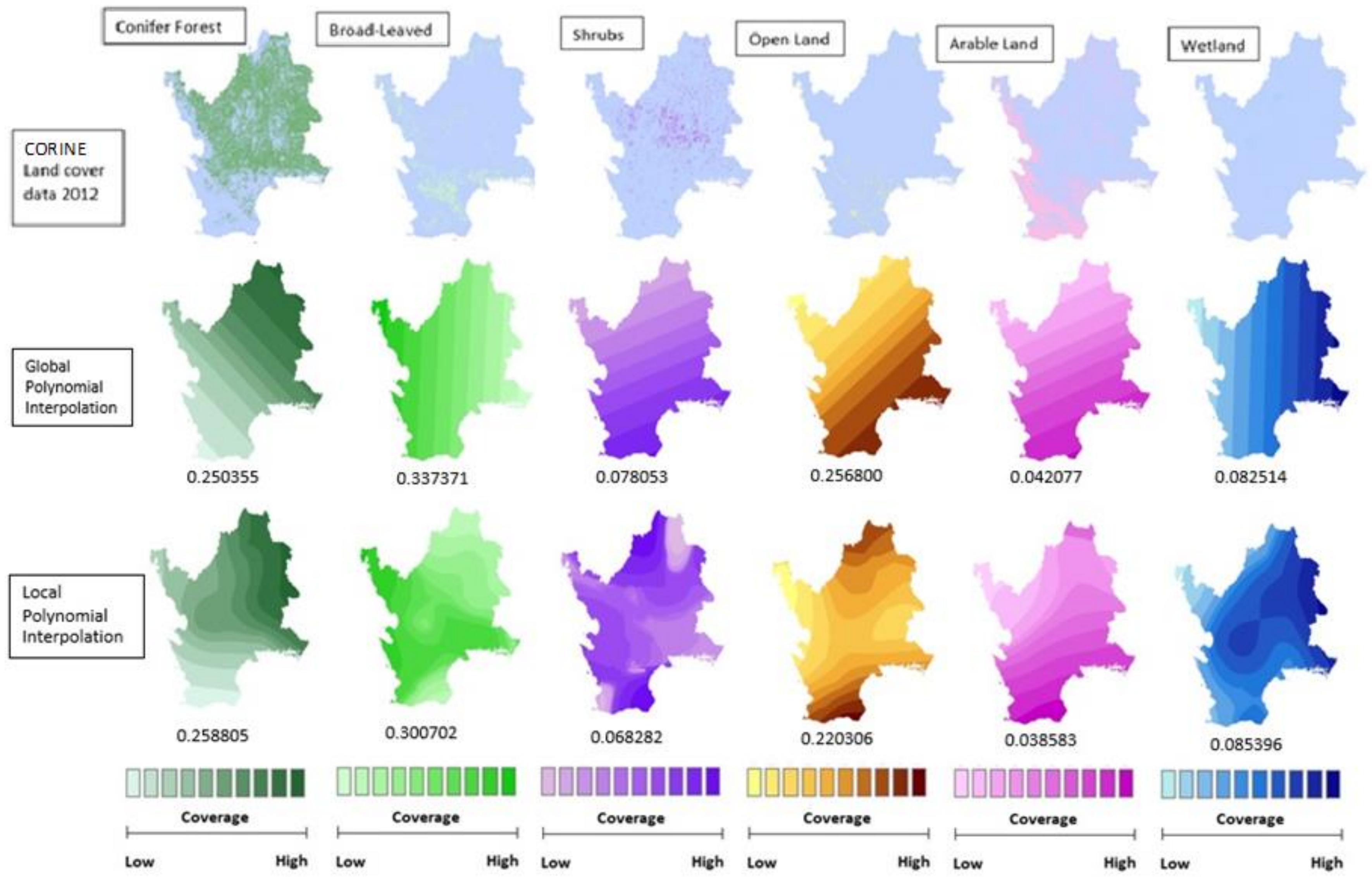


Figure 10. *Raster surfaces created from interpolated pollen data with the geostatistical tool in ArcMap, using 13 methods from table 7 for time window 1. Colour code as per figure 7. Numbers under surfaces = RMSE value (yellow = top value, blue = improvement on top). CORINE data are also shown for visual comparison. For detailed scaled bars see appendix table 8.*

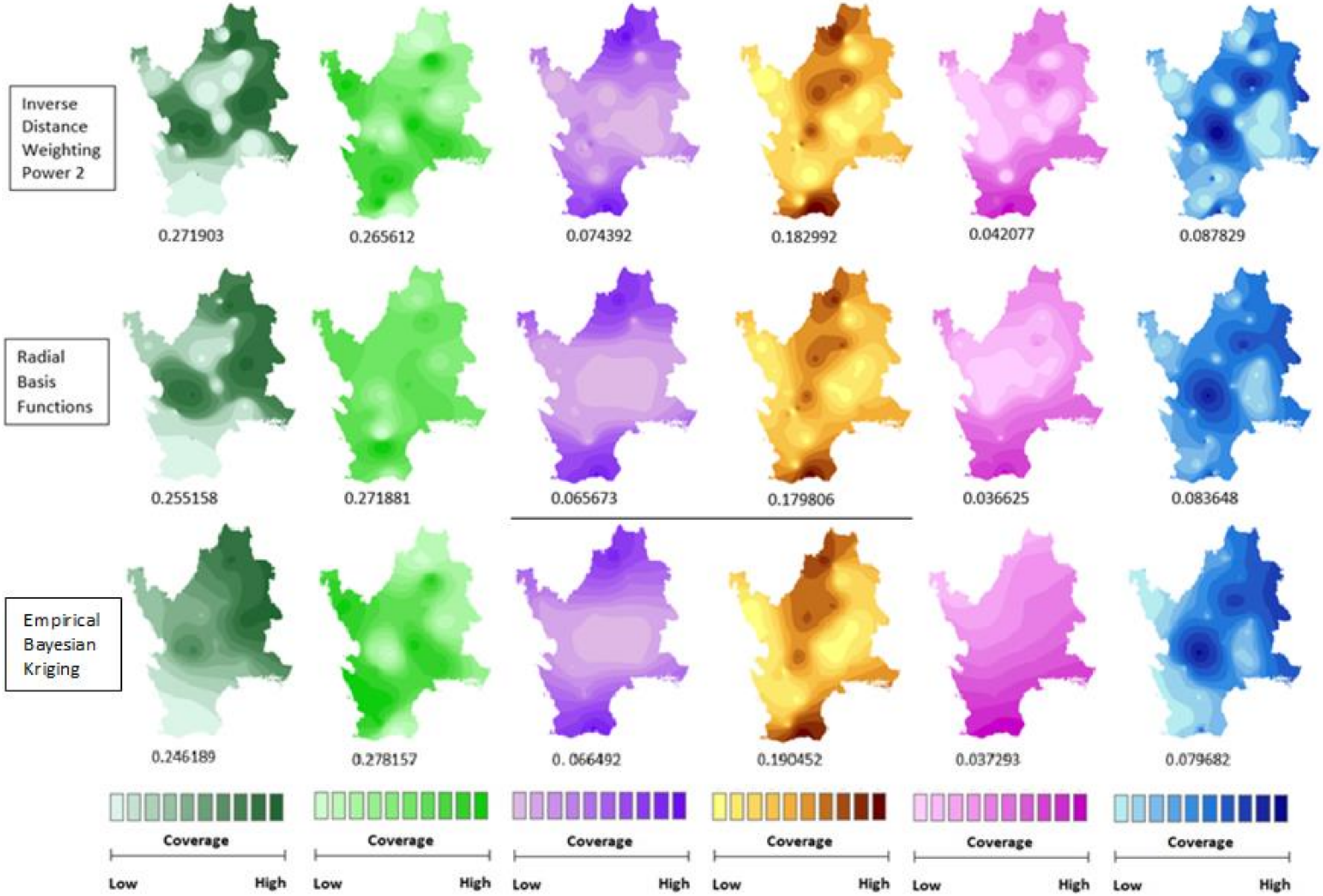


Figure 10. *continued.*

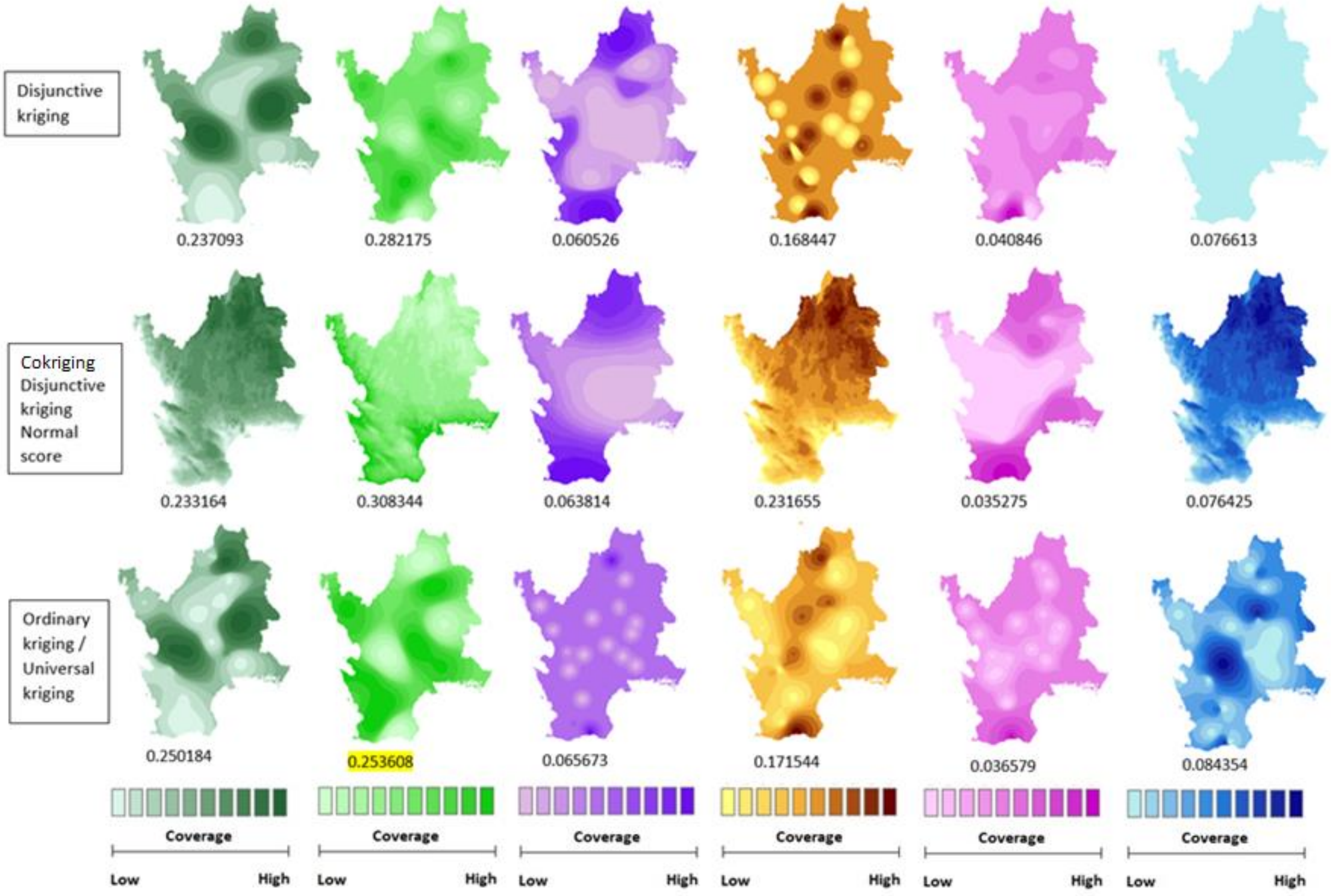


***Figure 10.** continued.*

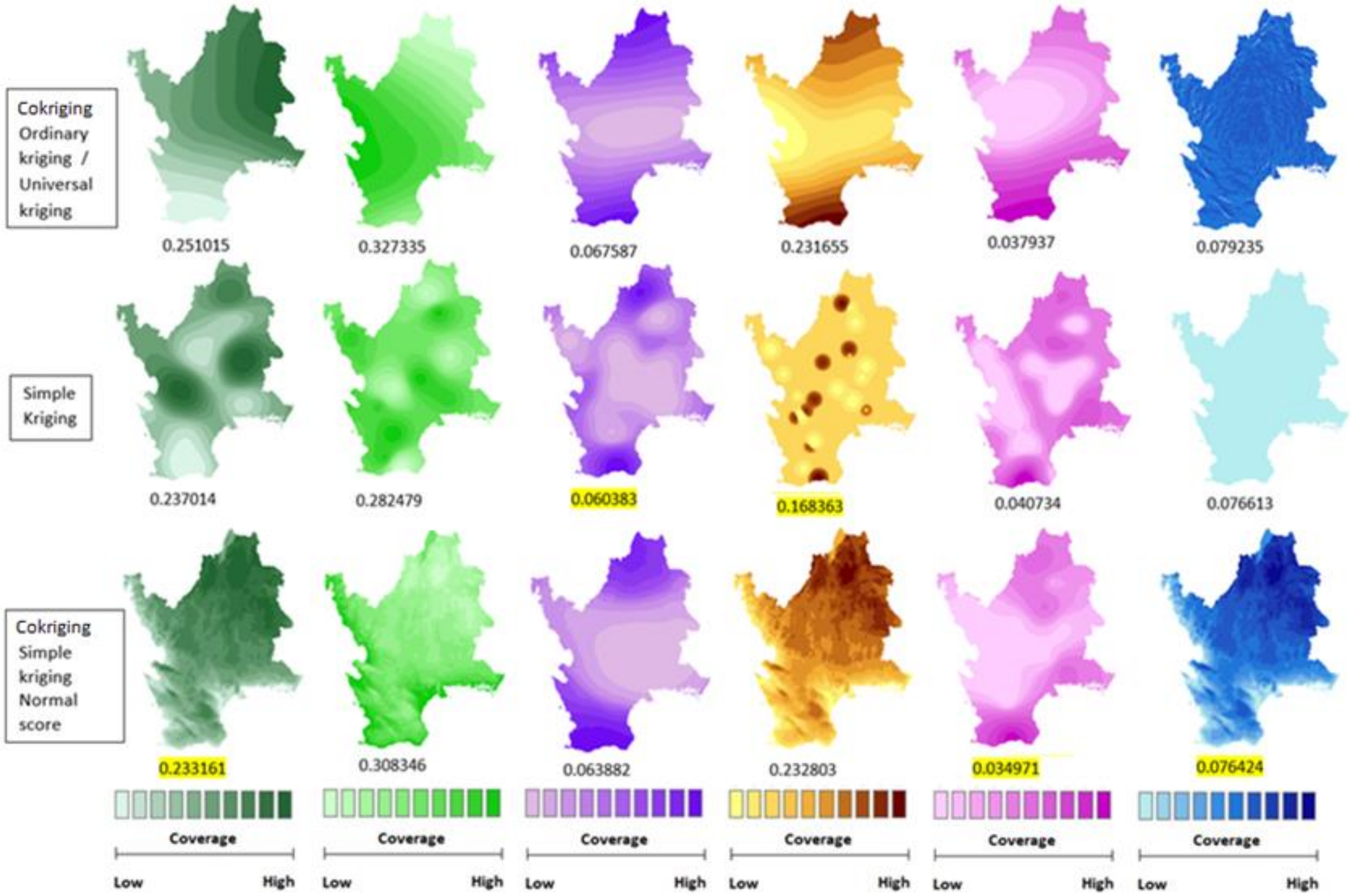


Figure 10. *continued.*

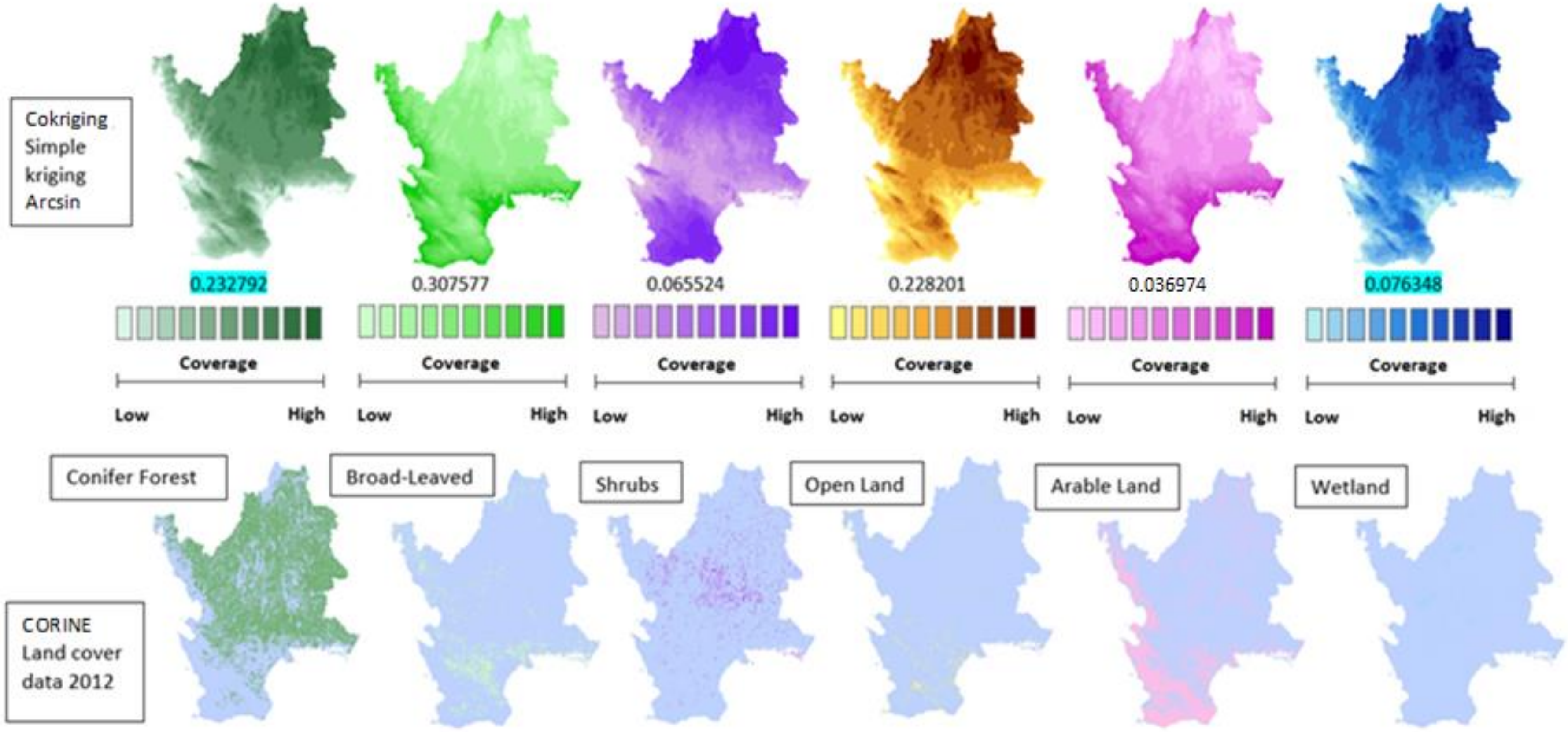


***Figure 10.** continued.*

4.2.3 Creating interpolated surfaces for land cover types and the successive time windows

Conifer forest

Conifer forest coverage decreased from 7250BP to 2550BP, where it was 0-0.05 coverage everywhere, and its lowest coverage (Fig. 11). From 2250BP coverage increased again up to present time, where it was at its highest levels. At present time the highest coverage (0.35-0.4) was in the north of the study site. When conifer forest coverage expanded over time it went from the north to the south.

Broad-leaved forest

Broad-leaved forest had a similar pattern to conifer forest but with different timing. Coverage decreased from 7250BP to 75BP (Fig. 12). Broad-leaved forest started to increase again from 25BP to present time. In 7250BP most of the study area was above 0.8 coverage for broad-leaved forest. In 1450BP and 550BP there was quite a lot of variation in coverage. In 75BP broad-leaved forest ranged from 0.25-0.55 coverage. In present time the higher coverage areas were around the coast and in the south. There appeared to be some loss of broad-leaved forest cover in the north between 1450 and 1050BP. This was restored in 750BP. It decreased again here in 550BP up to present time. Between 2550BP and 1950BP there was some broad-leaved forest loss in the south of the study area.

Shrubs

Shrubs were at their highest in 75BP, with some areas up to 0.17 coverage (Fig. 13). There was quite a lot of variation in coverage for this TW though, with coverage ranging from 0-0.17. Shrubs decreased from 7250BP where it was up to 0.05 coverage, to 2250BP were it was 0-0.01 coverage everywhere. Like conifer forest it increased from here but only up to 75BP. It then decreased to present time, where the range was 0.01-0.05 coverage. It was hard to see any pattern in terms of coverage in space, but in 75BP the highest cover was in the north.

Open Land

Open land coverage was low between 7250 and 3250BP (0-0.3) (Fig. 14). It increased slowly from 7250BP to 75BP, where it was between 0.35 and 0.70 coverage (highest overall coverage). It then started to decrease to present time levels of 0.15-0.25 coverage. Between 7250 and 4250 there was more open land up the north than the south. In 3250 it was 0.15-0.2 coverage everywhere. Between 2550 and 1950 it was higher in the south. Between 1450 and 750BP it was mixed in terms of space. Between 550 and 75BP it was more uniform with higher coverage than previous TW's. At present time it was at low levels again (0-15-0.25 coverage).

Arable Land

Arable land coverage was quite low in all TWs (≤0.04) (Fig. 15). In 4050BP it was 0.01 coverage or less everywhere, except the north where no arable land was present. There was an increasing coverage trend from 4050BP to present time. With max levels at 0.04 coverage in some areas in that TW. There was statistically not enough difference between the data points for TW28, 33, 37 and 41 to interpolate. 150BP to present time had the highest amount of arable land coverage. In 150BP it was mostly uniform (0.01-0.02 coverage) with some higher coverage in the north (0.02-0.03). From 75BP to present time a gap opened up in the middle with lower coverage. In present time it was highest in the south (0.03-0.04 coverage), with much lower coverage in the north (0-0.01 coverage).

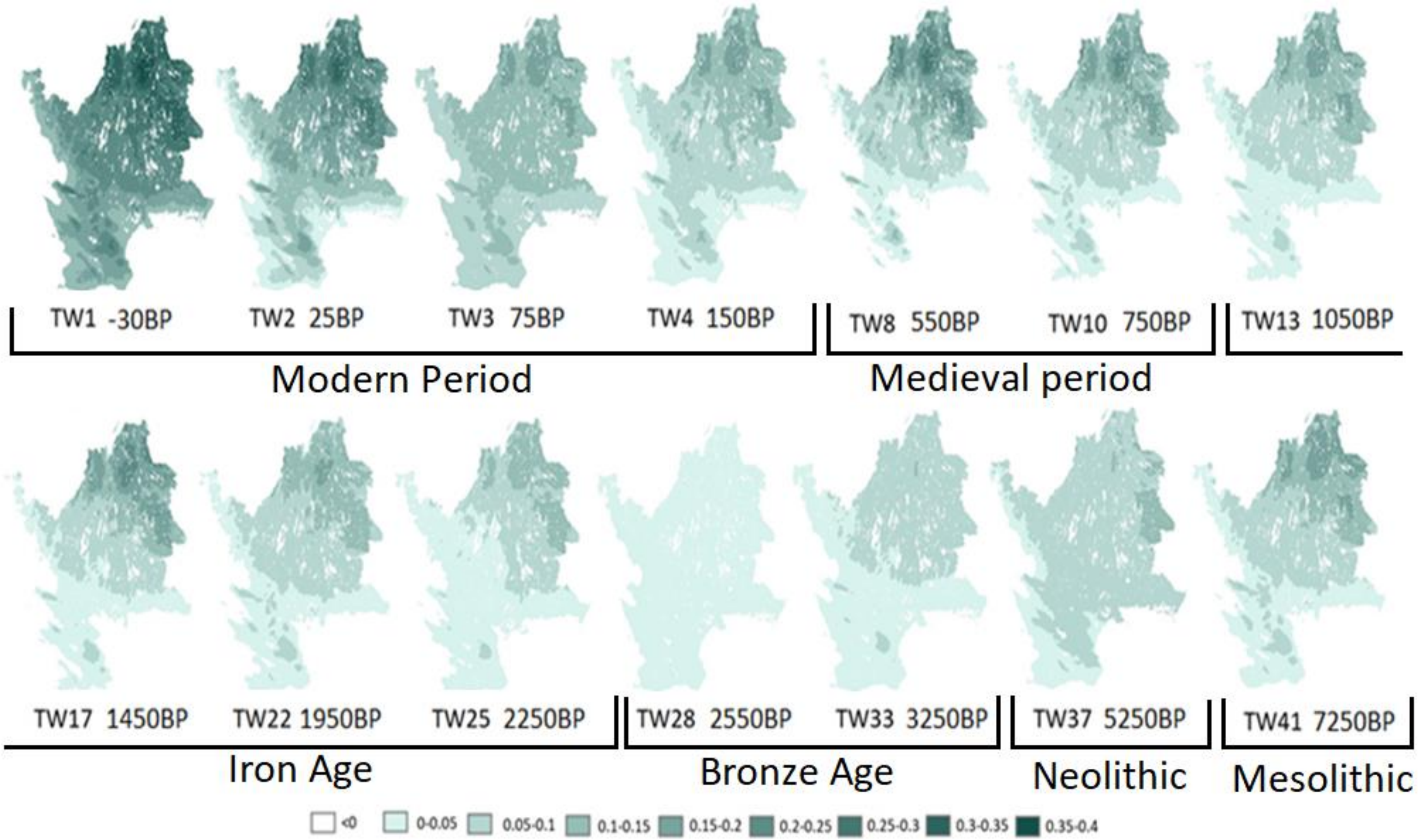


Figure 11. *Conifer forest cover 7205BP to present, five counties, southern Götaland. Method: simple kriging with cokriging using arcsin transformation. Units are 0-1.0 coverage. 1.0 being total coverage for a land cover type.*

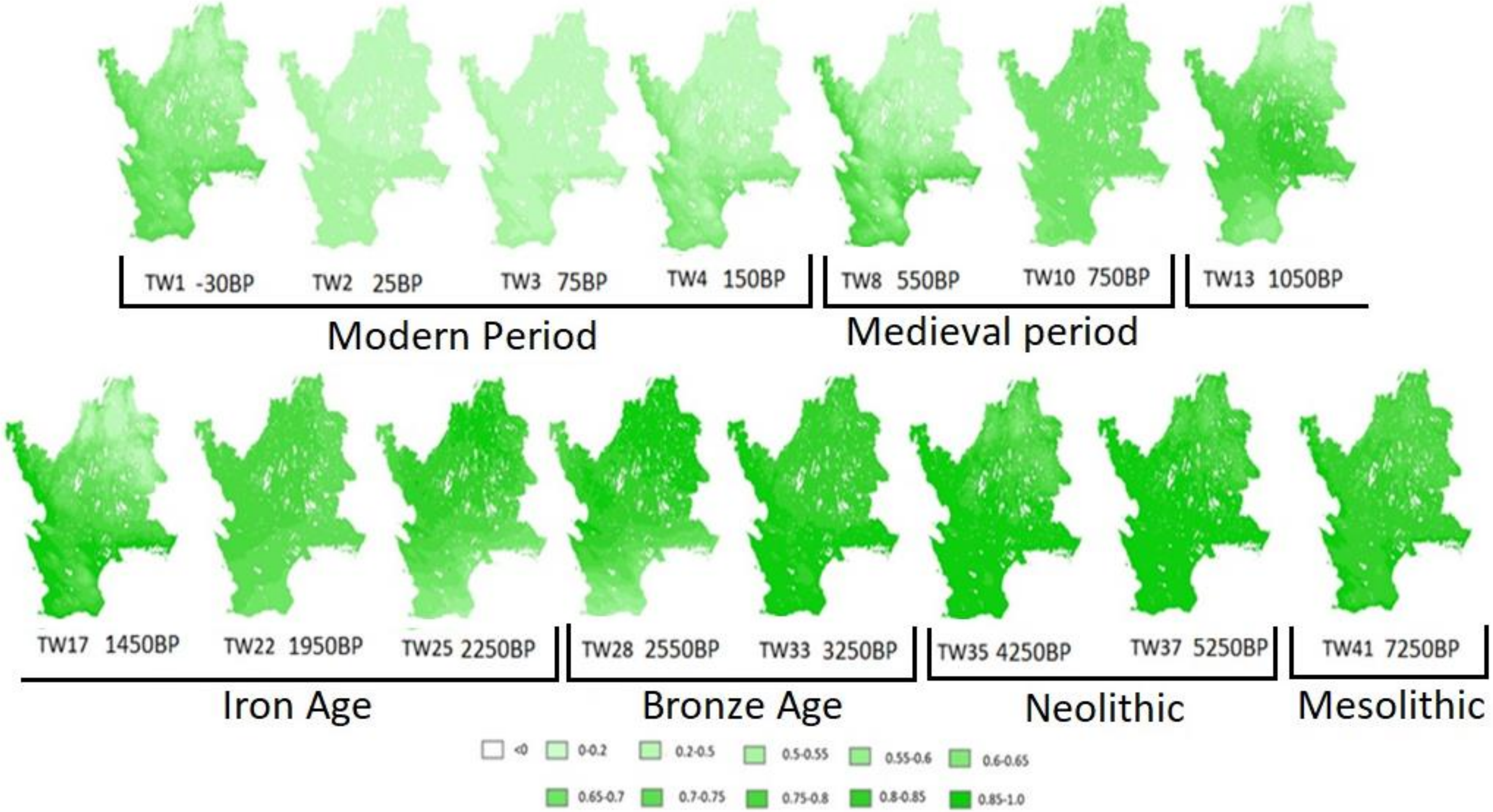


Figure 12. *Broad-leaved forest cover 7205BP to present, five counties, southern Götaland. Method: simple kriging with cokriging using arcsin transformation. Units are 0-1.0 coverage. 1.0 being total coverage for a land cover type.*

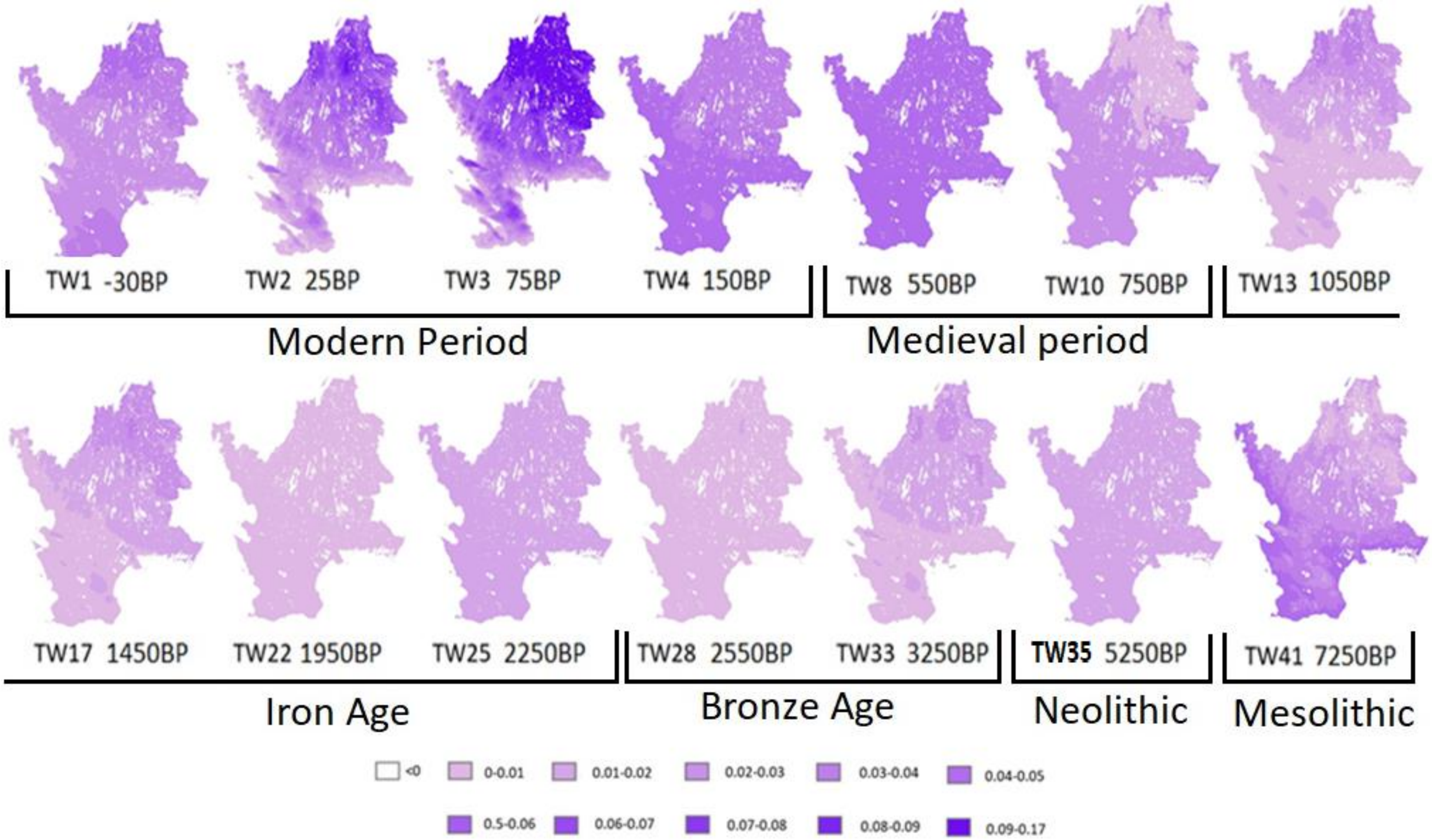


Figure 13. *Shrubs cover 7250BP to present, five counties, southern Götaland. Method: simple kriging with cokriging using arcsin transformation. Units are 0-1.0 coverage. 1.0 being total coverage for a land cover type.*

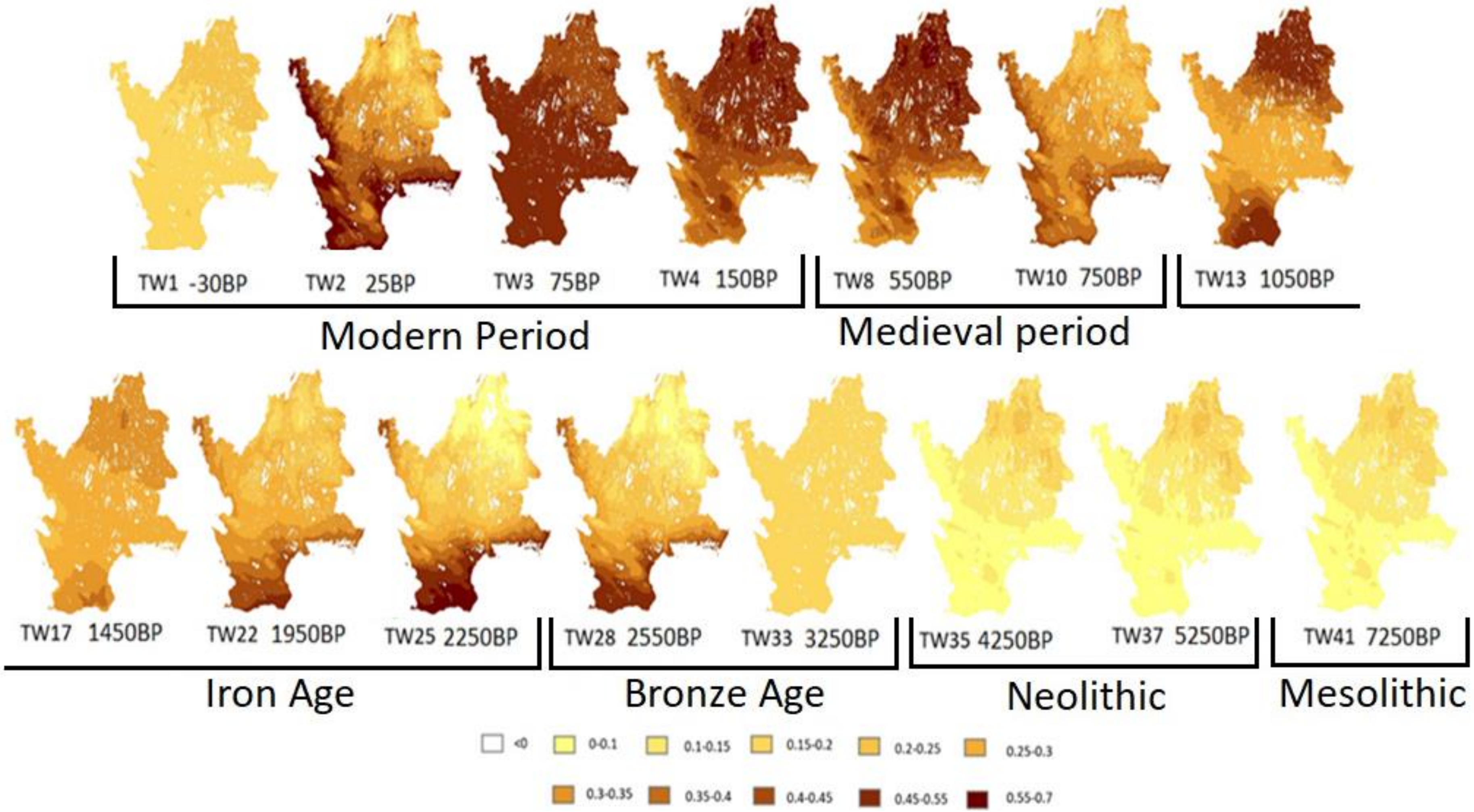


Figure 14. *Open land cover 7250BP to present, five counties, southern Götaland. Method: simple kriging with cokriging using arcsin transformation. Units are 0-1.0 coverage. 1.0 being total coverage for a land cover type.*

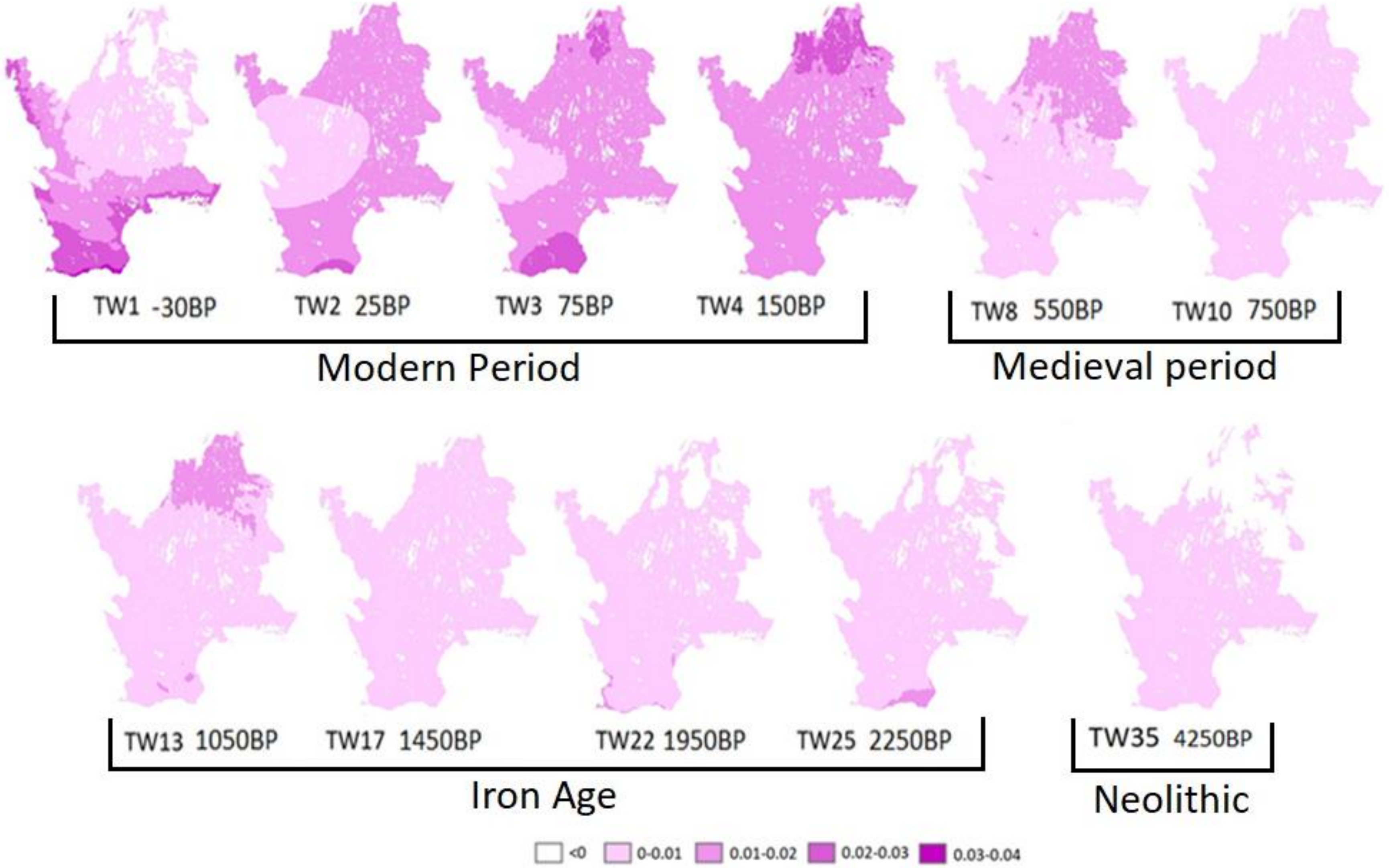


Figure 15. *Arable land cover 4250BP to present time, five counties, southern Götaland. Method: simple kriging with cokriging using arcsin transformation. Units are 0-1.0 coverage. 1.0 being total coverage for a land cover type.*

4.2.4 County-by-county analysis

Modern Period -60 to 300 BP

Conifer forest cover increased through the Industrial Period up to the present time, moving from the northern regions in Jönköping down to the very south in Skåne (Fig. 11, A1 - A5). At present time (-60 to 0 BP) the highest conifer forest cover was seen for all TWs (40%), and was at this coverage over most of the study site. Broad-leaved forest cover had areas of higher cover along the coasts (up to 70%) before the Industrial Period, and much lower cover inland (Fig. 12, A1 - A5). This cover decreased over this time period through the Industrial Period to very low levels everywhere (down to 25%), until the present time where it increased again (up to 75%), mostly in the south and around the coast (South Skåne, coastal Halland and Blekinge). Shrub cover started around 4% coverage over the whole study site before the Industrial Period (Fig. 13, A1 - A5). It then decreased to zero in southern and coastal areas (South Skåne, coastal Halland and Blekinge), during the Industrial Period, but increased to high levels (17%) in the very north (Jönköping and East Kronoberg). At present time (-60 to 0 BP) it was again down to around 4% coverage over the whole study site, with some higher cover in Southern Skåne and Northern Jönköping. Open land was at peak high levels (65%) at the beginning of this time period (Fig. 14, A1 - A5). It then decreased during the Industrial Period in the north in Jönköping and Kronoberg to very low levels at first, and eventually is low coverage (15%) everywhere at present time. Arable land was also at peak high levels (3-4%) at the beginning of this time period, with the highest cover in the north in Northern Jönköping (Fig. 15, A1 - A5). An area of low coverage (1%) then opened up on the west coast in Halland in the Industrial Period, and spread inwards to Kronoberg and upwards to Jönköping. At present time there was low to no cover of arable land inland (Kronoberg) and in northern regions (Jönköping). In the south and along the coast there was high cover, 3-4% (South Skåne, coastal Halland and Blekinge) in the present time.

Medieval Period 300 to 900 BP

Conifer forest cover was increasing in the northern regions (Kronoberg and Jönköping) during this period (Fig. 11, A1 - A5). It was at low levels (0-5%) in the south and coastal areas though (Skåne, Halland and Blekinge). Broad-leaved forest started off at a medium to high range (60-70%) in the early Medieval Period over much of the study site (Fig. 12, A1 - A5). Then it decreased to low levels (down to 5%) in the north and inland (Kronoberg and Jönköping) by mid to late Medieval Period, with a contrasting high level (up to 85%) in the south and along the coasts (Skåne, Halland and Blekinge). Shrub cover was the opposite pattern from the end of the following Iron Age, with low cover (1-2%) in the north in Jönköping and East Kronoberg in the early Medieval Period, and somewhat higher cover (2-3%) in the lower half of the study site (South Kronoberg, Skåne, Halland and Blekinge) (Fig. 13, A1 - A5). There was higher cover still (3-4%) on the North West coast (North West Halland). By mid-Medieval Period this 3-4% coverage spread over much of the study site. Open land was at low levels (15-20%) in the north at the early Medieval Period (Jönköping and East Kronoberg), with a medium range (35-40%) inland (South Kronoberg) and higher levels (40-45%) along the coasts (South Skåne, coastal Halland and Blekinge) (Fig. 14, A1 - A5). By the mid-Medieval period there was higher cover (50-55%) of open land over much of the study site, with medium cover along the coasts (South Skåne, coastal Halland and Blekinge). Arable land went from low cover (0-1%) everywhere early Medieval Period to some low to medium range cover (1-2%) in the northern parts of the study site (Jönköping and East Kronoberg) by mid-Medieval Period (Fig. 15, A1 - A5).

Iron Age 900 to 2400 BP

Conifer forest was increasing during this time (Fig. 11, A1 - A5). The highest cover in the Pre-Roman Iron Age (1-15%) was seen in the north in Jönköping, with slightly lower conifer forest cover (5-10%) moving south somewhat, close to Kronoberg up to the Viking period, with northern parts in the Viking Period up to 25% coverage. In the south and coastal areas (Skåne, Halland and Blekinge) cover was generally still low (0-5%) for the whole period, and some pockets of higher cover (5-10%)

appeared here and there (East Skåne) throughout the period. Broad-leaved forest cover fluctuated during this period (Fig. 12, A1 - A5). It was decreasing (50-55%) in the south in Skåne between the Pre-Roman and Roman Iron Age, and stayed high (up to 95%) inland in Kronoberg, and in the north in Jönköping and west coast in Halland at that time. Then it increased again in the south in Skåne in the Migration Period, and decreased in the north in Jönköping up to the Viking Period. Shrub cover started off higher than in the following Bronze Age (Fig. 13, A1 - A5). Here it was at around 1-2% coverage overall in the Pre-Roman Iron Age. Then it decreased to a low level (0-1%) everywhere in the Roman Iron Age. In the Migration Period higher cover (3-5%) was seen inland in Kronoberg and in the north of the study site in Jönköping, which increased further up to the Viking Period. High open land cover (up to 70%) in the south in Skåne and coastal areas of Blekinge in the Pre-Roman Iron Age decreased down to between 40% and 45% in the Migration Period, and up again in the Viking Period to 55% (Fig. 14, A1 - A5). Inland areas (Kronoberg) had a medium cover (25-30%). Northern areas had a low cover, 0-10% (Jönköping) until the Viking Period, when they had high open land cover (up to 70%). Arable land cover was relatively low (0-1%) over most of the study site for this period (Fig. 15, A1 - A5). At the start of this period, in the Pre-Roman Iron Age there was a higher (1-2%) pocket of arable land in the very south in South East Skåne. In the north an area of no cover in northern Jönköping in the Pre-Roman Iron Age was beginning to be filled in by low level (0-1%) arable land cover up to the Viking Period, when there was higher cover (1-2%) of arable land at the north in North West Jönköping. Otherwise there was low level arable land all over the study site by the end of the period (0-1%).

Bronze Age 2400 to 3500 BP

Conifer forest was reducing in this period (Fig. 11, A1 - A5). The low coverage (0-5%) in the south and coasts (Skåne, Halland and Blekinge) in the early Bronze Age spread north over this period (Kronoberg and Jönköping), until all the study site was low cover for this LCT by the late Bronze Age. Broad-leaved forest started high overall (80-90%), but then cover began to decrease in the south and south-east coast, down to 50% coverage in late Bronze Age (Skåne and Blekinge) (Fig. 12, A1 - A5). Shrub cover reduced in this period starting in the south and along the coasts (Skåne, Halland and Blekinge), and then moved north through Kronoberg to Jönköping, until most of the study site was at a low level in the late Bronze Age (0-1%) (Fig. 13, A1 - A5). Open land was at a low to medium range (15-20%) over the whole study site at the early Bronze Age (Fig. 14, A1 - A5). Then high areas of cover (up to 55%) were seen in the south and the coasts (Skåne, Halland and Blekinge), with a reduction in the north in Jönköping by the late Bronze Age (down to 0-10%). There was no suitable data for arable land for this period (Fig. 15, A1 - A5).

Neolithic Period 3500 to 6000 BP

Conifer forest was now more uniform throughout the study site, with a low to medium range of cover (0-15%) (Fig. 11, A1 - A5). The south and coasts had low cover, 0-5% (Skåne, Halland and Blekinge) in this period. In the north (Jönköping) this low to medium range cover was lower than in the following Mesolithic Period, with some parts of the north and in the east with pockets of higher cover, 10-15% (East Kronoberg). Broad-leaved forest was still at a high level (85-100%) over the whole study site for this period (Fig. 12, A1 - A5). Shrub cover had reduced to a lower range (1-2%) over the whole study site by mid Neolithic (Fig. 13, A1 - A5). Open land cover was similar to the following Mesolithic period, with low cover (5-15%) in most places for this period (Fig. 14, A1 - A5). The lowest cover (0-5%) was in the south and the coasts (Skåne, Halland and Blekinge), a low to medium range (15-20%) was found in the middle (Kronoberg), and higher cover in the north in Jönköping (up to 35%). There was slightly less open land cover overall however in this period. There was low cover (0-1%) for arable land over the whole study site in mid Neolithic, with little to no cover in the north (Jönköping and East Kronoberg) (Fig. 15, A1 - A5).

Mesolithic Period 6000 to 9000 BP

Conifer forest cover was highest (20-25%) in the north in Jönköping in this period, with low cover (0-5%) in the south and coasts (Skåne, Halland and Blekinge) and a low to medium range (5-15%) in the centre (Kronoberg) (Fig. 11, A1 - A5). Broad-leaved forest cover was high (80-90%) over the whole study area for this period (Fig. 12, A1 - A5). Shrub cover was high (4-5%) in the south and along the coast (Skåne, Halland and Blekinge) for this period (Fig. 13, A1 - A5). With low cover (0-1%) in the north in Jönköping, and a low to medium range cover (2-3%) in the center (Kronoberg). Open land cover was low (0-25%) over the whole study site for this period (Fig. 14, A1 - A5). Highest cover (25%) was in the north in Jönköping, with the lowest cover (0-5%) in the south in Skåne. There was no suitable data for arable land for this period (Fig. 15, A1 - A5).

4.3 Ecosystem Services

4.3.1 Ecosystem service number for land cover types

Alternative 1, Götaland with all 34 LCTs. Land principally occupied by agriculture, with significant areas of natural vegetation, and the three forests: mixed forest, broad-leaved forest and conifer forest had the highest ES number of all LCTs at 25 (Table 8). Moors and heathland and fruit trees and berry plantations were not far behind with an ES number of 21 and 20 respectively. Artificial surfaces provided little in the way of ES (0-2). Ecosystem service grade did not provide more information than ES number.

Alternative 2, Götaland land cover merged into 13 LCTs. Arable land and the three forests: mixed forest, broad-leaved forest and conifer forest had the highest ES number of all LCTs at 25 (Table A3). Waterbodies had the next highest at 22, followed by moors and heathland at 21, and wetlands at 20. Areas of little or no vegetation had the lowest ES number at 12.

Alternative 3, Götaland land cover merged into 11 LCTs. Arable land has the highest ES number at 27 (Table A3). The three forests: mixed forest, broad-leaved forest and conifer forest have the next highest ES number of all LCTs at 25. Waterbodies have the next highest at 22, followed by moors and heathland at 21, and wetlands at 20. Areas of little or no vegetation had the lowest ES number at 12.

Alternative 4, Götaland land cover merged into 7 LCTs. Arable land had the highest ES number at 27 (Table A3). The three forests: mixed forest, broad-leaved forest and conifer forest had the next highest ES number of all LCTs at 25. Shrubs had the next highest at 21, followed by wetlands at 20, and open land also at 20.

4.3.2 Number of land cover types for individual goods

Abiotic heterogeneity and biodiversity had the greatest number of land cover types associated with them, 33 (Table 8). The next highest were exergy capture and reduction of nutrient loss at 25. After this were local climate regulation, aesthetic appreciation and inspiration for culture, art and design and food protection at 22, 22 and 21 respectively. All other goods had 19 or lower LCTs associated with them. These results are for alternative 1. Note that alternatives 2, 3 and 4 were characterized by few differences in terms of number of LCT for the individual goods because of the low numbers of LCTs in those alternatives (Table A3).

4.3.3 Ecosystem service categories

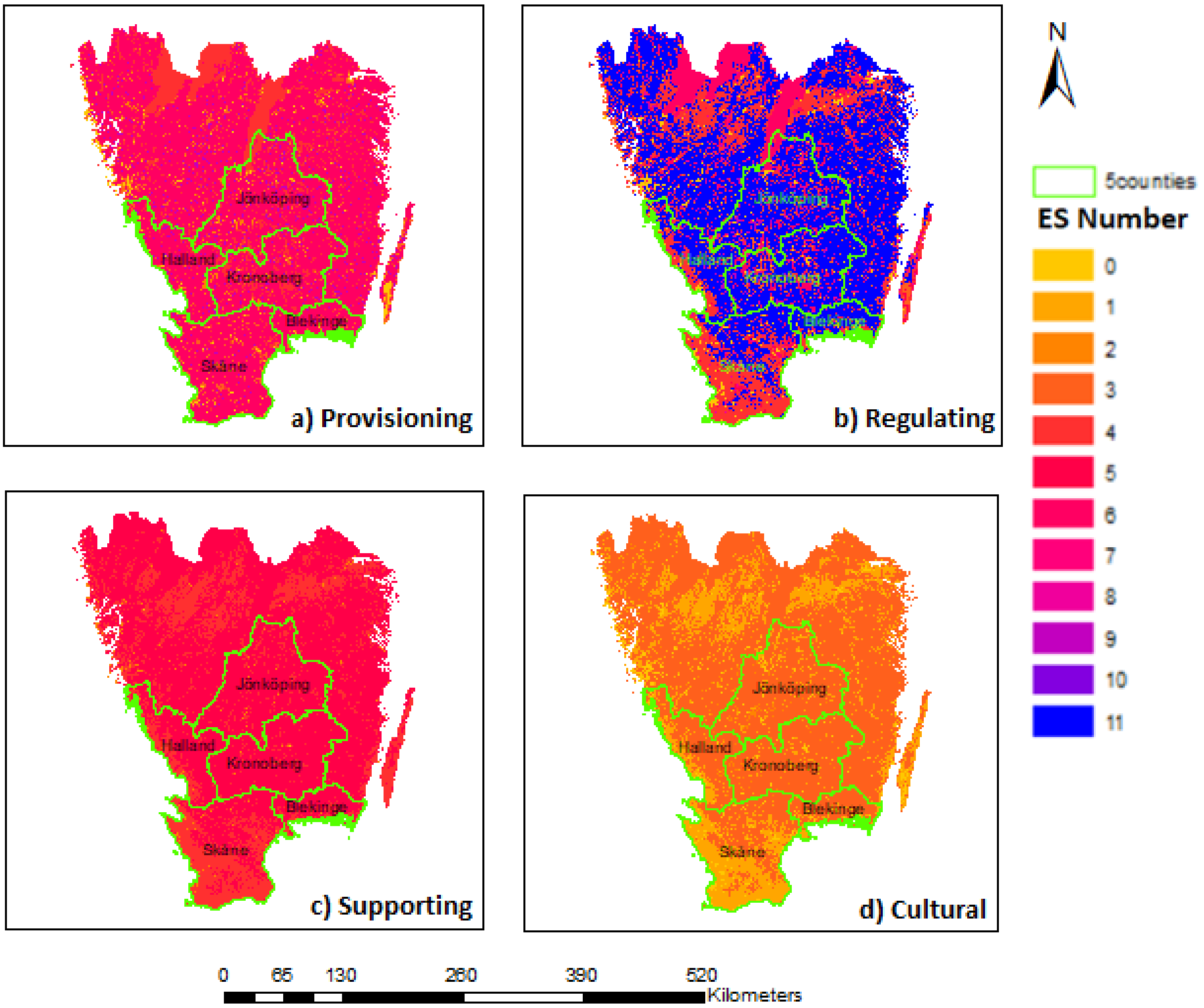
For Götaland as a whole (Table 8), regulating services had the highest ES number (152), followed by supporting services (131), then provisioning services (92), and then cultural services (51). In figure 16 Götaland was broken down into the four ES categories, based on the values in table 8. LCTs per category had a smaller ES number when compared to ES number in general for Götaland. For provisioning services, the average ES number per LCT was 5.31 (Fig. 16), with nearly half the land cover

Table 8. *Assessment matrix for the present and alternative 1, 34 LCTs. 34 land cover types taken from the CORINE 2012 data set that are present in Götaland were placed on the y-axis, and the ES on the x-axis. The ES were further divided into supporting, provisioning, regulating and cultural services. A value of 0 was given to a land cover type that has no relevant capacity to provide a particular ecosystem service. A value of 1 was given to a land cover type that had a capacity to provide a particular ecosystem service. Adding up the 1's for a land cover type gave its ecosystem service number. This represented alternative 1 LCTs. Additionally, these values were graded from 1 to 15 based on the lowest to highest ecosystem service number as an alternative grading system to see if this provided more information.*

CLC code	Land Cover Type	Provisioning services												ES number provisioning services	Regulating services											ES number regulating services	Supporting services					ES number supporting services	Cultural services			ES number cultural services	ES number for each land-cover type	Grade
		Crops	Livestock	Fodder	Capture fisheries	Acquaculture	Wild foods	Timber	Wood fuel	Energy (biomass)	Genetic resources	Medicine	Fresh water		Local climate regulation	Global climate regulation	Food protection	Groundwater recharge	Air quality regulation	Erosion regulation	Nutrient regulation	Water purification	Pollination	Carbon sequestration and storage	Moderation of extreme events		Abiotic heterogeneity	Biodiversity	Genetic diversity	Exergy capture (radiation)	Reduction of nutrient loss		Recreation and tourism	Aesthetic appreciation and inspiration for culture, art and design	Intrinsic value of biodiversity			
111	Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	**0**	0	0	0	**0**	**0**	**1**
121	Industrial or commercial units	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	0	0	**2**	0	0	0	**0**	**2**	**2**
122	Road and rail networks and associated land	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	0	0	**2**	0	0	0	**0**	**2**	**2**
131	Mineral extraction sites	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	0	0	**2**	0	0	0	**0**	**2**	**2**
132	Dump sites	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	0	0	**2**	0	0	0	**0**	**2**	**2**
133	Construction sites	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	0	0	**2**	0	0	0	**0**	**2**	**2**
334	Burnt areas	0	0	0	0	0	0	0	0	0	0	0	0	**0**	1	0	0	0	0	0	0	0	0	0	0	**1**	1	1	0	0	0	**2**	0	0	0	**0**	**3**	**3**
123	Port areas	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	1	0	0	0	0	0	0	0	0	**1**	1	1	0	0	0	**2**	1	1	0	**2**	**5**	**4**
124	Airports	0	0	1	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	1	1	**4**	0	0	0	**0**	**5**	**4**
332	Bare rocks	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	1	1	0	0	0	1	0	0	0	**3**	1	1	0	0	0	**2**	0	1	0	**1**	**6**	**5**
112	Discontinuous urban fabric	1	0	1	0	0	1	0	0	0	0	0	0	**3**	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	1	1	**4**	0	0	0	**0**	**7**	**6**
333	Sparsely vegetated areas	0	0	0	0	0	0	0	0	0	0	0	0	**0**	1	0	1	1	0	0	0	0	0	0	0	**3**	1	1	0	1	1	**4**	0	0	0	**0**	**7**	**6**
331	Beaches, dunes, sands	0	0	0	0	0	0	0	0	1	0	0	0	**1**	0	0	1	1	0	0	0	0	0	0	0	**2**	1	1	0	1	1	**4**	1	1	1	**3**	**10**	**8**
142	Sport and leisure facilities	0	0	0	0	0	0	0	0	0	0	0	0	**0**	1	1	0	1	1	1	1	1	1	0	0	**8**	1	1	0	1	1	**4**	1	0	0	**1**	**13**	**9**
231	Pastures	0	1	1	0	0	0	0	0	0	1	0	0	**3**	1	1	1	1	0	1	0	0	0	0	0	**5**	1	1	0	1	1	**4**	0	1	0	**1**	**13**	**9**
242	Complex cultivation patterns	1	0	1	0	0	0	0	0	0	1	1	0	**4**	1	1	1	1	0	0	0	0	0	0	0	**4**	1	1	0	1	1	**4**	0	1	0	**1**	**13**	**9**
421	Salt marshes	0	1	0	0	0	0	0	0	0	1	0	0	**2**	1	0	1	0	0	0	1	0	0	1	1	**5**	1	1	1	1	1	**5**	0	1	0	**1**	**13**	**9**
141	Green urban areas	0	0	0	0	0	1	0	1	0	0	0	0	**2**	1	1	0	1	1	1	1	1	1	0	0	**8**	1	1	0	1	1	**4**	1	0	0	**1**	**15**	**10**
211	Non-irrigated arable land	1	1	1	0	0	0	0	0	1	1	1	0	**6**	1	1	1	1	0	0	0	0	0	0	0	**4**	1	1	0	1	1	**4**	0	1	0	**1**	**15**	**10**
324	Transitional woodland-shrub	0	1	0	0	0	1	0	1	0	1	0	0	**4**	1	0	0	0	0	0	0	0	1	1	0	**3**	1	1	1	1	1	**5**	1	1	1	**3**	**15**	**10**
411	Inland marshes	0	1	1	0	0	0	0	0	0	1	0	0	**3**	1	1	1	1	0	0	1	0	0	1	1	**7**	1	1	1	1	1	**5**	0	1	0	**1**	**16**	**11**
521	Coastal lagoons	0	0	0	1	1	1	0	0	1	1	0	0	**5**	1	0	1	0	0	0	0	0	0	1	0	**3**	1	1	1	1	1	**5**	1	1	1	**3**	**16**	**11**
522	Estuaries	0	0	0	1	1	1	0	0	1	1	0	0	**5**	0	0	1	0	0	0	1	1	0	1	0	**4**	1	1	1	1	1	**5**	0	1	1	**2**	**16**	**11**
523	Sea and ocean	0	0	1	1	1	0	0	0	0	1	0	0	**4**	1	1	0	0	0	0	1	0	0	1	0	**4**	1	1	1	1	1	**5**	1	1	1	**3**	**16**	**11**
321	Natural grasslands	0	1	0	0	0	1	0	0	0	1	0	0	**3**	1	1	1	1	0	1	1	1	0	0	0	**7**	1	1	1	1	1	**5**	1	1	1	**3**	**18**	**12**
412	Peat bogs	0	0	0	0	0	0	0	0	1	1	0	0	**2**	1	1	1	1	0	0	1	1	1	1	1	**9**	1	1	1	1	1	**5**	0	1	1	**2**	**18**	**12**
511	Water courses	0	0	0	1	0	1	0	0	0	1	0	1	**4**	1	0	1	1	0	0	1	1	0	1	0	**6**	1	1	1	1	1	**5**	1	1	1	**3**	**18**	**12**
512	Inland water bodies	0	0	0	1	0	1	0	0	0	1	0	1	**4**	1	1	1	1	0	0	1	0	0	1	0	**6**	1	1	1	1	1	**5**	1	1	1	**3**	**18**	**12**
222	Fruit trees and berry plantations	1	0	0	0	0	0	1	1	0	1	0	0	**4**	1	1	1	1	1	1	1	1	1	1	0	**10**	1	1	0	1	1	**4**	0	1	0	**1**	**19**	**13**
322	Moors and heathland	0	1	0	0	0	1	0	1	1	1	0	0	**5**	1	1	1	1	0	0	1	1	1	1	0	**8**	1	1	1	1	1	**5**	1	1	1	**3**	**21**	**14**
243	Land principally occupied by agriculture, with significant areas of natural vegetation	1	1	1	0	0	1	1	1	1	1	1	0	**9**	1	1	1	1	1	1	0	1	0	1	0	**8**	1	1	1	1	1	**5**	1	1	1	**3**	**25**	**15**
311	Broad-leaved forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1	**11**	1	1	1	1	1	**5**	1	1	1	**3**	**25**	**15**
312	Coniferous forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1	**11**	1	1	1	1	1	**5**	1	1	1	**3**	**25**	**15**
313	Mixed forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1	**11**	1	1	1	1	1	**5**	1	1	1	**3**	**25**	**15**
	Number of land-cover types for individual goods	5	8	11	5	3	13	5	8	7	19	6	2	**92**	22	16	21	19	7	9	15	13	9	15	6	**152**	33	33	15	25	25	**131**	15	22	14	**51**	**426**	

around ES number 6. Lower values were found on the lakes, in pockets on the west coast, and inland and southern Öland. These services were provided at a medium level in all the five counties, with some small lower level pockets in the west and north east parts of Skåne. For regulating services, the average ES number per LCT was 6.94 (Fig. 16), with a nearly a third of the land cover over 11. Lower values were found on and around the lakes in the north, down the very south, and on the coasts, and Öland. Higher values were inland in forested areas. These services were provided at a high level in Jönköping and Kronoberg, and inland parts of Halland and Blekinge, and in northern parts of Skåne. Coastal parts of Halland and Blekinge, and the southern half of Skåne provided medium levels of these services. For supporting services, the average ES number per LCT was 4.65 (Fig. 16), with the majority of the land cover at this value. There were some scatterings of lower ES number areas throughout the map. These services were also provided at a medium level in all five counties. The lower half and west coast of Skåne and west coast of Halland had lower levels of supporting services. For cultural services the average ES number per LCT was 2.28 (Fig. 16), with over two thirds the land cover at this value. Around one third had an ES number of 1. This was found inland at the north between the lakes and in the very south. All counties provided low levels of these services, with the coasts and the lower half of Skåne having had very low levels.

Figure 16. *Spatial representation of the ecosystem service number by category, for Götaland and the present time. A) provisioning services. b) regulating services. c) supporing services. d) cultural services. Four identical land cover maps for Götaland (3.2.2) for alternative 1 were reclassified in ArcGIS 10 into the ecosystem service number for each LCT by each of the four ES sub categories mentioned above, to visualize which areas have higher or lower ES number by category. An extra field was added to the layers attribute table in ArcMap. The ES number from the assessment matrix for each LCT was added in the ES number field for each particular LCT. The symbology for the four layers was then changed to the ES number field, and a colour scheme selected.*



5. Discussion

5.1 Spatial changes in the land cover types through millennia in southern Sweden: plant resources for human societies

Götaland, the third and southern most land in Sweden (Gren & Isacs, 2009), is currently over 50% (56.2%) covered in coniferous forest according to the 2012 CORINE land cover data (Fig. 7). A second forest type, broad-leaved forest, covers 10% of the land in Götaland. Götaland also has around 2% mixed forest cover. Arable land accounts for 19% of the land cover in Götaland. Water bodies such as lakes and rivers account for 11% of the land cover in Götaland. Overall Götaland is 63% forested, 19% arable land and 11% water bodies. It wasn't always the way it is today however. The pollen estimates used in this study along with interpolation in ArcMap allowed insights into land cover of the past.

In this study LRA data was used with an ArcMap interpolation method to create broad-scale reconstructions of land cover in five counties in Götaland spanning 15 TWs from 7500BP to present time (Fig. 11-15). The simple kriging with cokriging with arcsin transformation method used was able to recreate the decrease in forest cover after the mid Holocene warm period for both forest types (Fig. 11 & 12). 2550BP showed the lowest point for conifer forest cover. This may coincide with the stabling of livestock and haymaking for overwintering i.e. forest clearance (Eriksson & Cousins, 2014). It also showed the increase in open land in the south and along the coasts (Fig. 14) around the time when manure was starting to be used as a fertiliser 2517BP (Eriksson & Cousins, 2014). The method also depicts an increase in arable land in Southern Skåne at this time (Fig. 15). The more or less stable period from the late medieval period up until the 18th century can also be seen. Then the start of the agricultural revolution (Eriksson & Cousins, 2014) is seen as a big jump in arable land in all of the 5 counties in 150BP. Additionally, when forests were starting to be replanted in the 20th century an increase in conifer forest and broad-leaved forest was seen along with a decrease in open land. Shrubs are generally present when forest cover opens up. It was highest around the coast in 7250BP and started to increase everywhere from 750BP (Fig. 13). This is when broad-leaved trees start to be cleared in Sweden. Indeed a big drop in this forest cover after this time is seen.

Björkman (1997) found an intense human impact on land cover in Halland around 400BP. For the county by county analysis in this study, conifer forest is very low in this area between 550 and 150BP (Fig. A1-A5). Pollen from cereal was also found around 1400BP in this area (Björkman, 1997). No change was seen here in arable land until 550BP or later. The simple kriging with cokriging method does show the increase in shrub cover that he mentions here in the middle of the 19th century though. The study by Björkman (19997) is over twenty years old at this stage, and more data points were used in this master's thesis. Additionally, he did not use any algorithms to more accurately determine local pollen estimates. The LRA data in this study is therefore likely more accurate.

5.2 Insights into ecosystem service changes through millennia: the use of plant resources by human societies

The ES assessment matrix for all 34 LCTs created in this study shows that all three forest types, along with land principally occupied by agriculture with significant areas of natural vegetation, provide the highest ES number (Table 8). And that other agricultural areas and certain waterbodies types also provide high ES numbers. Therefore, at present as an area, Götaland is providing or able to provide a high number of ecosystem services, the majority of these regulating services.

Focusing on the five counties area in the 2012 data; provisioning services (e.g. crops, livestock, timber etc.) are provided at a medium level in all counties (Fig. 16). With some small lower level pockets in the west and north east parts of Skåne. Supporting services (e.g. biodiversity, genetic diversity, reduction of nutrient loss etc.) are also provided at a medium level in all counties. The lower half and west coast of Skåne and west coast of Halland have lower levels of supporting services. For cultural services (recreation and tourism, aesthetic appreciation and inspiration for culture, art and design, etc.) all counties provide low levels, with the coasts and the lower half of Skåne having very low levels. This is somewhat understandable as Skåne has more agricultural land than forested land or natural areas. However, the lower levels for the forested areas does not quite add up as they would have high recreational capacity. This due to the lower number of ES services (3) used for the cultural services category. Regulating services on the other hand (e.g. local climate regulation, nutrient regulation, water purification) are provided at a high level in Jönköping and Kronoberg, and inland parts of Halland and Blekinge, and in northern parts of Skåne. These areas are highly forested, which, as a LCT have high regulating capacity. Coastal parts of Halland and Blekinge, and the southern half of Skåne provide medium levels of these services, which makes sense as these are either built up areas or areas of intense agriculture.

Modern Period -60 to 300 BP

In this period conifer forest is higher than the periods after the Neolithic (up to 40%) (Fig. 11). It is found all over the study site. This would have provided high amounts fodder, wild foods, timber, wood fuel genetic resources and medicine from this LCT to the people of the period. Spruce plantations become increasingly common in Southern Sweden, and in particular the province of Småland, in the industrial period (Cui, et al., 2014). In out-land areas deciduous forest is replaced by dense coniferous forest (Lindbladh, 1999). This corresponds to what is seen in this study. Just before and during the industrial period there are lower levels (50%) of broad-leaved forest cover compared to the other periods (Fig. 12). In the present time there is high broad-leaved forest cover (75%) in the south and along the coasts. This LCT would have provided high amounts of fodder, wild foods, timber, wood fuel genetic resources and medicine. Broad-leaved forests were increasingly cleared and lakes and wetlands drained in this period (Eriksson & Cousins, 2014). Forest grazing is banned in 22 BP, so as to produce more timber in Sweden, with resultant declines in grasslands (Eriksson & Cousins, 2014). Broad-leaved forests increase in the present time and along the coastal areas due to ships no longer being built out of wood. Forest cover increased to around 70% by this time (Mazier et al., 2015). This corresponds to the increase in both forest types seen in the present time in this study.

Shrub cover is at medium levels (4-5%) pre and post-industrial period, but is at high levels in the north in the industrial period (up to 17%) (Fig. 13). In the north shrubs would have provided high amounts of livestock, wild foods, wood fuel, biomass and genetic resources. Open land was high (up to 0.65) pre the industrial period and during the industrial period (Fig. 14). It is quite low in the present time though corresponding to the increase in forest cover. Just before the present time this LCT would have provided high amounts of livestock, fodder, wild foods, biomass, and genetic resources.

Arable land was at its highest in this period (2-3%), reducing towards the present time, with concentrations (3-4%) in the south and along the coast then (Fig. 15). Arable land would have provided high amounts crops, livestock, fodder, wild foods, timber, wood fuel, biomass, genetic resources and medicine. The agricultural revolution starts in this period with an increase in science and technology. An increasing demand for food lead to massive expansion of agriculture (Eriksson & Cousins, 2014), which is seen in this study during this period. Crop rotation and fertilizers are introduced now. Semi natural grasslands are used for crop production and forests are less used for grazing. Machines run on oil replace horses requiring reducing the need for meadows (Eriksson & Cousins, 2014). The largely constant agricultural land cover feeds more people due to more efficient nutrient supply to the arable land, land divisions, more efficient manuring, irrigation and marling (Fredh et al., 2017). Small scale agriculture later gives way to modern land-use, focusing on commercial forestry and crop cultivation (Fredh et al., 2017). This is evident in the increased forest cover in this study for this period and the concentration of agricultural areas.

Medieval Period 300 to 900 BP

Conifer forest cover in this period is medium to high (10-30%) in central and northern parts of the study site, but low in the south and along the coasts (Fig. 11). In central and northern parts of the study site fodder, wild foods, timber, wood fuel genetic resources and medicine would have been available in good amounts from this LCT. At the start of this period broad-leaved forest cover was high all over the study site (75%) (Fig. 12) providing fodder, wild foods, timber, wood fuel genetic resources and medicine. Towards the middle of this period these resources would have been less available in northern and central areas due to a reduction in this LCT, but they remained highly available along the coasts. This is the end of the previous warm period, with a change to a cool/moist climate. Broad-leaf trees start to be cleared in Sweden for use in ship building (Björkman & Bradshaw, 1996), which is seen in this study for this period. The remaining forests are mixed deciduous with increasing presence of Fagus sylvatica (Björkman & Bradshaw, 1996).

Shrub cover was low (1%) in northern parts of the study site at the start of this period but there was a medium range (5%) in the other parts which spread north by the mid to late Medieval Period (Fig. 13). Shrub cover would have provided a medium range of livestock, wild foods, wood fuel, biomass and genetic resources during this period. Open land cover started at a medium cover (35%) at the start of this period but by the mid to late Medieval Period it was high (>50%) in most parts (Fig. 14). Open land would have provided a lot of livestock, fodder, wild foods, biomass, and genetic resources during this period. Pastures and meadows decline by 40-50% in this period, possibly due to the Black Death pandemic that first struck Sweden in 600 BP, and again between 600 and 500 BP (Fredh et al., 2017). The results from this study suggest for at least the areas in the study site, pastures and meadows actually started to increase during this time.

Arable land was at 0-1% cover everywhere at the start of this period (Fig. 15). By the mid to late Medieval Period there was higher cover (2-3%) in more northern parts. Arable land would have provided an increasing amount of crops, livestock, fodder, wild foods, timber, wood fuel, biomass, genetic resources and medicine during this period. In the early Medieval Period agriculture intensifies on the in-fields, most importantly for cereal cultivation. Out-fields were used for forest grazing and slash-and-burn agriculture (Lindbladh, 1999; Fredh et al., 2017). By the mid to late Medieval Period cold conditions prevail with a severe effect on agriculture (mid-Medieval agrarian crisis) (Berglund, 2003). 60-70% of all farms in the uplands of Southern Sweden were abandoned because of this (Fredh et al., 2017). In this study the northern areas seems to be a hot spot for agricultural practices in the mid to later Medieval Period TW. No decline was seen. However there are 200 years still to go in this period which may have shown the decline in this area.

Iron Age 900 to 2400 BP

Conifer forest is mostly found in the central and northern parts of the study site in this period, ranging from 10-25% (Fig. 11). In the south and coastal areas cover is generally low (0-5%) for the whole period. The ES from this LCT i.e. fodder, wild foods, timber, wood fuel genetic resources and medicine, would have been lower than the previous two periods. Broad-leaved forest cover is high in this period, in most areas >50% coverage, and many areas up to 95% coverage (Fig. 12). A lot of fodder, wild foods, timber, wood fuel genetic resources and medicine would have been obtained from this LCT during this period. During the Roman Iron Age woodlands in the south cover limited areas. Burning is used to open up and keep the landscape open (Eriksson & Cousins, 2014). This explains the low conifer forest cover and reducing broad-leaved forest cover seen in the south in this study during this period. Later at the time the Roman Empire collapses, leading to reforestation of large areas (Berglund, 2003). These forests spread south again taking over the previously agricultural areas. In this study this is seen for conifer forest but not so much for broad-leave forest. People would have gone back to old ways of foraging in the forests for wild foods and using them as outfields for cattle.

Shrub cover is relatively low during this period, ranging from 0 up to max 5% (small pockets) coverage (Fig. 13). Not a lot of ES would have been obtained from this LCT during this period. High open land cover (up to 70%) is found in the south in Skåne and coastal areas of Blekinge in this period, and in the north in the Viking Period (Fig. 14). Inland areas have a medium range cover (20-25%). These high coverage areas would have provided a lot of livestock, fodder, wild foods, biomass, and genetic resources during this period. Stabling of livestock starts in the Pre-Roman Iron Age. This is around the coasts and in the south (as see in this study). This It is an efficient way to collect manure. Late in the Roman Iron Age grasslands are mostly used as hay-meadows for livestock (Eriksson & Cousins, 2014).

Arable land cover is relatively low (0-1%) over most of the study site for this period, providing little in terms of ES (Fig. 15). During the Migration Period there is a period of rapid cooling, causing agriculture to retreat, such as pasturing and cultivation of crops (Berglund, 2003), which might explain the low arable land cover in this study for much of this period. In the Viking Period the climate becomes warmer and drier (Medieval Warm Epoch, Northwest Europe). Around this time new areas are cleared for colonization and expanding of settlements and agriculture, with permanently cultivated land areas (Berglund, 2003). In this study arable land cove increases in parts of the north in the Viking Period.

Bronze Age 2400 to 3500 BP

Conifer forest is at a low coverage for this time period (Fig. 11). Between 0 and 15% at the start and 0-5% everywhere at the end, providing little in terms of ES. In the early Bronze Age forest structure and composition over much of South-West Sweden was impacted largely by Bronze Age activity (Hannon et al., 2018). Forests were initially opened up to improve grazing with cultivation then becoming more important (Lindbladh, 1999). Around ca. 3000 BP forest cover was estimated as below 40% (Eriksson & Cousins, 2014). However, from the results in this study it appears that the low conifer forest cover was more to do with high broad-leaved forest cover. Mixed deciduous forest are still the dominant forest type in this time period (Björkman and Bradshaw, 1996). Broad-leaved forest is high (80-90%) in this study in most parts for this time period (Fig. 12), providing a lot of fodder, wild foods, timber, wood fuel genetic resources and medicine.

Shrub cover is at a low level in this time period, mostly 0-3% everywhere, providing little in terms of ES, again most likely attributed to the high broad-leaved forest cover (Fig. 13). Open land is at a low medium range (15-20%) over the whole study site for this period, with high areas of cover (up to 55%) in the south and the coasts (Fig. 14). These high coverage areas in the south and the coasts would have provided a lot of livestock, fodder, wild foods, biomass, and genetic resources during this period. At this time (late Bronze Age) wooded and semi-natural vegetation and cultivated fields are mostly found in outer hummocky and coastal zones (Berglund, 1988). Manure from livestock was used to fertilize fields to increase crop yields at this time. These crops would have then outcompeted wild plants (Eriksson & Cousins, 2014). These cultivation practices would still have been restricted to southern Skåne and coastal areas of Halland and Blekinge. However, it was starting to move inwards (Berglund, 2003). There was no suitable data for arable land for this period (Fig. 15), implying low pollen levels for this LCT and hence low ES. However, in this case as the literature says otherwise it may have just been poor quality data rather than low pollen counts.

Neolithic Period 3500 to 6000 BP

Conifer forest has a low to medium range of cover (0-15%) in this period, mostly in the north (Fig. 11). The south and coasts have low cover (0-5%). This LCT would have also provided little in terms of ES in this period but would have been a low level source of fodder, wild foods, timber, wood fuel genetic resources and medicine in the north. Broad-leaved forest is at a high level (85-100%) over the whole study site for this period (Fig. 12), providing a lot of fodder, wild foods, timber, wood fuel genetic resources and medicine. Shrub cover is at a lower range (1-2%) over the whole study site for this period (Fig. 13), again providing little in terms of ES. Open land cover is at a low cover (0-5%) in the south and the coasts, and a 15-35% range in the middle and northern parts (Fig. 14). In the south little to no ES would have been provided in this period, but in the more northern parts low levels of livestock, fodder, wild foods, and biomass would have been available. There is low cover (0-1%) for arable land over the whole study site (Fig. 15), providing little in terms of ES.

The climate had started to cool in this period (Imbrie et al., 1992), and it's a starting point of records of human-induced vegetation changes and expansion of the open landscape (Eriksson & Cousins, 2014). Mainly coastal areas are utilized still at this stage (Berglund, 2003). Both events led to fluctuations in plant populations (Marquer et al., 2014), although other factors such as plant diseases could have affected vegetation composition changes (Berglund et al., 1991). These events are not really observed in this study. The only indication of such events is the lower conifer forest cover in the south of the study site.

Mesolithic Period 6000 to 9000 BP

Conifer forest cover is mostly found in central inland areas (5-15%), and in the north (2-25%) in this period (Fig. 11). These parts would have provided an increasing amount of fodder, wild foods, timber, wood fuel genetic resources and medicine in this period and going further back in time. Broad-leaved forest cover is high (80-90%) over the whole study area for this period (Fig. 12), providing a lot of fodder, wild foods, timber, wood fuel genetic resources and medicine. Shrub cover is high (4-5%) in the south and along the coasts but lower elsewhere for this period (Fig. 13). In these areas shrub cover would have provided livestock, wild foods, wood fuel, biomass and genetic resources during this period. Open land cover is low (0-25%) over the whole study site for this period, with the highest areas in the north (Fig. 14). In the north low levels of livestock, fodder, wild foods, biomass, and genetic resources would have been available from this LCT. There was no suitable data for arable land for this period (Fig. 15), implying low pollen levels for this LCT and hence low ES.

This was a time of low human impact and population density around the Baltic catchment (Kuosmanen et al., 2018), and a maximum extent of forest cover (e.g. Fyfe et al., 2015; Marquer et al, 2017). Initial pioneers would have arrived in the south to a land filled with broad-leaved forest, with some conifer forests in the north (Jönköping). Various shrubs would have been found around the coastal areas.

According to the literature the development of the agrarian society in Sweden was stepwise, dependent on the level of technology, and societal needs, and interactions with these and the ecological capacity. Climate here played a fundamental role (Berglund, 2003). A warm period between 8000-5500BP enabled a time of maximum forest cover (Fyfe et al. 2015). Conversely a cooling due to declining summer insolation and or disease such as elm disease opened up these forests, allowing newly arrived human populations to more easily start agricultural practices (Berglund et al. 1991). Humans kept these forests open by slashing and burning them, and created a mosaic landscape of fields, meadows and managed semi-open woodlands. Which expanded and contracted in some part due to climate change but for the most part due to the collapsing of civilizations and or outbreaks of human diseases (Eriksson & Cousins, 2014). In modern times human disease epidemics were generally under control, and with the industrial revolution hay-meadows were not so in demand for work horses. Then the forests were replanted after farmers were instructed to do so, rather than naturally returning due to favourable conditions (Eriksson & Cousins, 2014).

5.3 How sustainable has the past land use been?

Human population estimates for Earth are predicted to be 8-12 billion people in the next century, with some studies anticipating a declining trend afterwards due to environmental degradation (Okuducu & Aral, 2017). Is there information in past land-use that can help in preventing us coming to this point of no return?

Human desire for ES creates a pressure on the land that may lead to altered land cover, land-use, and / or altered ecosystem structure and functioning (Potschin & Haines-Younget, 2011). From the results of this study it is clear that human land-use throughout the Holocene had a major impact on land cover. At first it was sustainable in the Mesolithic and Neolithic Periods (Fig. 11-15), with only the most southern and coastal areas of forest cover being converted into open land for livestock and crops, with the interiors continuing to have dense forest cover. Then by the end of the Bronze Age conifer forest cover drops dramatically over the whole study site (Fig. 11) for grazing and cultivation, with large areas of open land in today’s Skåne and along the coasts for human use, spreading inland (Fig. 14).

In the Iron Age burning of forests is used to further open up the landscape. Hay-making and stabling of livestock develops with a subsequent expansion of open land (Fig. 14). Arable land cover also increases (Fig. 15), with now permanently cultivated areas providing food for many people. Later the Roman Empire collapses and the Migration Period begins, coupled with a period of rapid cooling. This causes agriculture to retreat and forest cover to expand once more (Fig. 11-15), requiring people to forage for wild foods again. This is until the climate changes to warmer times in the Viking Period, with subsequent expansion of open and arable land (Fig. 14 & 15), and contraction of broad-leaved forest cover (Fig. 12) for timber production.

The climate changes to cooler conditions in the Medieval Period. Broad-leaved trees are cut down at an increasing rate for ship building, which is seen in this study (Fig. 12). Agriculture intensifies (starts in the north in TW 8 (550BP)), until a cold period and during the time of the Black Death (Fig. 14 & 15). However, in general the structure and composition of the landscape and vegetation is fairly stable with heathland, grassland and patchy woodland from here until the 18th century (Fig. 11-15). This all changes with the onset of the agricultural revolution in the Industrial Period. There is a large increase in arable land in TW 4 (Fig. 15, 150BP). With advances in technology comes great expansion in agriculture and a time of food aplenty. From 50 - 0 BP forest grazing is banned and forests are replanted. By the present time forest cover is 70% of the land cover (also the highest conifer cover in all TW's (Fig. 11) and broad-leaved forest is increasing again in TW1 (Fig. 12). Arable land is found in more confined areas such as Skåne and along the coastal regions (Fig. 15). This is connected to further efficiencies in cultivation practices.

With a trend of increasing global temperatures, it is envisaged that forests will keep expanding with or without human influence, providing the ecosystem services and their goods attributed to this LCT for some time to come. This mostly applies to arctic regions and areas of higher altitudes rather than Götaland though. Additionally, conditions will be increasingly favourable for arable land cover and the goods that go with this LCT such as crops. This all assumes that there will be no repeat of the Little Ice Age at the end of the Medieval Period, no major outbreaks of tree species disease like the elm disease in 3100BC (or spruce bark beetles that threaten todays monoculture spruce forests), or indeed no major human disease outbreaks like the Black Death in medieval times to put an end to or greatly reduce our agricultural practices. Whether or not more agricultural land is required in southern Sweden is a question for decision makers there.

5.4 Issues associated with the methods trialled for interpolating past land cover

Although only one method was finally chosen, there are a number of issues associated with each of the interpolation methods trialled. Starting with the deterministic methods: Global polynomial interpolation surfaces are hard to attribute physical meaning to, the more complex the polynomial, and the surfaces are highly susceptible to outliers, especially at the edges. Local polynomial interpolation is sensitive to the neighbourhood distance, and when using a small searching neighbourhood empty areas may be created in the predicted surface. Inverse distance weighting makes the assumption that the phenomenon being modelled is driven by local variation that can be modelled by defining an adequate search neighbourhood. This study started with 45 pollen records spread out across Götaland. And the plan was to use them all to create LCT maps of the past of the same area as the 2012 CORINE data map. They even included the relative source area of pollen (RSAP) in meters for each location for each TW. It basically means if the RSAP is 1000m for a particular location for arable land for e.g. TW8, then for 1000m around this location in TW8 it was most likely arable land at a certain coverage in all directions. The deterministic interpolation method Inverse distance weighted (IDW) has the option to plug in this information in the form of a search radius field. However, as the pollen records are so few and far between, maps with 45 little circles of vegetation coverage are produced and not much in-between. Nielsen et al. (2012) used IDW with a search radius of 110km. This resulted in maps with general trends and regional differences, and doesn't represent the true vegetation composition at specific points in the landscape. Therefore to be as accurate as possible by using the RSAP information and e.g. IDW, then thousands of pollen records spread across Götaland are required. But that is not economically feasible. Or if it was it would take a lot of time to take the sediment cores and process the fossil pollen. The whole point of interpolation is to avoid this as much as possible and work with much smaller data sets. Radial basis functions interpolations are inappropriate when large changes in the surface values happen over short distances or the sample data is prone to measurement error or uncertainty. With the pollen data having so few points over a large area the former might not have been a problem but the data itself was not always of the best quality.

For the geostatistical methods: Empirical Bayesian kriging takes a lot longer to perform than other kriging methods. There are a number of models available which are difficult to choose from, each with their advantages and disadvantages. Some being they are less flexible to data that don't have a trend present. For ordinary kriging it is assumed that the unknown mean is a constant. This is one of the main issues when using this method. Also when the samples are further away the worse the estimation and the variance does not measure the uncertainty of estimation that the local variable produces. For simple kriging the assumption that you will know the exact mean is often unrealistic. If this assumption does not hold the kriging might be bad. For universal kriging you model the errors to be autocorrelated. However, there is no way to decide based on the data alone on the proper decomposition. For indicator kriging the unknown population of indicator values are continuous at a constant value of either 0 or 1 i.e. every point x in the space being estimated has an indicator value of either 0 or 1. However, variogram computation and kriging equations make no use of this property, instead treat the indicator as if it were a measure on a continuous interval scale. Probability kriging tries to exploit the extra information in the original data on top of the binary variable. The problem with this is you have to do much more estimation, including estimating the autocorrelation for each variable and their cross-correlation, which introduces more uncertainty. Disjunctive kriging needs to use the bivariate normality assumption and other approximations. These assumptions are hard to verify, and their solutions are computationally and mathematically complicated.

The simple kriging with cokriging with arcsin transformation method finally used in this study may have a number of limitations, mostly inherent in the data (see following uncertainties section), but it did produce visually very good maps in fine detail. Pirzamanbein et al. (2014) used a rather similar approach in terms of model selection. The maps were created by combining maps of REVEALS model data and simulated potential vegetation using LPJ-GUESS. Coniferous, broad-leaved forest and open land was mapped for three TWs in the past. Cross-validation was used first, and then deviance information criteria (something that would have made this study less subjective) and finally visually comparing the most recent map (50BP) with present day land cover data compiled from the European Forest Institute. While reconstructed vegetation cover on a European wide scale going back 6000 years was produced, the maps are very blocky, it is hard to see finer details in vegetation cover changes, and shrubs or arable land were not looked at, like in this study. However, their results were for a larger region and used process based simulations to aid in the interpolation methods. The outcome of which might have been the best that could be done at that scale using the available data. Zanon, et al (2018), used the Modern Analog Technique (MAT), to map forest cover in Europe over the Holocene. This method couples modern pollen samples with corresponding satellite-based forest-cover data, and then performs fossil reconstructions with fossil pollen samples by assigning the average forest cover of its closest modern analog to them. Unlike the Pirzamanbein et al. (2014) study the maps produced were smooth. However, they have the same cover for half or whole countries and only for forest cover. No other LCT maps were produced like in the study in this master's thesis or in such fine detail.

5.5 Sources of uncertainty

Uncertainties in the Landscape Reconstruction Algorithm reconstruction

The pollen records used in this study are from sites found in the EPD (plus the LANDCLIM dataset and other researchers). The number of sites in each country is not particularly high (Fig. 2).

Southern Sweden actually has a higher concentration than many other locations though. Brewer et al. (2017) plotted the percentage of pollen for different taxa at sites in Europe using all the points in the database. These plots were of individual taxa rather than LCTs, and they did not create interpolated surfaces, using instead circles of abundance around the pollen sites. They do make a good point in their conclusions, in that new sites are constantly being added to the EPD. As such any maps created with EPD data are moving targets. Likewise it is the same with the maps in this study. If new sites with new information are added, the maps can be updated and become more accurate. The aim in this study was to get the pollen records as close as possible by the only means available i.e. working with a smaller area. No pollen records were omitted, the layer boundary was set to only include the five counties, cutting off any areas outside. There were only 4 pollen records outside these 5 counties. But the interpolated area between them and the rest of the records would have been the least accurate in terms of reconstructed vegetation coverage.

Longer term perspectives can give a more accurate picture of a systems natural state when compared to short term environmental data (Pogue et al., 2015). At present there are a limited number of studies creating sub-continental scale reconstructions of land cover on Holocene time scales (Fyfe et al. 2015; Trondman et al., 2016; Marquer et al., 2017; Roberts et al., 2018; Zanon et al., 2018). For those that do exist and those that are being created, they need to be as accurate as possible to be able to make valid connections in the past and well informed decisions and predictions for the future such as for land management, restoration and conservation strategies (Pogue et al., 2015). An issue with the pollen records was that the further you go back in time the less information was available. For example at TW1, 32 pollen records had information for all five LCTs. But at TW44 only 12 records contained any information. This is to do with disturbed sedimentation accumulation at certain times. It is not often the case where continuous sedimentation occurs over the entire Holocene at a fossil pollen site. Also at some TWs some LCTs had no pollen at all at any of the 45 locations. For example with arable land it’s possible that the plant species that make up that land cover type just weren’t around during that TW. Or the fossil pollen sites might have been located close to forests preventing arable land pollen reaching the lake catchment. The fact that in TW1 only 32 out of 45 pollen records had data is another issue. That’s 13 pollen records without data. It’s 16 for TW2, and it’s for all 25 plant taxa, so it’s not pollen species specific. This is because there were no undisturbed sediments for these time windows. Some sediment cores do not record the first time windows because the sediments have been disturbed or removed (dams or use of water) by human activities. Dating could be another issue, when no high dating resolution for the upper part of the sediment cores have been done. Either way it removes a lot of valuable information when interpolating the data and reduces the accuracy of the results.

The choice of the LRA over REVEALS or other algorithms was because local vegetation at a specific spatial scale was being explored to create maps. By using REVEALS it would have only been possible to get land cover estimates for the entire study region and not for the point estimates that are necessary to create the maps. No other methods other than LRA exist so far for this purpose using pollen data. Until better methods become available LRA is the top of the line.

Uncertainties due to the interpolation methods used

Another problem with the data was that some of the 15 TWs could not be made into interpolated surfaces for certain LCTs. This was because even though the pollen data vegetation estimates were available, the difference between these estimates was not statistically high enough between locations for ArcMap to interpolate the surface. This happened more often with shrubs and arable land than the other LCTs. The vegetation estimate values were quite low for these LCTs. However, using SKC for TW 44, which only had 12 pollen records, produced interpolated surfaces for five of the LCTs (Arable land had the same problem as mentioned at the start of this paragraph), and with RMSEs similar to or lower than for TW1 (data not shown). This shows that the SKC method is a valid method to use for lower pollen record sites from deeper in the past.

After creating the interpolated surfaces they had to be reclassified so they were comparable between LCTs and TWs. Initially 0.05 steps were chosen for the coverage classes for all 5 LCTs. But this was too broad for shrubs and arable land. No changes could be seen in coverage over the TWs at that separation. Then the steps were refined to 0.01 for these two. Changes were then possible to see over the 15 TWs. However, a number of the classes for broad-leaved forest, open land and shrubs had to be merged, as the colours were too similar to see a difference. Changes were better seen by doing this but with a loss in resolution. For shrubs and arable land the coverage was max 0.17 and 0.04. Using an even finer class range may have allowed changes in these land cover types to be seen in more detail in specific areas of the study area. But a different colour scheme would have then been required. This and the points in the previous paragraphs are considered a limitation of working with fossil pollen data with interpolation methods in ArcMap.

The value of interpolating land cover classes is also under question. These classes are categorical and not continuous like rainfall or temperature and so don't necessarily follow the same smooth and predictable gradients. Land cover is controlled by people and so just next to a grassland there might be a forest. Interpolation therefore requires many other bio-physical layers that could affect the land cover type. Simple kriging with cokriging was the interpolation method used to recreate the past land cover in this study. For cokriging an elevation layer of the study site was used as the second data set. This extra data appeared to aid greatly in producing maps similar to the 2012 CORINE land cover data maps. However, it is most likely not enough to accurately recreate past land cover for this area. Additional datasets such as soil type for example would have increased the accuracy of these maps.

Uncertainties in the comparison between CORINE data and Landscape Reconstruction Algorithm for time window 1

After narrowing down the interpolation methods from 17 to 13 based on RMSE value, the original plan was to create mixed land cover maps of all 6 LCTs for each of the 13 interpolation methods (RMSE < 0.45), and then compare these 13 mixed land cover maps statistically one by one with the 2012 CORINE data map. This would have been a sort of ensemble approach like the kind Araújo and New, (2006) used when forecasting species distributions. Doing this would have resulted in a double pronged non subjective approach to choosing the best interpolation method i.e. RMSE and percentage of land cover with the same LCT. However, an objective comparison via statistics was not possible based on the data available.

Tree species like *Betula* (birch), which produce relatively light pollen do so in very high quantities (Geburek et al., 2012). Geburek measured temporal pollen patterns in 12 tree genera over 17 years and found *Betula* to be the highest pollen producer by far, producing 60 times more pollen than *Larix*, and 25 times more than *Fagus*. Like in the study by Geburek et al., (2012), *Betula sp.* fossil pollen in this master's thesis study swamped all other pollen types. However, removing this taxa created maps that looked only marginally like the 2012 CORINE data maps, and led to other issues by removing species from a LCT. The LRA data was provided as it was. No training was given in that modelling technique nor was it within the scope of this thesis to produce that data, so the data was used as it was i.e. *Betula sp.* was included. Given more time and training on preparing the data, it may have been possible to make it more suitable for statistical comparisons with the 2012 CORINE land cover data. For example the *Betula sp*. data should be further processed to more accurately represent percentage land cover for this tree species. However, as it was all 13 interpolation methods had to be visually compared with the 2012 CORINE LCT data, which made it a somewhat subjective process.

Even if the ensemble approach did work, the TW that represented 'present time' covered the period from 1950 to 2010. Lots of changes to land cover and to land-use occurred over that 60 year time period. After the Second World War the number of farms were drastically reduced and a general abandonment of low productive arable fields and pastures was initiated, most being replaced with conifer forest for timber production (Eriksson and Cousins, 2014). A perfect match between the CORINE data and the TW1 data could therefore not be expected. As such statistical validation would have been heavily influenced by uncertainties associated with land cover changes. Therefore a visual comparison between interpolated surfaces and LCT data, although subjective, was regarded to be sufficient.

Uncertainties in the ecosystem service assessment approach

The ecosystem services data collected for this study and to create the assessment matrix of present time are taken from work by Burkhard et al (2009) and an EEA Technical Report (EEA, 2013). No assessment of the study site has been made with onsite samples in this study. The CORINE land cover data is relatively recent (2012), however, it has a coarse resolution of several hundred meters and so does not represent conditions on a local scale. Therefore, only general patterns can be discussed and not local site data. This can lead to a somewhat globalisation of the data, which can be considered as bad and good. In this type of study, it is advisable that supplementary case study-specific land cover / type and ecosystems should be integrated to represent particular circumstances at the individual study site (Burkhard et al, 2009).

Some cover categories that might be important as ESs were not taken into account in this study, i.e. sea and ocean. This needs to be kept in mind because this means that in the past humans have used other natural resources other than the ones being discussed here. Only the natural resources from land are being considered.

In order to make the land cover data comparable between present and past TWs, the LCTs were simplified, and this simplification affects mostly land-use categories. This is mainly because in pollen data only Arable and Open land are categories for agriculture, farming crops etc. Pollen data cannot go into more detail for land-use related to open land. However, tree plantation can be identified in pollen data, such as Spruce and Pine plantations from the last century. Nothing can be done about this issue, it just needs to be kept this in mind when discussing the results. Note that the land-use simplification further reduces the numbers of ESs related to land-use.

Not all ESs for each of the past TWs could be reviewed in this Master project, it would have been too time consuming, and a close collaboration with an archaeologist would have been needed. A TW-dependent assessment matrix would have been good. This could be for future studies (perspectives).

Ultimately the assessment matrix used in this thesis was not the most useful of tools. It could be used to inform local decision makers where concentrations of certain ES categories were in the study site in 2012, but as it was not used for past TW's it had limited function for comparison purposes. Unless it can be applied to the past too, the visual interpretation of ES per LCT for the 2012 CORINE data maps was just as good.

5.6 Future work

With land cover data available for five LCTs at 15 TWs going back to 7250BP up until present, down to the county level scale, researchers and stakeholders in those 5 counties can use this data to make much more informed decisions. For example if they want to restore an area for conservation purposes back to the original forests of the warm period in the early Holocene, or even just before the lakes and wetlands were drained in the modern period. The temporal scale can help decision makers to know what the "natural" vegetation is in the case that they want to preserve the natural state of forest or an area. The maps can provide a location of the area that would be the most suitable for this conservation purpose. However, as it is LCTs and not individual taxa, the land cover is made up of a mix of those taxa. It is possible to redo the work with maps for each of the 25 taxa if that is so required. Maps for all 25 plant taxa using the method in this study can be created and so not limit the work to LCTs, specifically for trees. This might give information for forest management. Indices of plant diversity and of compositional changes as well as the rate of vegetation change can be estimated and provide additional data in terms of how much vegetation has changed over the last thousand years and how fast those changes have occurred. Local vegetation evenness could also be calculated from the abundances of the 25 taxa provided by the LRA approach to assess the major trends of change in plant diversity.

Additionally independent climate data such as the ECHAM climate data provided by the Max-Planck-Institute/University of Wisconsin-Madison Earth System Model (MPI/UW EMS), which is simulated mean annual temperature and precipitation estimates (Mikolajewicz et al., 2007), could be rescaled to achieve spatial compatibility with the LRA reconstructions. The temporal resolution can be averaged to fit the time windows used for the LRA reconstructions. This would allow a more accurate, less subjective evaluation on how the climate has affected land cover over the Holocene. Climate data as well as land-use estimates (based on simulations and/or archaeological/historical data) can be used to quantify the degree of human influence on plant resources and how much vegetation is still responding to climate today. These additional analyses would have extended the project too long, and so were not possible to have in the scope of this master thesis. This thesis is however the foundation for that work to build on from. The maps created in this study are the first generation, and more sophisticated maps using additional datasets and more advanced statistical approaches can be used in the future to get more accurate maps.

6. Conclusion

Climate change and human impact play an important role in the sustainability and development of ecosystems over temporal and spatial scales. The aim of this study was to evaluate spatial changes in land cover in southern Sweden, through a long-term perspective and the related ecosystem services, to determine how land cover may change in the study site going forward and what ecosystem services can be expected for society, and how best to manage that land cover to get the most ecosystem services for the benefit of future societies. As such a number of questions were asked, the answers to which are as follows:

1) What is the current land cover in Götaland?

The present-day map of Götaland created in this study showed the main land cover types to be forest (63%), arable land (19%), and water bodies (11%).

2) What is the most appropriate interpolation method for recreating past land cover with fossil pollen data converted into vegetation estimates with the Landscape Reconstruction Algorithm (LRA)?

Simple kriging (a geostatistical method), with cokriging had the lowest RMSE values for 3 out of 6 LCTs. Using an arcsine transformation with this interpolation method produced the most visually comparable land cover maps to the 2012 CORINE data land cover maps.

3) How much have plant resources (land cover) changed through time and location in the study site?

Forest cover was high in the Mesolithic and Neolithic periods. In the Bronze Age forest cover was reduced greatly, to return in the Iron Age but not to complete cover like earlier periods. Broad-leaved forests were brought down to low levels from the medieval period up until present time were it increases again. Conifer forest cover gets to low levels in medieval times but increases again up until its highest levels in present time. Shrub cover had the opposite pattern to broad-leaved forest where when broad-leave forest cover was high shrub cover was low and vice-versa. Open land cover was low in the Mesolithic and Neolithic periods. It starts to increase in the Bronze Age, mainly along the coasts. This cover fluctuates from high to low in different counties in the Iron Age and becomes high in the Medieval and Modern periods. At the end of the Modern period, and into the present time levels become similar to the Bronze Age. Arable land cover is very low in the Neolithic and only really starts to increase at the end of the Iron Age, and mostly in the north. Levels get high at the beginning of the Modern Period and then reduce to lower levels, with most arable land found around the coasts in the present time.

4) How much have temporal and spatial changes in plant resources (land cover) affected the services offered to societies, including the ES found today in the study site?

Forests provide fodder, wild foods, timber, wood fuel, genetic resources and medicine in terms of ES. These would have been readily available in the Mesolithic and Neolithic periods. In the Bronze Age a lot of trees were felled in the study region and these resources would have been rarer as a result. In the Iron Age and Medieval period due to new agricultural practices these ES were not as high as the early periods but due to climate change and human diseases affecting human activities they never got that low. In the modern period due to the industrial revolution forest cover was greatly reduced, lowering the ES from this land cover substantially. In the present time many forests were planted for timber production and the ES from this LCT skyrocketed. Shrubs provide live stock, wild foods, wood fuel, biomass and genetic resources as ES. These were high along the coasts in the Mesolithic period but low up until the end of the Medieval period over the whole study site. Forest cover is greatly reduced from here until the present time allowing shrubs to spread increasing the ES available from this LCT. Open land provides livestock, fodder, wild foods, biomass and genetic resources. These were in low supply up until the Bronze Age when human start to have an impact on the land, opening it up. The areas with the most open land cover are in the south and coasts and in the north. Civilization does not advance much in the Iron Age and Medieval period, and it is not until the end of the Medieval period and start of the modern period that the whole study site starts to be opened up by human activities. Here a lot of ES is available from this LCT. In present time most of the study site is again forest cover, and so ES from open land is again low. Arable land cover provides crops, livestock, fodder, wild foods, timber, wood fuel, biomass, genetic resources and medicine in terms of ES. Agricultural practices did not have much of an impact on the study site up until the end of the Iron Age, providing little in terms of ES from this LCT. At the end of the Iron Age many farms are found in the north providing lots of ES. This doesn’t change much for the Medieval period, but in the modern period technological advancements allowed much more food to be produced on less land, and a sustained favourable climate allowed human progress to continue unhindered. In the present time much less land is needed to feed the population, and so the main areas of arable land are found around the coasts where most of the ES from this LCT is. An assessment matrix for Götaland in 2012 determined that all three forest types (conifer, broad-leaved, and mixed forest) provide the most ES value in terms of goods, and that arable land and water bodies also have high values.

5) How is aim 4 important for today’s ecosystem service management?

With the trend of increasing yearly average global temperatures, based on what has happened in the past, conditions will become even more favourable for forest cover with or without human influence, providing the ecosystem services and their goods attributed to this LCT for some time to come. Additionally, conditions will be increasingly favourable for arable land cover and the goods that go with this LCT such as crops, with land area being the limiting factor.

The maps created in this study largely concur with what other studies have shown during the Holocene in Southern Sweden, and gave more detail in terms of changes in particular locations. Breaking up the study region up into five counties: Blekinge, Halland, Jönköping, Kronoberg and Skåne allowed the changes in land cover from mid Holocene to present time to be seen down to county scale. The method used in this study has a number of limitations mostly attributed to the fossil pollen data. Many pollen record locations did not have any information for the TWs and some that did had poor quality data. With this being said, the EPD is always adding more pollen sites to its database. With more data points with good quality information, the maps created in this study would have been even more representative of past land cover. However, as it is, it is one of the few studies with such high resolution land cover for the area studied. Key moments in human history were mapped in fine detail land cover change, and some changes not documented were also seen, which require further interpretation. The method can also be used with individual plant taxa and not just the five land cover types used if required, and coupling it with simulated climate data will open up the study area to even finer details of past land cover.

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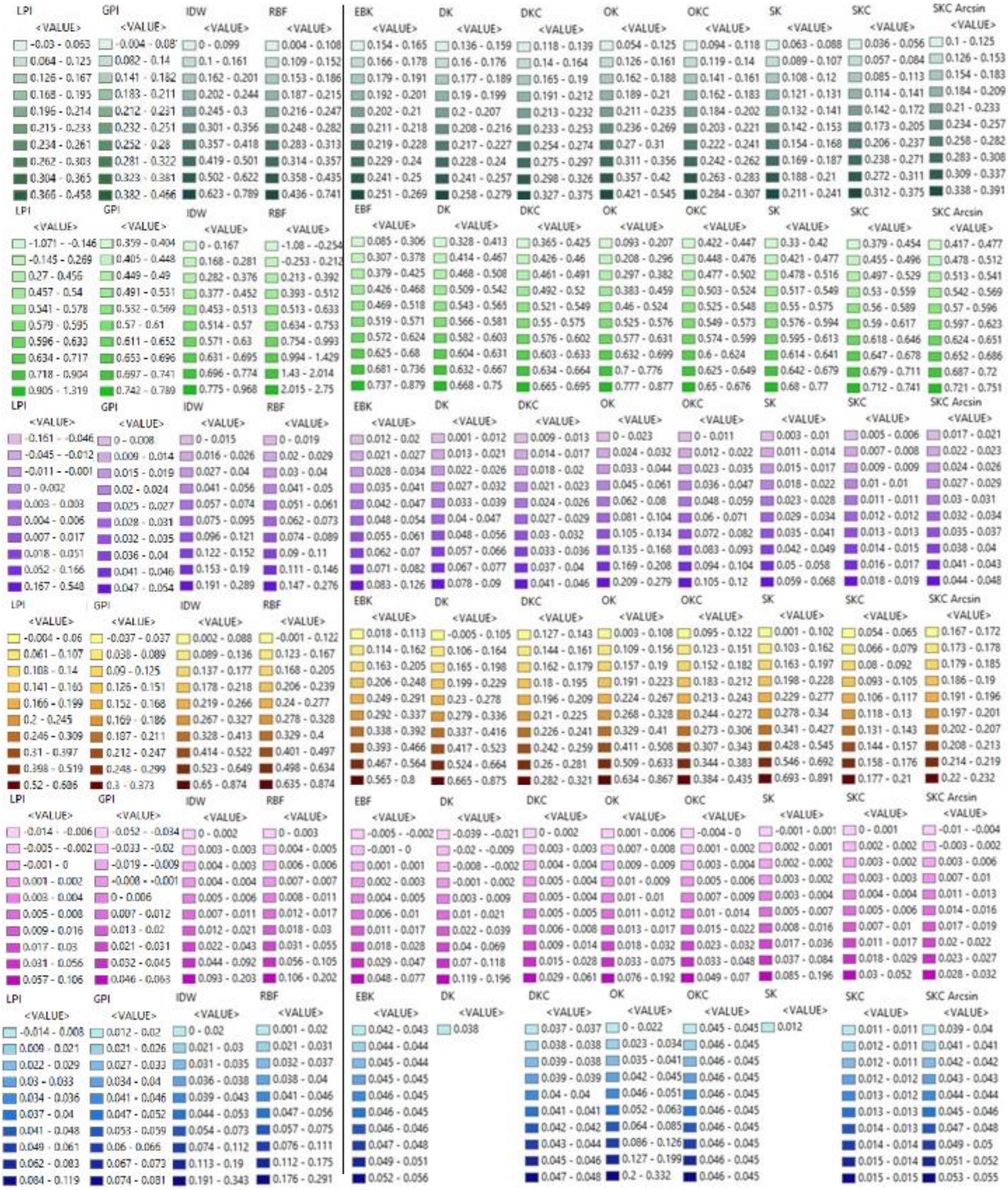
8. Appendix

Table A1 *Step by step instructions of how to use the deterministic and geostatistical interpolation methods in the geostatistical analyst tool in ArcMap.*

Deterministic methods
Global polynomial interpolation In the deterministic methods section global polynomial interpolation was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Local polynomial interpolation In the deterministic methods section local polynomial interpolation was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Inverse distance weighted In the deterministic methods section inverse distance weighted was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. The maximum and minimum neighbours values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Radial basis functions In the deterministic methods section radial basis functions was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. The maximum and minimum neighbours values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Geostatistical methods
Empirical Bayesian kriging In the geostatistical methods section empirical bayesian kriging was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. The maximum and minimum neighbours values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Disjunctive kriging In the geostatistical methods section disjunctive kriging was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. In the window Kriging step 2, for Kriging Type disjunctive kriging was selected. In the searching neighbourhood window the maximum and minimum neighbours values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Indicator kriging In the geostatistical methods section indicator kriging was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. In the window Kriging step 2, for Kriging Type disjunctive kriging

was selected. In the searching neighbourhood window the maximum and minimum neighbours values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Ordinary kriging In the geostatistical methods section ordinary kriging was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. In the window Kriging step 2, for Kriging Type disjunctive kriging was selected. In the searching neighbourhood window the maximum and minimum neighbour's values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Probability kriging In the geostatistical methods section probability kriging was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. In the window Kriging step 2, for Kriging Type disjunctive kriging was selected. In the searching neighbourhood window the maximum and minimum neighbour's values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Simple kriging In the geostatistical methods section disjunctive kriging was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. In the window Kriging step 2, for Kriging Type disjunctive kriging was selected. In the searching neighbourhood window the maximum and minimum neighbour's values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.
Universal kriging In the geostatistical methods section disjunctive kriging was selected. Next in input Data for the Data Field, each LCT from the TW 1 shapefile was selected in turn. The mean value was used for handling the coincidental sample points. In the window Kriging step 2, for Kriging Type disjunctive kriging was selected. In the searching neighbourhood window the maximum and minimum neighbour's values were both set to 41 to cover all fossil pollen record sites. No other settings were changed. Next was pressed until the final window and the Root-Mean-Square value recorded before pressing finish to create the surface.

***Table A2**. Vegetation coverage scales for interpolation methods in figure 10. Left = deterministic methods, Right = geostatistical methods. LPI = local polynomial interpolation. GPI = global polynomial interpolation. IDW = inverse distance weighted. RBF = radial basis functions. EBK = empirical bayesiann kriging. DK = disjunctivie kriging. DKC = disjunctive kriging with cokriging. OK = ordinary kriging. OKC = ordinary kriging with cokriging. SK = simple kriging. SKC = simple kriging with cokriging. SKC Arcsin = simple kriging with cokriging using arcsin transformation.*



LPI	GPI	IDW	RBF	EBK	DK	DKC	OK	OKC	SK	SKC	SKC Arcsin
<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>
-0.03 - 0.063	-0.004 - 0.08	0 - 0.099	0.004 - 0.108	0.154 - 0.165	0.136 - 0.159	0.118 - 0.139	0.054 - 0.125	0.094 - 0.118	0.063 - 0.088	0.036 - 0.056	0.1 - 0.125
0.064 - 0.125	0.082 - 0.14	0.1 - 0.161	0.109 - 0.152	0.166 - 0.178	0.16 - 0.176	0.14 - 0.164	0.126 - 0.161	0.119 - 0.14	0.089 - 0.107	0.057 - 0.084	0.126 - 0.153
0.126 - 0.167	0.141 - 0.182	0.162 - 0.201	0.153 - 0.186	0.179 - 0.191	0.177 - 0.189	0.165 - 0.19	0.162 - 0.188	0.141 - 0.161	0.108 - 0.12	0.085 - 0.113	0.154 - 0.183
0.168 - 0.195	0.183 - 0.211	0.202 - 0.244	0.187 - 0.215	0.192 - 0.201	0.19 - 0.199	0.191 - 0.212	0.189 - 0.21	0.162 - 0.183	0.121 - 0.131	0.114 - 0.141	0.184 - 0.209
0.196 - 0.214	0.212 - 0.231	0.245 - 0.3	0.216 - 0.247	0.202 - 0.21	0.2 - 0.207	0.213 - 0.232	0.211 - 0.235	0.184 - 0.202	0.132 - 0.141	0.142 - 0.172	0.21 - 0.233
0.215 - 0.233	0.232 - 0.251	0.301 - 0.356	0.248 - 0.282	0.211 - 0.218	0.208 - 0.216	0.233 - 0.253	0.236 - 0.269	0.203 - 0.221	0.142 - 0.153	0.173 - 0.205	0.234 - 0.257
0.234 - 0.261	0.252 - 0.28	0.357 - 0.418	0.283 - 0.313	0.219 - 0.228	0.217 - 0.227	0.254 - 0.274	0.27 - 0.31	0.222 - 0.241	0.154 - 0.168	0.206 - 0.237	0.258 - 0.282
0.262 - 0.303	0.281 - 0.322	0.419 - 0.501	0.314 - 0.357	0.229 - 0.24	0.228 - 0.24	0.275 - 0.297	0.311 - 0.356	0.242 - 0.262	0.169 - 0.187	0.238 - 0.271	0.283 - 0.308
0.304 - 0.365	0.323 - 0.381	0.502 - 0.622	0.358 - 0.435	0.241 - 0.25	0.241 - 0.257	0.298 - 0.326	0.357 - 0.42	0.263 - 0.283	0.188 - 0.21	0.272 - 0.311	0.309 - 0.337
0.366 - 0.458	0.382 - 0.466	0.623 - 0.789	0.436 - 0.741	0.251 - 0.269	0.258 - 0.279	0.327 - 0.375	0.421 - 0.545	0.284 - 0.307	0.211 - 0.241	0.312 - 0.375	0.338 - 0.391

LPI	GPI	IDW	RBF	EBF	DK	DKC	OK	OKC	SK	SKC	SKC Arcsin
<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>
-1.071 - -0.146	0.359 - 0.404	0 - 0.167	-1.08 - -0.254	0.085 - 0.306	0.328 - 0.413	0.365 - 0.425	0.093 - 0.207	0.422 - 0.447	0.33 - 0.42	0.379 - 0.454	0.417 - 0.477
-0.145 - 0.269	0.405 - 0.448	0.168 - 0.281	-0.253 - 0.212	0.307 - 0.378	0.414 - 0.467	0.426 - 0.46	0.208 - 0.296	0.448 - 0.476	0.421 - 0.477	0.455 - 0.496	0.478 - 0.512
0.27 - 0.456	0.449 - 0.49	0.282 - 0.376	0.213 - 0.392	0.379 - 0.425	0.468 - 0.508	0.461 - 0.491	0.297 - 0.382	0.477 - 0.502	0.478 - 0.516	0.497 - 0.529	0.513 - 0.541
0.457 - 0.54	0.491 - 0.531	0.377 - 0.452	0.393 - 0.512	0.426 - 0.468	0.509 - 0.542	0.492 - 0.52	0.383 - 0.459	0.503 - 0.524	0.517 - 0.549	0.53 - 0.559	0.542 - 0.569
0.541 - 0.578	0.532 - 0.569	0.453 - 0.513	0.513 - 0.633	0.469 - 0.518	0.543 - 0.565	0.521 - 0.549	0.46 - 0.524	0.525 - 0.548	0.55 - 0.575	0.56 - 0.589	0.57 - 0.596
0.579 - 0.595	0.57 - 0.61	0.514 - 0.57	0.634 - 0.753	0.519 - 0.571	0.566 - 0.581	0.55 - 0.575	0.525 - 0.576	0.549 - 0.573	0.576 - 0.594	0.59 - 0.617	0.597 - 0.623
0.596 - 0.633	0.611 - 0.652	0.571 - 0.63	0.754 - 0.993	0.572 - 0.624	0.582 - 0.603	0.576 - 0.602	0.577 - 0.631	0.574 - 0.599	0.595 - 0.613	0.618 - 0.646	0.624 - 0.651
0.634 - 0.717	0.653 - 0.696	0.631 - 0.695	0.994 - 1.429	0.625 - 0.68	0.604 - 0.631	0.603 - 0.633	0.632 - 0.699	0.6 - 0.624	0.614 - 0.641	0.647 - 0.678	0.652 - 0.686
0.718 - 0.904	0.697 - 0.741	0.696 - 0.774	1.43 - 2.014	0.681 - 0.736	0.632 - 0.667	0.634 - 0.664	0.7 - 0.776	0.625 - 0.649	0.642 - 0.679	0.679 - 0.711	0.687 - 0.72
0.905 - 1.319	0.742 - 0.789	0.775 - 0.968	2.015 - 2.75	0.737 - 0.879	0.668 - 0.75	0.665 - 0.695	0.777 - 0.877	0.65 - 0.676	0.68 - 0.77	0.712 - 0.741	0.721 - 0.751

LPI	GPI	IDW	RBF	EBK	DK	DKC	OK	OKC	SK	SKC	SKC Arcsin
<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>
-0.161 - -0.046	0 - 0.008	0 - 0.015	0 - 0.019	0.012 - 0.02	0.001 - 0.012	0.009 - 0.013	0 - 0.023	0 - 0.011	0.003 - 0.01	0.005 - 0.006	0.017 - 0.021
-0.045 - -0.012	0.009 - 0.014	0.016 - 0.026	0.02 - 0.029	0.021 - 0.027	0.013 - 0.021	0.014 - 0.017	0.024 - 0.032	0.012 - 0.022	0.011 - 0.014	0.007 - 0.008	0.022 - 0.023
-0.011 - -0.001	0.015 - 0.019	0.027 - 0.04	0.03 - 0.04	0.028 - 0.034	0.022 - 0.026	0.018 - 0.02	0.033 - 0.044	0.023 - 0.035	0.015 - 0.017	0.009 - 0.009	0.024 - 0.026
0 - 0.002	0.02 - 0.024	0.041 - 0.056	0.041 - 0.05	0.035 - 0.041	0.027 - 0.032	0.021 - 0.023	0.045 - 0.061	0.036 - 0.047	0.018 - 0.022	0.01 - 0.01	0.027 - 0.029
0.003 - 0.003	0.025 - 0.027	0.057 - 0.074	0.051 - 0.061	0.042 - 0.047	0.033 - 0.039	0.024 - 0.026	0.062 - 0.08	0.048 - 0.059	0.023 - 0.028	0.011 - 0.011	0.03 - 0.031
0.004 - 0.006	0.028 - 0.031	0.075 - 0.095	0.062 - 0.073	0.048 - 0.054	0.04 - 0.047	0.027 - 0.029	0.081 - 0.104	0.06 - 0.071	0.029 - 0.034	0.012 - 0.012	0.032 - 0.034
0.007 - 0.017	0.032 - 0.035	0.096 - 0.121	0.074 - 0.089	0.055 - 0.061	0.048 - 0.056	0.03 - 0.032	0.105 - 0.134	0.072 - 0.082	0.035 - 0.041	0.013 - 0.013	0.035 - 0.037
0.018 - 0.051	0.036 - 0.04	0.122 - 0.152	0.09 - 0.11	0.062 - 0.07	0.057 - 0.066	0.033 - 0.036	0.135 - 0.168	0.083 - 0.093	0.042 - 0.049	0.014 - 0.015	0.038 - 0.04
0.052 - 0.166	0.041 - 0.046	0.153 - 0.19	0.111 - 0.146	0.071 - 0.082	0.067 - 0.077	0.037 - 0.04	0.169 - 0.208	0.094 - 0.104	0.05 - 0.058	0.016 - 0.017	0.041 - 0.043
0.167 - 0.548	0.047 - 0.054	0.191 - 0.289	0.147 - 0.276	0.083 - 0.126	0.078 - 0.09	0.041 - 0.046	0.209 - 0.279	0.105 - 0.12	0.059 - 0.068	0.018 - 0.019	0.044 - 0.048

LPI	GPI	IDW	RBF	EBK	DK	DKC	OK	OKC	SK	SKC	SKC Arcsin
<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>
-0.004 - 0.06	-0.037 - 0.037	0.002 - 0.088	-0.001 - 0.122	0.018 - 0.113	-0.005 - 0.105	0.127 - 0.143	0.003 - 0.108	0.095 - 0.122	0.001 - 0.102	0.054 - 0.065	0.167 - 0.172
0.061 - 0.107	0.038 - 0.089	0.089 - 0.136	0.123 - 0.167	0.114 - 0.162	0.106 - 0.164	0.144 - 0.161	0.109 - 0.156	0.123 - 0.151	0.103 - 0.162	0.066 - 0.079	0.173 - 0.178
0.108 - 0.14	0.09 - 0.125	0.137 - 0.177	0.168 - 0.205	0.163 - 0.205	0.165 - 0.198	0.162 - 0.179	0.157 - 0.19	0.152 - 0.182	0.163 - 0.197	0.08 - 0.092	0.179 - 0.185
0.141 - 0.165	0.126 - 0.151	0.178 - 0.218	0.206 - 0.239	0.206 - 0.248	0.199 - 0.229	0.18 - 0.195	0.191 - 0.223	0.183 - 0.212	0.198 - 0.228	0.093 - 0.105	0.186 - 0.19
0.166 - 0.199	0.152 - 0.168	0.219 - 0.266	0.24 - 0.277	0.249 - 0.291	0.23 - 0.278	0.196 - 0.209	0.224 - 0.267	0.213 - 0.243	0.229 - 0.277	0.106 - 0.117	0.191 - 0.196
0.2 - 0.245	0.169 - 0.186	0.267 - 0.327	0.278 - 0.328	0.292 - 0.337	0.279 - 0.336	0.21 - 0.225	0.268 - 0.328	0.244 - 0.272	0.278 - 0.34	0.118 - 0.13	0.197 - 0.201
0.246 - 0.309	0.187 - 0.211	0.328 - 0.413	0.329 - 0.4	0.338 - 0.392	0.337 - 0.416	0.226 - 0.241	0.329 - 0.41	0.273 - 0.306	0.341 - 0.427	0.131 - 0.143	0.202 - 0.207
0.31 - 0.397	0.212 - 0.247	0.414 - 0.522	0.401 - 0.497	0.393 - 0.466	0.417 - 0.523	0.242 - 0.259	0.411 - 0.508	0.307 - 0.343	0.428 - 0.545	0.144 - 0.157	0.208 - 0.213
0.398 - 0.519	0.248 - 0.299	0.523 - 0.649	0.498 - 0.634	0.467 - 0.564	0.524 - 0.664	0.26 - 0.281	0.509 - 0.633	0.344 - 0.383	0.546 - 0.692	0.158 - 0.176	0.214 - 0.219
0.52 - 0.686	0.3 - 0.373	0.65 - 0.874	0.635 - 0.874	0.565 - 0.8	0.665 - 0.875	0.282 - 0.321	0.634 - 0.867	0.384 - 0.435	0.693 - 0.891	0.177 - 0.21	0.22 - 0.232

LPI	GPI	IDW	RBF	EBF	DK	DKC	OK	OKC	SK	SKC	SKC Arcsin
<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>
-0.014 - -0.006	-0.052 - -0.034	0 - 0.002	0 - 0.003	-0.005 - -0.002	-0.039 - -0.021	0 - 0.002	0.001 - 0.006	-0.004 - 0	-0.001 - 0.001	0 - 0.001	-0.01 - -0.004
-0.005 - -0.002	-0.033 - -0.02	0.003 - 0.003	0.004 - 0.005	-0.001 - 0	-0.02 - -0.009	0.003 - 0.003	0.007 - 0.008	0.001 - 0.002	0.002 - 0.001	0.002 - 0.002	-0.003 - 0.002
-0.001 - 0	-0.019 - -0.009	0.004 - 0.003	0.006 - 0.006	0.001 - 0.001	-0.008 - -0.002	0.004 - 0.004	0.009 - 0.009	0.003 - 0.004	0.002 - 0.002	0.003 - 0.002	0.003 - 0.006
0.001 - 0.002	-0.008 - -0.001	0.004 - 0.004	0.007 - 0.007	0.002 - 0.003	-0.001 - 0.002	0.005 - 0.004	0.01 - 0.009	0.005 - 0.006	0.003 - 0.002	0.003 - 0.003	0.007 - 0.01
0.003 - 0.004	0 - 0.006	0.005 - 0.006	0.008 - 0.011	0.004 - 0.005	0.003 - 0.009	0.005 - 0.004	0.01 - 0.01	0.007 - 0.009	0.003 - 0.004	0.004 - 0.004	0.011 - 0.013
0.005 - 0.008	0.007 - 0.012	0.007 - 0.011	0.012 - 0.017	0.006 - 0.01	0.01 - 0.021	0.005 - 0.005	0.011 - 0.012	0.01 - 0.014	0.005 - 0.007	0.005 - 0.006	0.014 - 0.016
0.009 - 0.016	0.013 - 0.02	0.012 - 0.021	0.018 - 0.03	0.011 - 0.017	0.022 - 0.039	0.006 - 0.008	0.013 - 0.017	0.015 - 0.022	0.008 - 0.016	0.007 - 0.01	0.017 - 0.019
0.017 - 0.03	0.021 - 0.031	0.022 - 0.043	0.031 - 0.055	0.018 - 0.028	0.04 - 0.069	0.009 - 0.014	0.018 - 0.032	0.023 - 0.032	0.017 - 0.036	0.011 - 0.017	0.02 - 0.022
0.031 - 0.056	0.032 - 0.045	0.044 - 0.092	0.056 - 0.105	0.029 - 0.047	0.07 - 0.118	0.015 - 0.028	0.033 - 0.075	0.033 - 0.048	0.037 - 0.084	0.018 - 0.029	0.023 - 0.027
0.057 - 0.106	0.046 - 0.063	0.093 - 0.203	0.106 - 0.202	0.048 - 0.077	0.119 - 0.196	0.029 - 0.061	0.076 - 0.192	0.049 - 0.07	0.085 - 0.196	0.03 - 0.052	0.028 - 0.032

LPI	GPI	IDW	RBF	EBK	DK	DKC	OK	OKC	SK	SKC	SKC Arcsin
<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>	<VALUE>
-0.014 - 0.008	0.012 - 0.02	0 - 0.02	0.001 - 0.02	0.042 - 0.043	0.038	0.037 - 0.037	0 - 0.022	0.045 - 0.045	0.012	0.011 - 0.011	0.039 - 0.04
0.009 - 0.021	0.021 - 0.026	0.021 - 0.03	0.021 - 0.031	0.044 - 0.044		0.038 - 0.038	0.023 - 0.034	0.046 - 0.045		0.012 - 0.011	0.041 - 0.041
0.022 - 0.029	0.027 - 0.033	0.031 - 0.035	0.032 - 0.037	0.045 - 0.044		0.039 - 0.038	0.035 - 0.041	0.046 - 0.045		0.012 - 0.011	0.042 - 0.042
0.03 - 0.033	0.034 - 0.04	0.036 - 0.038	0.038 - 0.04	0.045 - 0.045		0.039 - 0.039	0.042 - 0.045	0.046 - 0.045		0.012 - 0.012	0.043 - 0.043
0.034 - 0.036	0.041 - 0.046	0.039 - 0.043	0.041 - 0.046	0.046 - 0.045		0.04 - 0.04	0.046 - 0.051	0.046 - 0.045		0.013 - 0.012	0.044 - 0.044
0.037 - 0.04	0.047 - 0.052	0.044 - 0.053	0.047 - 0.056	0.046 - 0.045		0.041 - 0.041	0.052 - 0.063	0.046 - 0.045		0.013 - 0.013	0.045 - 0.046
0.041 - 0.048	0.053 - 0.059	0.054 - 0.073	0.057 - 0.075	0.046 - 0.046		0.042 - 0.042	0.064 - 0.085	0.046 - 0.045		0.014 - 0.013	0.047 - 0.048
0.049 - 0.061	0.06 - 0.066	0.074 - 0.112	0.076 - 0.111	0.047 - 0.048		0.043 - 0.044	0.086 - 0.126	0.046 - 0.045		0.014 - 0.014	0.049 - 0.05
0.062 - 0.083	0.067 - 0.073	0.113 - 0.19	0.112 - 0.175	0.049 - 0.051		0.045 - 0.046	0.127 - 0.199	0.046 - 0.045		0.015 - 0.014	0.051 - 0.052
0.084 - 0.119	0.074 - 0.081	0.191 - 0.343	0.176 - 0.291	0.052 - 0.056		0.047 - 0.048	0.2 - 0.332	0.046 - 0.045		0.015 - 0.015	0.053 - 0.055

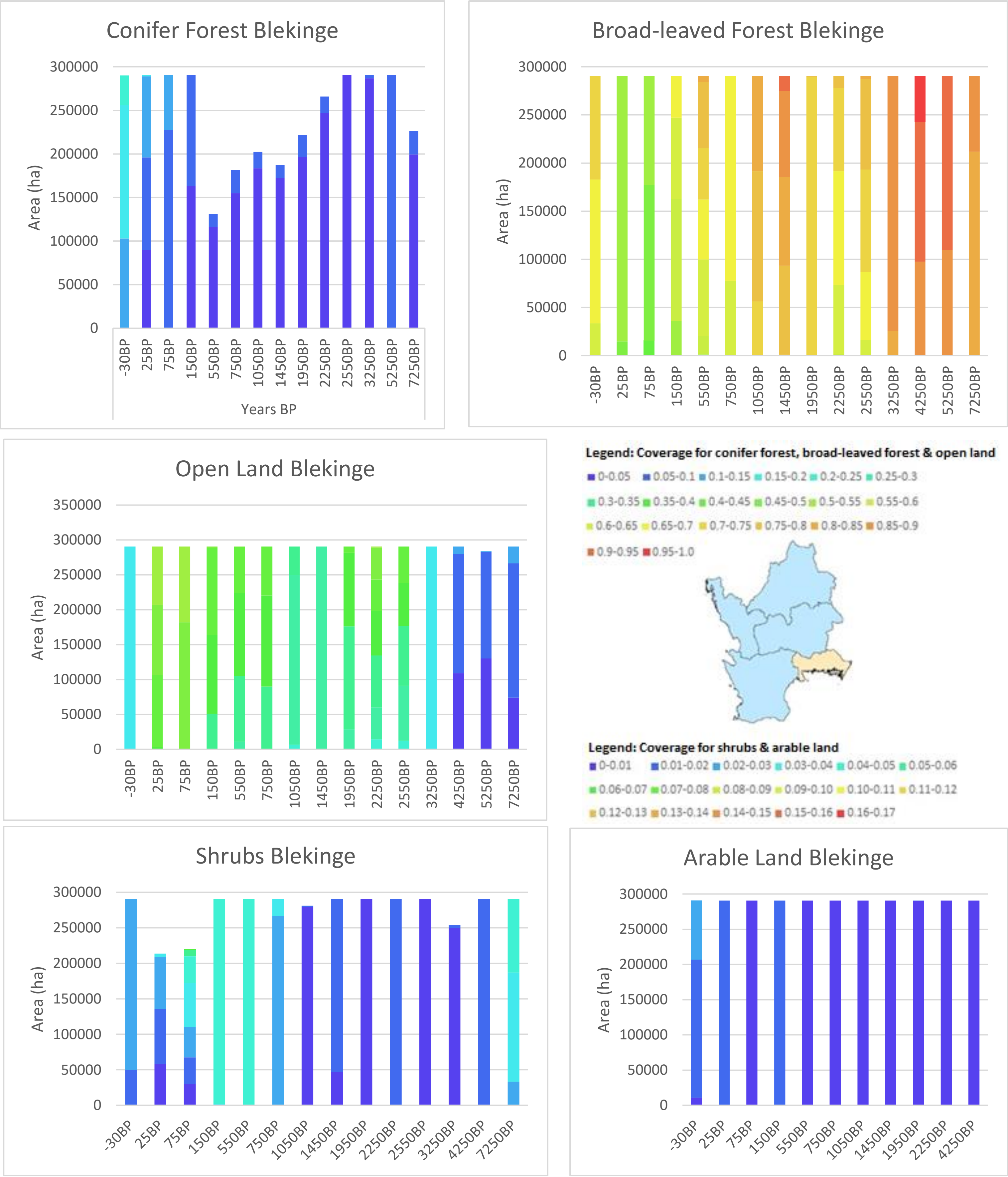


Figure A1. *Bar charts of Land cover in Blekinge, 7250BP to present. After reclassification in ArcMap, the study area was split into the five county boundaries: Blekinge, Halland, Jönköping, Kronoberg and Skåne. The coverage ranges for each class were then exported to excel and converted into bar charts.*

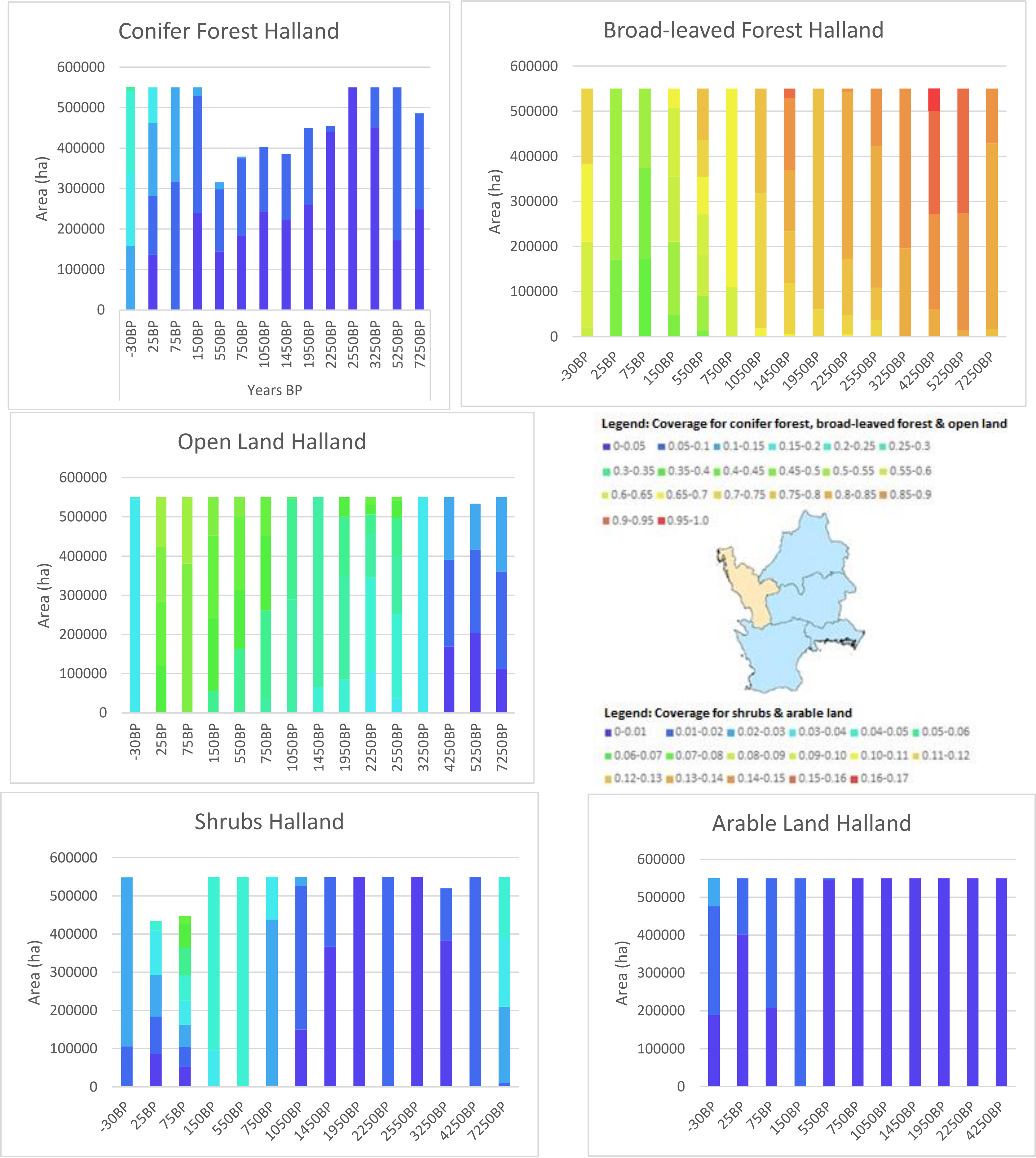


Figure A2. *Bar charts of Land cover in Halland, 7250BP to present. After reclassification in ArcMap, the study area was split into the five county boundaries: Blekinge, Halland, Jönköping, Kronoberg and Skåne. The coverage ranges for each class were then exported to excel and converted into bar charts.*

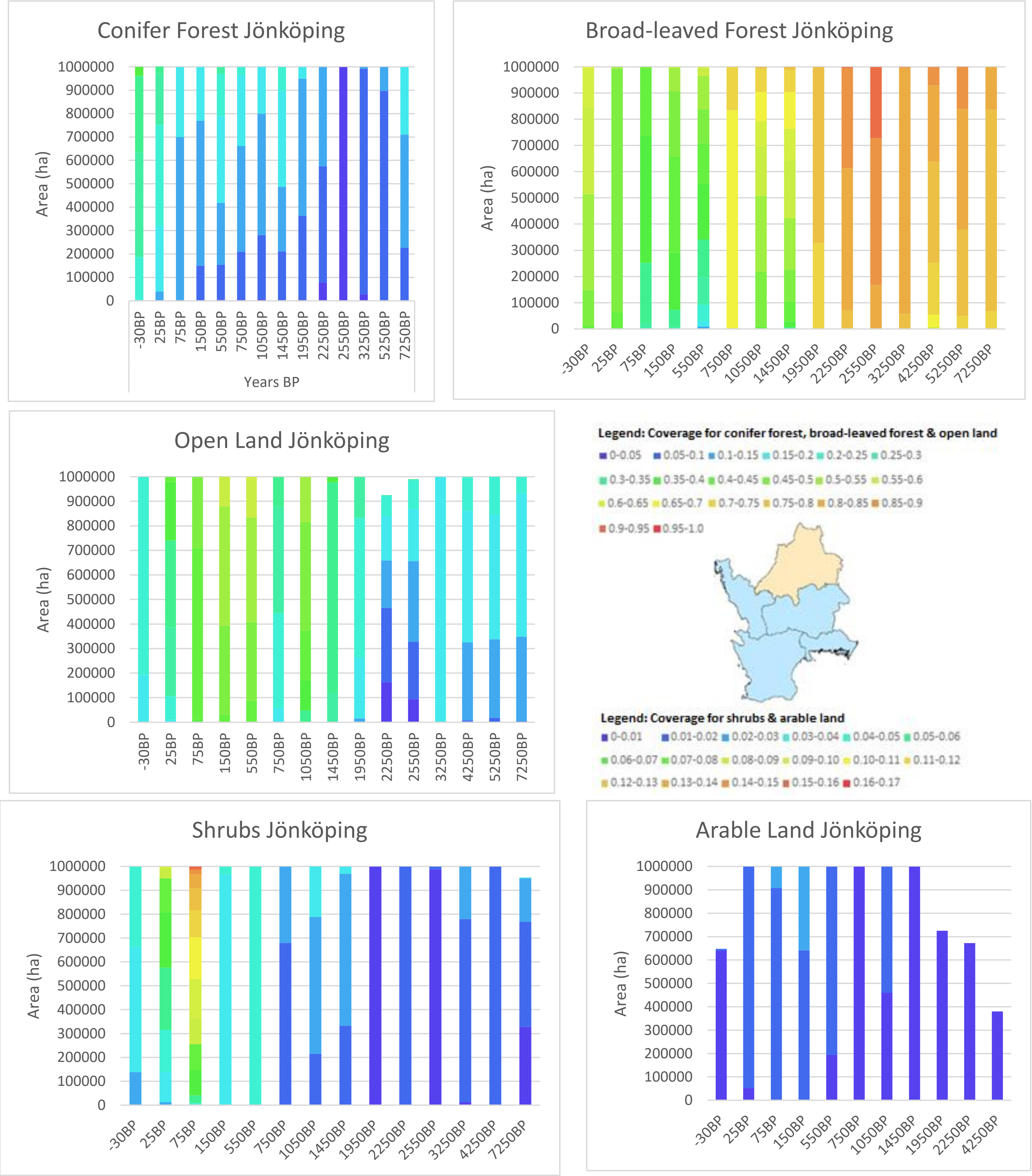


Figure A3. *Bar charts of Land cover in Jönköping, 7250BP to present. After reclassification in ArcMap, the study area was split into the five county boundaries: Blekinge, Halland, Jönköping, Kronoberg and Skåne. The coverage ranges for each class were then exported to excel and converted into bar charts.*

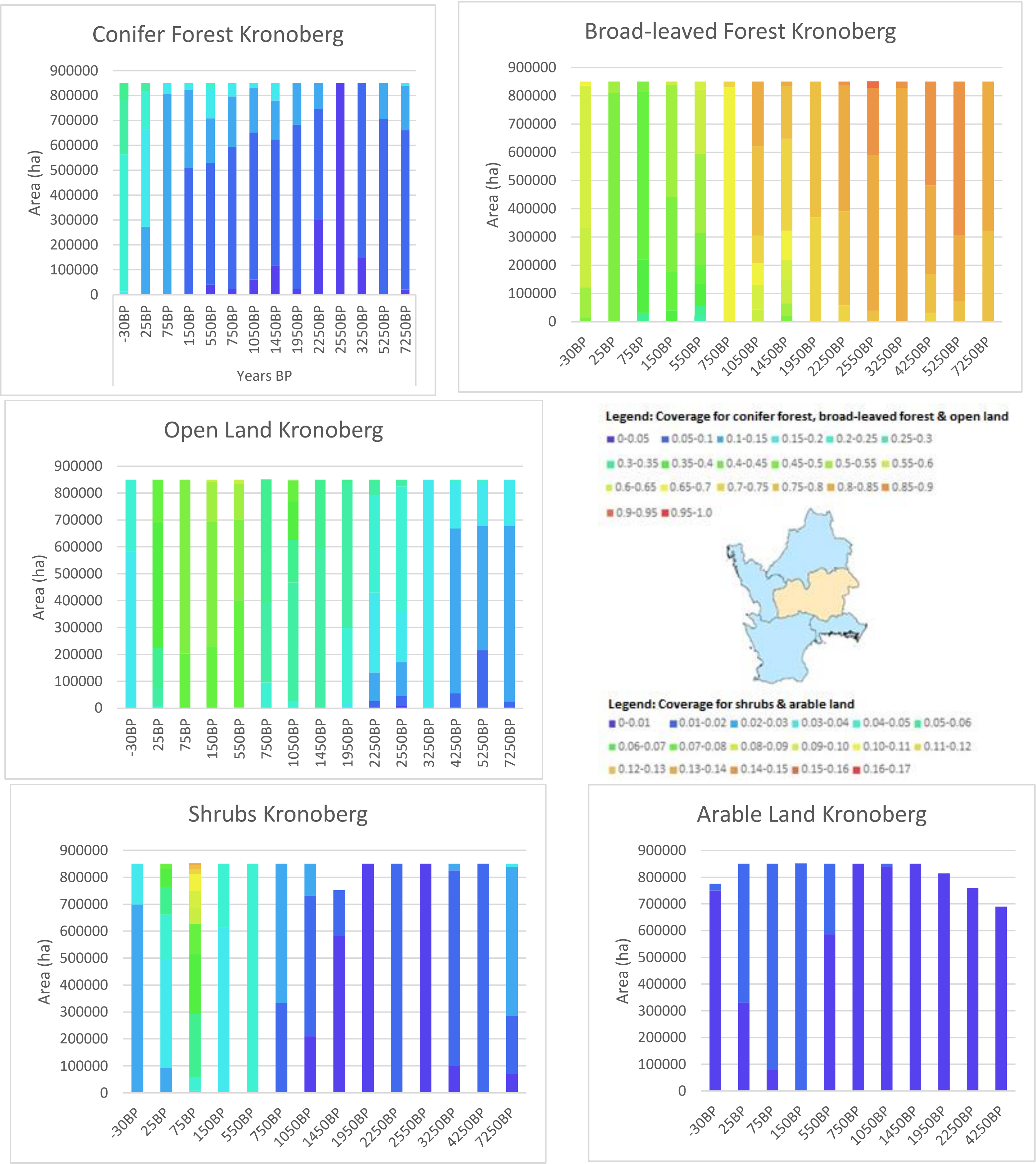


Figure A4. *Bar charts of Land cover in Kronoberg, 7250BP to present. After reclassification in ArcMap, the study area was split into the five county boundaries: Blekinge, Halland, Jönköping, Kronoberg and Skåne. The coverage ranges for each class were then exported to excel and converted into bar charts.*

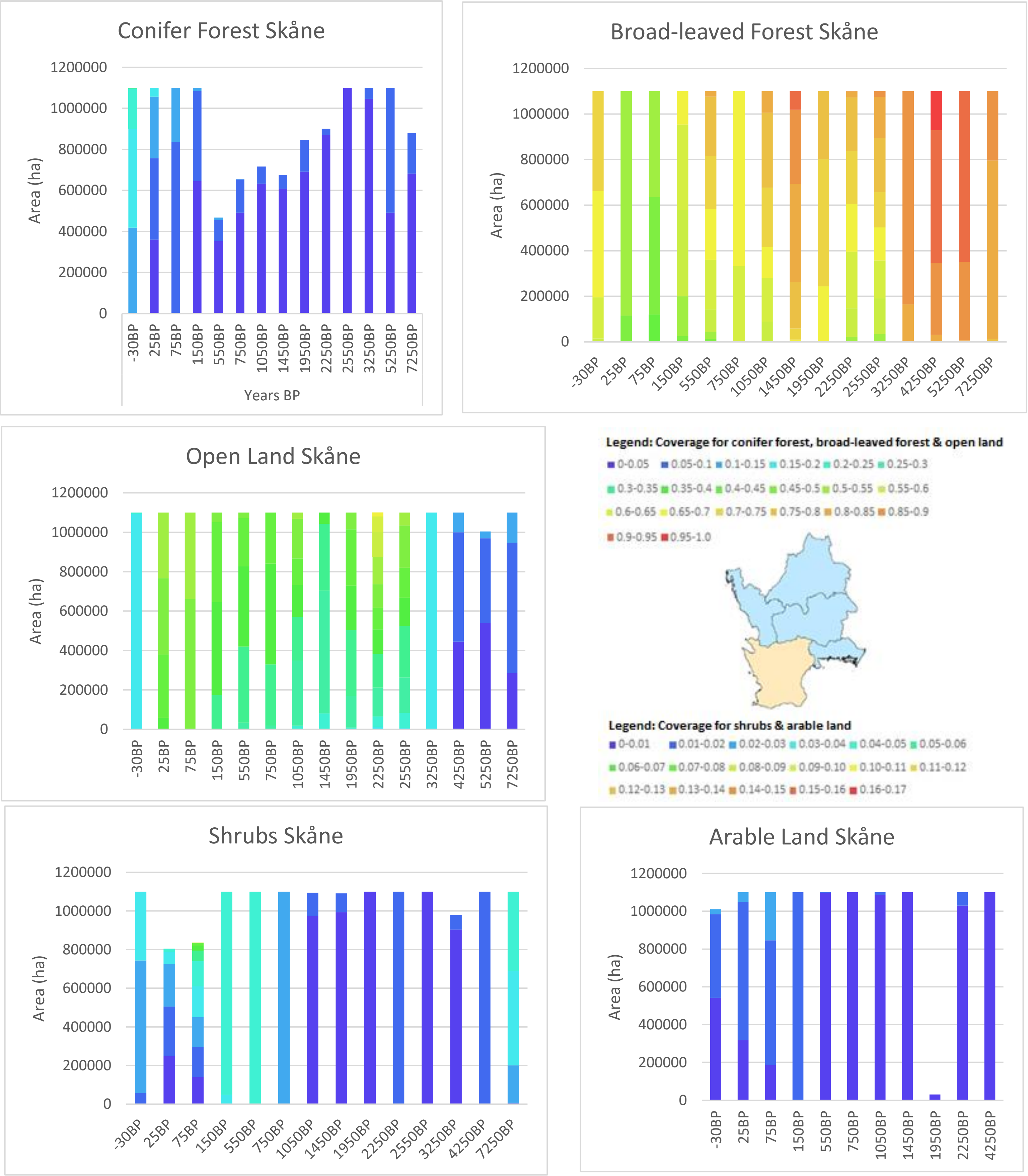
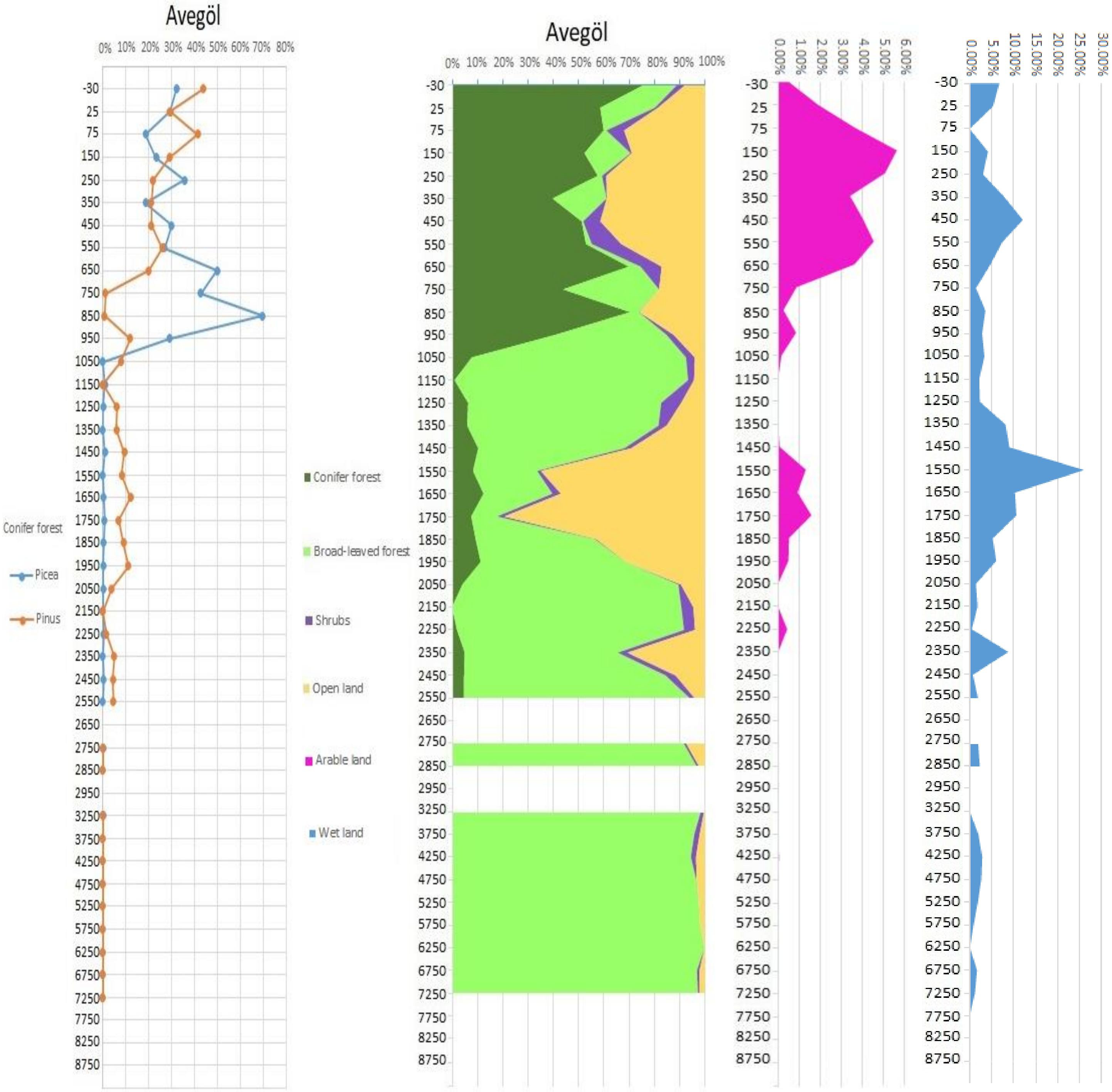


Figure A5. *Bar charts of Land cover in Skåne, 7250BP to present. After reclassification in ArcMap, the study area was split into the five county boundaries: Blekinge, Halland, Jönköping, Kronoberg and Skåne. The coverage ranges for each class were then exported to excel and converted into bar charts.*

Table A3. *Assessment matrix for the present, alternatives 2, 3 and 4. Land cover types taken from the CORINE 2012 data set that are present in Götaland were placed on the y-axis, and the ES on the x-axis. The ES were further divided into supporting, provisioning, regulating and cultural services. A value of 0 was given to a land cover type that has no relevant capacity to provide a particular ecosystem service. A value of 1 was given to a land cover type that had a capacity to provide a particular ecosystem service. Adding up the 1's for a land cover type gave its ecosystem service number. Additionally, these values were graded from 1 to 15 based on the lowest to highest ecosystem service number as an alternative grading system to see if this provided more.*

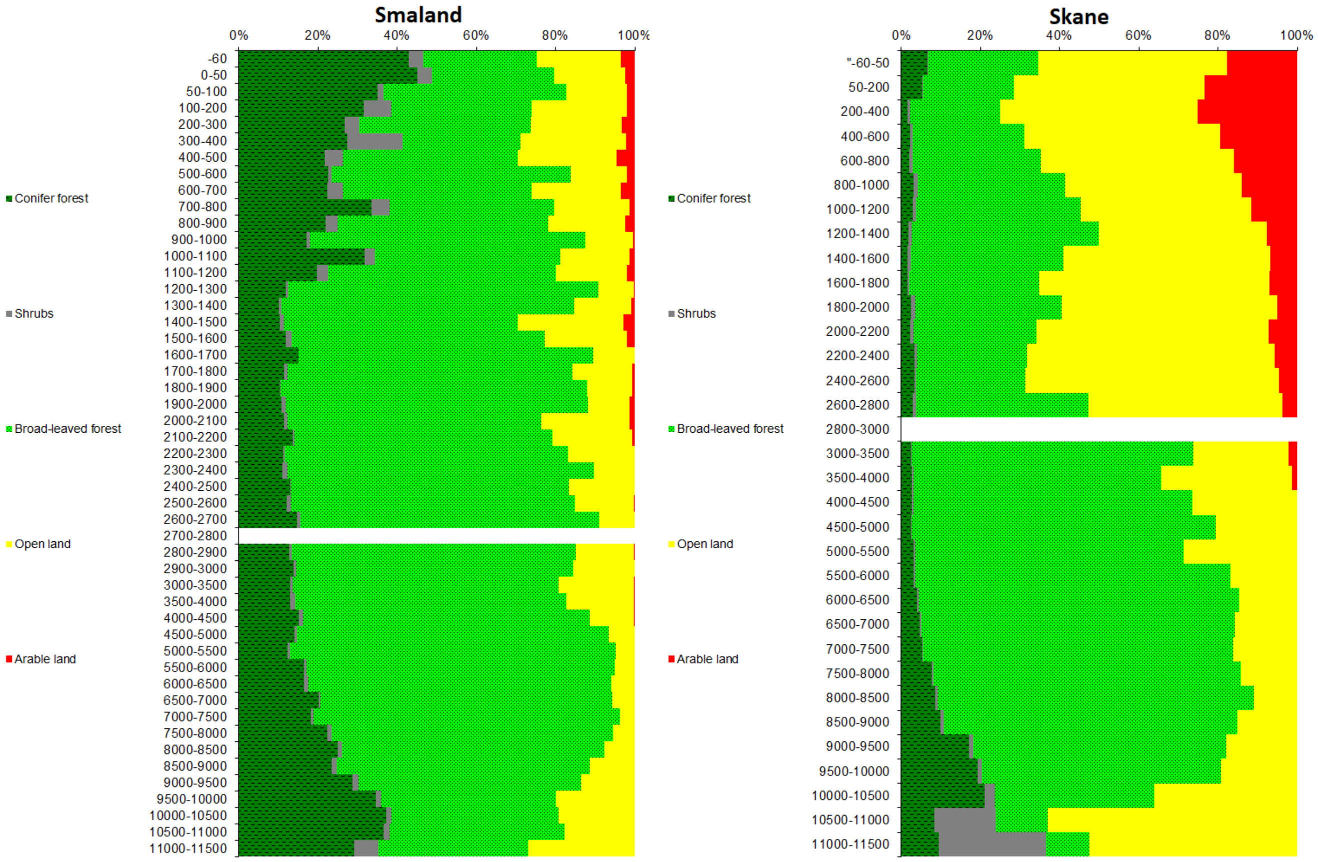
	Land Cover Type	**Provisioning services**												**ES number provisioning services**	**Regulating services**											**ES number regulating services**	**Supporting services**					**ES number supporting services**	**Cultural services**			**ES number cultural services**	**ES number for each land-cover type**	**Grade**
		Crops	Livestock	Fodder	Capture fisheries	Acquaculture	Wild foods	Timber	Wood fuel	Energy (biomass)	Genetic resources	Medicine	Fresh water		Local climate regulation	Global climate regulation	Food protection	Groundwater recharge	Air quality regulation	Erosion regulation	Nutrient regulation	Water purification	Pollination	Carbon sequestration and storage	Moderation of extreme events		Abiotic heterogeneity	Biodiversity	Genetic diversity	Exergy capture (radiation)	Reduction of nutrient loss		Recreation and tourisim	Aesthetic appreciation and inspiration for culture, art and design	Intrinsic value of biodiversity			
Alternative 2	Little or no vegetation	0	0	0	0	0	0	0	0	1	0	0	0	**1**	1	0	1	1	0	0	0	1	0	0	0		1	1	0	1	1		1	1	1		**13**	**1**
	Pastures	0	1	1	0	0	0	0	0	0	1	0	0	**3**	1	1	1	1	0	1	0	0	0	0	0		1	1	0	1	1		0	1	0		**13**	**2**
	Transitional woodland-shrub	0	1	0	0	0	1	0	1	0	1	0	0	**4**	1	0	0	0	0	0	0	0	1	1	0		1	1	1	1	1		1	1	1		**19**	**3**
	Natural grasslands	0	1	0	0	0	1	0	0	0	1	0	0	**3**	1	1	1	1	0	1	1	1	0	0	0		1	1	1	1	1		1	1	1		**21**	**4**
	Permanent crops	1	0	0	0	0	0	1	1	0	1	0	0	**4**	1	1	1	1	1	1	1	1	1	1	0		1	1	0	1	1		0	1	0		**23**	**5**
	Urban areas	1	0	1	0	0	1	0	1	0	0	0	0	**4**	1	1	1	1	1	1	1	1	1	0	0		1	1	0	1	1		1	1	0		**23**	**5**
	Wetlands	0	1	1	0	0	0	0	0	1	1	0	0	**4**	1	1	1	1	0	0	1	1	1	1	1		1	1	1	1	1		0	1	1		**24**	**6**
	Moors and heathland	0	1	0	0	0	1	0	1	1	1	0	0	**5**	1	1	1	1	0	0	1	1	1	1	0		1	1	1	1	1		1	1	1		**26**	**7**
	Water bodies	0	0	1	1	1	1	0	0	1	1	0	1	**7**	1	1	1	1	0	0	1	1	0	1	0		1	1	1	1	1		1	1	1		**29**	**8**
	Arable land	1	1	1	0	0	1	1	1	1	1	1	0	**9**	1	1	1	1	1	1	0	1	0	1	0		1	1	1	1	1		1	1	1		**34**	**9**
	Mixed forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**9**
	Broad-leaved forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**9**
	Coniferous forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**9**
	Number of land-cover types for individual goods	1	4	6	1	1	8	3	6	4	8	3	1		10	8	9	9	4	5	8	9	7	7	4		10	10	8	10	10		9	10	9		**202**	
Alternative 3	Little or no vegetation	0	0	0	0	0	0	0	0	1	0	0	0	**1**	1	0	1	1	0	0	0	1	0	0	0		1	1	0	1	1		1	1	1		**13**	**1**
	Transitional woodland-shrub	0	1	0	0	0	1	0	1	0	1	0	0	**4**	1	0	0	0	0	0	0	0	1	1	0		1	1	1	1	1		1	1	1		**19**	**2**
	Urban areas	1	0	1	0	0	1	0	1	0	0	0	0	**4**	1	1	1	1	1	1	1	1	1	0	0		1	1	0	1	1		1	1	0		**23**	**3**
	Grassland	0	1	1	0	0	1	0	0	0	1	0	0	**4**	1	1	1	1	0	1	1	1	0	0	0		1	1	1	1	1		1	1	1		**23**	**3**
	Wetlands	0	1	1	0	0	0	0	0	1	1	0	0	**4**	1	1	1	1	0	0	1	1	1	1	1		1	1	1	1	1		0	1	1		**24**	**4**
	Moors and heathland	0	1	0	0	0	1	0	1	1	1	0	0	**5**	1	1	1	1	0	0	1	1	1	1	0		1	1	1	1	1		1	1	1		**26**	**5**
	Water bodies	0	0	1	1	1	1	0	0	1	1	0	1	**7**	1	1	1	1	0	0	1	1	0	1	0		1	1	1	1	1		1	1	1		**29**	**6**
	Broad-leaved forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**7**
	Mixed forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**7**
	Coniferous forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**7**
	Arable land	1	1	1	0	0	1	1	1	1	1	1	0	**9**	1	1	1	1	1	1	1	1	1	1	0		1	1	1	1	1		1	1	1		**36**	**8**
	Number of land-cover types for individual goods	1	4	7	1	1	8	3	6	4	8	3	1		10	8	9	9	4	5	8	9	7	7	4		10	10	8	10	10		9	10	9		**203**	
Alternative 4	Open land	0	1	1	0	0	1	0	0	1	1	0	0	**5**	1	1	1	1	0	1	1	1	0	0	0		1	1	1	1	1		1	1	1		**25**	**2**
	Wetlands	0	1	1	0	0	0	0	0	1	1	0	0	**4**	1	1	1	1	0	0	1	1	1	1	1		1	1	1	1	1		0	1	1		**24**	**2**
	Shrubs	0	1	0	0	0	1	0	1	1	1	0	0	**5**	1	1	1	1	0	0	1	1	1	1	0		1	1	1	1	1		1	1	1		**26**	**3**
	Broad-leaved forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**4**
	Mixed forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**4**
	Coniferous forest	0	0	1	0	0	1	1	1	0	1	1	0	**6**	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1		**31**	**4**
	Arable land	1	1	1	0	0	1	1	1	1	1	1	0	**9**	1	1	1	1	1	1	1	1	1	1	0		1	1	1	1	1		1	1	1		**36**	**5**
	Number of land-cover types for individual goods	0	3	5	0	0	5	3	4	3	6	3	0		6	6	6	6	3	4	6	6	5	5	4		6	6	6	6	6		5	6	6		**136**	

Figure A6 *LOVE modelled profile of pollen site Avegöl in Småland.as a) times series for conifer forest species Picea and Pinus and b) area charts of four LCTs: conifer forest, broad-leaved forest, shrubs and open land, and arable land and wet land (shown separately). Blank spaces for TWs represent areas with no pollen counts available.*



a) **b)**

Figure A7 *REVEALS modelled profiles for two lakes in Småland and Skåne consisting of five LCTs: conifer forest, shrubs, broad-leaved forest, open land and arable land. Arable land cover is contained within open land cover, so it is not a true representation of 100% land cover. Blank spaces for TWs represent areas with no pollen counts available.*



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