Dataset of 1-km cropland cover from 1690 to 1999 in Scandinavia

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Abstract

~~High resolution~~Spatially explicit historical land cover datasets are essential not only for simulations of climate and environmental dynamics but also for projections of future land use, food security, climate, and biodiversity. However, widely used global datasets are developed for continental-to-global scale analysis and simulations and ~~. The~~their accuracy ~~of global datasets~~ depends on the verification of more regional reconstruction results. This study collected cropland area data of each administrative unit (~~Parish~~parish/~~Municipality~~municipality/~~County~~county) in Scandinavia from multiple ~~-~~sources. The cropland area data ~~was~~ were validated, calibrated, interpolated, and allocated into 1 km × 1 km grid cells. Then, we developed a dataset with spatially explicit cropland area from 1690 to 1999. Results indicated that the cropland area increased from 1.82 million ha to 6.71 million ha from 1690 to 1950, then decreased to ~~6~~5.90 million ha in 1999. Before 1810, cropland cover expanded in southern Scandinavia and remained stable in northern Scandinavia. From 1810 to 1910, northern Scandinavia experienced slight cropland expansion, and the cropland area increased rapidly in the southern part of the study area~~. Then, it~~ before

changinggged gentlyslightly. After 1950, the cropland areas began to decrease in most regions, especially in eastern Scandinavia. When comparing global datasets with this study, although the total Scandinavia cropland area is in agreement in Scandinavia among HYDE 3.2, PJ, and this study, the spatial patterns of cropland show considerable differences, except for in Denmark between HYDE 3.2 and this study. The dataset can be downloaded from https://doi.org/10.1594/PANGAEA.926591https://doi.pangaea.de/10.1594/PANGAEA.926591 (Wei et al., 2021).

1 Introduction

The Anthropocene was has been defined as a new epoch of geologic time, partly because human-influenced land is a major component of anthropogenic global changes in the earth Earth system System (Crutzen and Stoermer, 2000; Lewis and Maslin, 2015; Crutzen and Stoermer, 2000; Verburg et al., 2016). During AD 800-_~ AD 1700, according to Pongratz et al. (2008), 5% of the area covered by natural vegetation was under human land use, compared to 44% in the following 300 years. Anthropogenic land cover change (ALCC) may have caused feedbacks to the climate system through modifying the surface roughness, surface albedo, latent heat flux, and river runoff, and through changing atmospheric CO_2 concentration (Foley et al., 2005; Pongratz et al., 2009a, 2010; Kaplan et al., 2017; Pongratz et al., 2009b; Pongratz et al., 2010; Houghton et al., 2012, 2018; Ciais et al., 2013; Yang et al., 2015; Liu et al., 2016; Kaplan et al., 2017;Ciais et al., 2013; Le Quéré et al., 2018). The conclusions of climate and environmental dynamics were all made by using highspatially-resolution explicit historical land cover datasets. Historical land cover change information is also essential as a baseline analysis for projections of future land use, food security, climate, and biodiversity (Foley et al., 2011; Hurtt et al., 2011; Foley et al., 2011; Ellis et al., 2012; Brovkin et al., 2013; Fuchs et al., 2015; Mehrabi et al., 2018; Fuchs et al., 2015).

To produce spatially explicit land cover datasets covering long periods, researchers used multiple -sources, such as satellite data, historical statistics, historical maps, and pollen records. Based on combined sources and hindcasting methods, the Center for Sustainability and the Global Environment (SAGE) (Ramankutty and Foley, 1999; Ramankutty and Foley, 2010), and the History Database of the Global Environment (HYDE) (Klein Goldewijk, 2001)

~~was~~ were produced as two representative datasets of global land use/cover. Based on SAGE and historical population data, the PJ dataset covers AD 800 ~~~~~ AD 1700 (Pongratz et al., 2008). Subsequently, ~~anthropogenic land cover change~~ALCC from 8000 BP to AD 1850 (KK10) was reconstructed (Kaplan et al., 2009~~; Kaplan et al.~~, 2011). These global datasets were widely used ~~by~~ in simulations ~~on~~ of global and regional climate change or carbon budget because of their ~~high~~ spatial resolutions and long-term coverages (Foley et al., 2005; Olofsson and Hickler, 2007; Strassmann et al., 2008; Pongratz et al., 2009b, 2010; Van Minnen et al., 2009; Arora and Boer, 2010; Hurtt et al., 2011; Kaplan et al., 2011; ~~Pongratz et al., 2010; Hurtt et al., 2011;~~ Brovkin et al., 2013; Yan et al., 2017; Zhang et al., 2017; Le Quéré et al., 2018).

However, using population data to estimate historical land use may induce large uncertainties and limitations in presenting regional scale ~~the~~ details ~~at the regional scale~~ (Klein Goldewijk and Verburg, 2013). Many regional land use reconstructions illustrated that global datasets had non-negligible~~unneglectable~~ discrepancies in reflecting ~~the~~ regional spatial land use patterns ~~of land use at the regional scale over history~~historically, especially for cropland. Historical document-based reconstructions concluded that SAGE, HYDE, and PJ had drawbacks ~~to~~ in ~~capture~~ capturing the spatial distribution of ~~the~~ historical cropland change in China (Li et al., 2010; Zhang et al., 2013; Li et al., ~~2015~~2016, 2019; Wei et al., 2019~~; Li et al., 2019~~). In the US, the HYDE maps ~~greatly~~ substantially underestimate crop density in high cropland coverage regions but overestimate it in the low-density areas ~~during~~ for 1850 ~~~~~ 2016 (Yu and Lu, 2018). Neither KK10 nor HYDE captures the fine-scale spatial pattern of open land as inferred from the pollen-based land cover reconstructions in Europe for four preindustrial time points (Kaplan et al., 2017). Uncertainties in global datasets could ~~be~~ trans~~ferred~~late into higher uncertainties in quantifying the climate and environmental effects of ALCC at both local and regional scales (Yang et al., 2018; Lejeune et al., 2018; Yu et al., 2019). Therefore, the PAGES LandCover6k and related projects aim to improve ALCC history at both regional and global scales based on empirical data (Gaillard et al., 2015a; Widgren, 2018a). Errors can be assessed or corrected using the regional quantitative reconstructed land cover data and regional agrarian history maps (Widgren, 2018b; Fang et al., 2020). ~~But~~ However, due to the lack of scrutinized and published datasets at ~~the~~ high spatial resolutions, it is impossible to reconstruct historical regional cropland change ~~at regional scales~~ in all parts of the world.

Scandinavia (~~includes~~ Sweden, Norway, and Denmark) has good historical cropland area data at the ~~Parish~~parish/~~Municipality~~municipality/~~County~~ county level. Scandinavia is located at a high latitude, and the cold climate is relatively unfavorable for crop growth. The soil suitable for cultivation is mainly distributed on the plains, around river valleys and lakes. The pollen-based reconstructions indicated that the cereal crop cover percentages ~~of cereals was~~were very high in southern Sweden and Denmark (Nielsen et al., 2012; Gaillard et al., 2015b). ~~The l~~Large forests and small agricultural land areas distinguish Scandinavia from continental Europe (Anderberg, 1991). Though arable land accounts for a small proportion of the land area, farmers ~~were~~ are historically drivers of economic and social change ~~in a long history~~ (Gadd, 2011; Jansson, 2011~~; Gadd, 2011~~). Over the past few centuries, agriculture in Scandinavia has undergone significant changes (Anderberg, 1991~~; Jansson, 2011~~; Almås, 2004; Vejre and Brandt, 2004; Jansson, 2011). During the middle of the seventeenth century, peasants ~~were the majority~~comprised most of the population, and~~. During the same period,~~ farms were scattered and close to the village (Almås, 2004; Cui, et al., 2014). The most ~~considerable~~ substantial population growth has occurred since ~~of population took place from~~ the beginning of the nineteenth century. Because of increasing food consumption, ~~the~~ technology introduction ~~of technologies~~, and land reforms, agricultural land use accelerated. The agrarian revolution altered the agricultural landscape as farms~~. Farms were~~ moved out of the villages and were ~~gathered~~ consolidated to form ~~one~~ single blocks. With the agricultural revolution, more land was cultivated~~. The~~ and arable land area expanded at the expense of meadows and through drainage projects (Jansson, 2011). Heathland was also cultivated and afforested. Sweden ~~changed~~ transformed from a ~~grain~~ grain-importing country to ~~taking~~ considering grain as one of the most important export commodities (Olsson and Svensson, 2010). In response to the intensification and specialization of agriculture and forestry during the twentieth century, land use development changed gradually. An increase in forest areas and a decrease in arable land was ~~showed~~observed.

Studies ~~on~~ of the agricultural history in Scandinavia have mainly concentrated on agricultural policy, agricultural economy, settlement and population, and landscape history (Anderberg, 1991; Olsson~~,~~ et al., 2000; Almås, 2004; Vejre and Brandt, 2004; Gustavsson~~,~~ et al., 2007; Olsson and Svensson, 2010; Jansson, 2011; Eriksson and Cousins, 2014; Levin~~,~~ et al., 2014; Jacks, 2019). However, ~~the~~ spatially explicit historical land cover data~~set~~ ~~of~~ for Scandinavia ~~was~~ are scarce. Pollen-based quantitative reconstruction of Holocene regional vegetation cover in Europe presented a 1° × 1° spatial scale dataset for climate modeling (Trondman~~,~~ et al., 2015). The agricultural land data for five Holocene time points ~~in Holocene is~~are available. To facilitate simulation studies with high-precision regional input data, Li et al. (2013) developed the ~~dataset of~~ cropland cover change dataset from 1875 to 1999 in Sweden and Norway. Materials from mainly two sources were collected, including Swedish data from the official agricultural statistics and the data provided by Norwegian Social Science Data Services (NSD). Methods of seed-cropland conversion, data interpolation and allocation, and data gridding were used to produce the cropland dataset ~~on~~ at the spatial resolution of 0.5 degrees. At present, the highest resolution of the existing historical cropland cover dataset for Scandinavia is 5′ × 5′ from HYDE 3.2 (Klein Goldewijk et al., 2017).

~~In this paper, based on the cropland datasets in Scandinavian Peninsula from 1875 to 1999 (Li et al., 2013), we extended the period to 1690-1999 by validating and integrating multi-sources data multi-sources. The spatial resolution of the dataset was improved to 1km×1km.~~ This study~~'~~'s main objective is to provide a longer historical gridded cropland ~~cover~~ dataset ~~over the period of~~for 1690~~-~~–1999 with high precision ~~and spatial resolution~~ in Scandinavia~~ from 1690 to 1999~~, by reconstructing cropland area at the parish, municipality, and county levels and allocating cropland area into 1 km × 1 km grid cells. Compared with existing datasets, our newly developed dataset of cropland cover ~~would give~~will provide more detailed information on spatial patterns of historical cropland change in Scandinavia.

2 Data sources

In this study, cropland from multiple data sources were first gathered~~ first~~ for further allocation. Meanwhile, administrative division maps and digital elevation model (DEM) data

~~are~~were also used. Land cover in ~~the year of~~ 2000 based on remote sensing methods was selected to constrain historical cropland allocation. More details are ~~following~~as follows.

2.1 Cropland data

Besides ~~the cropland data of~~ the Scandinavian Peninsula (Sweden and Norway) cropland data after 1875 provided by Li et al. (2013), the cropland data used in this study were from different sources. Data sources in this study are shown in Table 1.

For Sweden, all the data before 1875 were from the *Svensk Nationell Datatjänst* (Swedish National Data Service, termed SND, https://snd.gu.se/en/catalogue/study/SND0910). Based on tax records, historical maps, land survey records, and farmer inventories ~~of farmers~~, Palm et al. (2014) developed an agricultural database (The database Sweden 1570~~-~~–1810: population, agriculture, land ownership), which covers all parishes within ~~Sweden's~~ Sweden’s contemporary boundaries and the periods between 1570 and 1810. In SND~~'~~’s database, cropland was called ~~"~~“åker~~"~~” in Swedish, which was also used in the data sources from 1875 to 1999 in Sweden. “Å~~å~~ker” from SND included land under temporary crops, land under temporary meadows and pastures, and land ~~with~~ temporarily fallow. However, the unit of ~~"~~“åker~~"~~” in the dataset ~~recorded was~~referred to ~~the volume~~ barrels of seeds ~~used in each Parish (*Socken*) but~~and not ~~the cropland area~~hectares.

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For Norway, cropland data in 1665 and 1723 were from *Statistiske studier over folkemængde og jordbrug i Norges landdistrikter i det syttende og attende aarhundrede* (Statistical studies on population and agriculture: in the rural areas of Norway in the seventeenth and eighteenth centuries, Aschehoug, 1890). Cropland data in 1809 was from ~~the study of~~ Hovland’s study (1978). In the above two sources, the volumes of different seed types ~~of seeds~~, such as wheat, rye, barley, oat, peas, and potatoes were recorded (land under temporary crops), ~~but not the cropland area.~~ The volumes of seeds in each ~~C~~county (~~*A*~~*amt*) were presented.

For Denmark, cropland data were from multiple sources. Data in 1688 ~~was~~ were based on the *Atlas over Denmark: Historisk-Geografisk Atlas* (Atlas over Denmark: Historical-Geographic Atlas, Dam and Jakobsen, 2008). Dam and Jakobsen~~'~~’s map showed a cropland fraction of each ~~"~~“~~*Ejerlav*~~*ejerlav*~~"~~” (area under a village, a manor, or a group of single farms) in

Denmark. The cropland was called ~~"~~“*ager*~~"~~” in ~~Denmark~~Danish, ~~and it meant~~referring to the total area under crop rotation, including the lands under temporary crops, temporary meadows and pastures, and~~lands with~~ temporarily fallow land~~arable land and the fallow cropland~~. Pia Frederiksen from Aarhus University provided the cropland data ~~in~~ for 1800, 1881, and 1998, based on data developed by Jørgen Rydén Rømer, Aalborg, Bernd Münier, and Morten Stenak, Roskilde (Odgaard and Rømer, 2009). Data ~~in~~ for 1800 ~~was~~ were from the map Videnskabernes selskabs kort (VSK) in 1762-1806 and further developed from agricultural statistics. The data ~~in~~ for 1881 and 1998 were merged from maps and national statistics. They had the smallest spatial unit of ~~"~~“*~~Sogn~~sogn*~~"~~” (~~Parish~~parish). The cropland was called ~~"~~“*agerjord*~~"~~”, and it ~~can~~ could be divided into two subgroups, namely ~~"~~“*Besået areal*~~"~~” (the lands annually sown with various one-year or two-year crops) and ~~"~~“*Græs i omdrift*~~"~~” (the lands for temporary meadow or fallow before the land was again plowed ~~up~~ for sowing ~~again~~). ~~"~~“*Besået areal*~~"~~” and ~~"~~“*Græs i omdrift*~~"~~” correspond to ~~the cultivated lands under~~ temporary croplands~~land~~, and the ~~fallowed cropland~~lands with temporary meadows and temporarily fallow in 1688, respectively. The cropland area data in 1907 ~~was~~ were from *Statistisk Aarbog 1912* (Statistical Yearbook 1912, Danmarks Statistik, 1912) and its spatial resolution ~~is~~ was the ~~"~~“*~~Amt~~amt*~~"~~” (~~County~~county). The cropland area data in 1936, 1950, and 1980 were from agricultural statistics of Statistiske Meddelelser (Danmarks Statistik, 1936, 1950, and 1980). The spatial resolutions of cropland data in 1936, 1950, and 1980 ~~was~~ were the ~~"~~“*~~Amt~~amt*~~"~~” (~~County~~county), ~~"~~“*~~Amtsrådskreds~~amtsrådskreds*~~"~~” (~~County~~ county council), and ~~"~~“*~~Kommuner~~kommuner*~~"~~” (~~Municipality~~municipality), respectively. The areas under temporary crops, under temporary meadows, and temporarily fallows were listed in tables by Danmarks Statistik.

Table 1 Description of cropland data sources used in this study

Data sources	Spatial coverage	Years	Spatial Resolution	Categories included in recorded cropland	Reference
Sockenvis jordbruksstatistik	Sweden	1690,1750,1810	Parish	A, B, C (*Åker*)	SND

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Statistiske studier over folkemængde og jordbrug i Norges	Norway	1665,1723	County	A	Aschehoug, 1890
Historisk Tidsskrift	Norway	1809	County	A	Hovland, 1978
Atlas over Denmark: Historisk-Geografisk Atlas	Denmark	1688	*Ejerlav*	A, B, C (*Ager*)	Dam and Jakobsen, 2008
Danske landbrugs-landskaber gennem 2000 år	Denmark	1800, 1881, 1998	Parish	A, B, C (*Agerjord*)	Odgaard and Rømer, 2009
Statistisk Aarbog 1912	Denmark	1907	County	A, B, C, D	Danmarks Statistik, 1912
Statistiske Meddelelser 1936, 1950 and 1980	Denmark	1936, 1950, 1980	County; County council; Municipality	A, B, C, D	Danmarks Statistik, 1936, 1950 and 1980
Cropland in Scandinavian Peninsula	Sweden, Norway	1875, 1910, 1930, 1950, 1980, 1999	County/0.5-degree	Sweden: A, B, C (*Åker*) Norway: A, B, C, D, E	Li et al., 2013

Notes: A—Areas under temporary crops; B—Areas under temporary meadows and pastures; C—Land with temporarily fallow; D—Areas under permanent crops; E—Permanent grassland and meadow.

2.2 Administrative division maps

The digital version of the administrative division maps of Sweden was initially developed at the National Archives of Sweden (*Riksarkivet*). It was later revised at the Department of Human Geography, Stockholm University. Ulf Jansson kindly provided the version used here. The administrative division maps of Norway were from Norwegian Centre for Research Data (termed NSD, https://nsd.no/nsd/english/). The base maps of Denmark were downloaded from the HisKIS network (http://hiskis2.dk/?page_id=110) and Danish Geodata Agency (http://download.kortforsyningen.dk/).

2.3 Satellite-based data

Spatial explicit land cover data and digital elevation model (DEM) were also used for cropland area allocation. Remote sensingSatellite-based based land cover data in the year 2000 iswere selected as a reference to constrain the spatial distribution of historical cropland allocation. There are servalseveral well developed and widely used land cover datasets (REFSZhang, et al., 2019). The satellite-based land cover data in 2000 used in this study was were provided by the CORINE Land Cover (CLC2000, https://land.copernicus.eu/pan-european/corine-land-cover/) (Büttner, 2014REF), which has been well evaluated in EruopeEurope (Feranec, et al., 2010REF).. Although CLC1990 data isare also prioveided, only CLC2000 iscontains the earliest data covering our study region in the CLC data series. There areIt consists of an inventory of land cover in 65 main categories and 44 classes.28 secondary classificaitons. The details of CLC2000 application in our model are explained in sSection 3.2.

GlobeLand30 maps of 2000 was also used for validating our cropland datasets. The images for land cover classification of development and update of GlobeLand30 are mainly 30-meter multispectral images, including TM5 ETM+, and OLI multispectral images of Landsat (USA) and HJ-1(China Environment and Disaster Reduction Satellite). GlobeLand30 includes 10 land cover classes in total (Chen, et al., 2014).

The DEM used in this study was from the NASA Shuttle Radar Topographic Mission (SRTM, https://cgiarcsi.community/data/srtm-90m-digital-elevation-database-v4-1/) 90 m digital elevation data (DEMs).

3 Methods

There are two main steps to develop the 1 km spatial resolution gridded cropland dataset for during 1969690 to 1999. 1) OrginalOriginal multiple-source cropland areea allocated in to identical administrative unitesdata wasere collected to reconstruct the cropland area of each administrative unit. 2) Using an allocation model whichthat featured the use of remote sensing land cover data as a constraint, cropland in administrative unites were further griddedallocated into 1 km × 1 km grid cells. Multi-source cropland data was processed into

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cropland areas matched with the administrative maps from 1690 to 1999. All the cropland areas were then allocated into 1km×1km grid cells using newly developed cropland area allocation models. The flow chart of the methods is described in Figure 1.

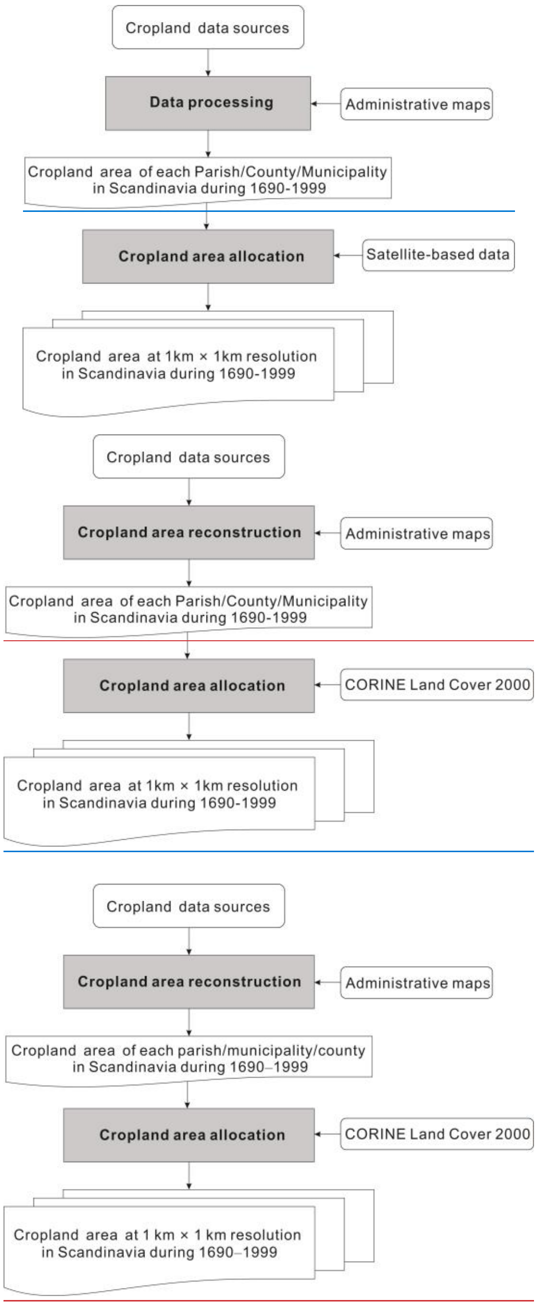
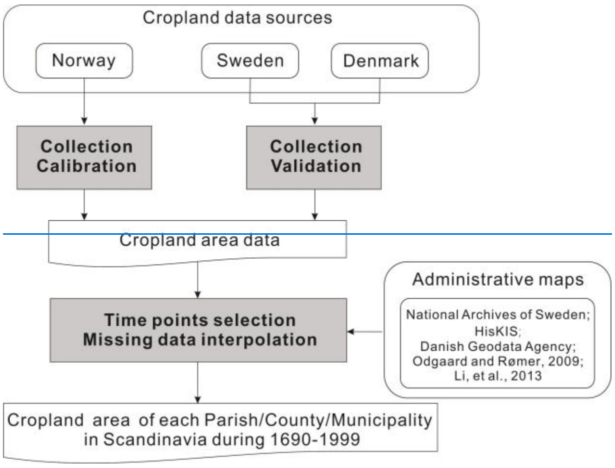


Figure 1 The fFlow chart of the methods

改：satellite-based data -> CCI CLC cropland in the year 2000

3.1 Cropland area reconstruction at the parish/municipality/ and county levels allocation into administrative unitsData processing

Based on the multiple sources, we collected cropland area data of each administrative unit parish/municipality/countyparish and county in Scandinavia from 1690 to 1999. Cropland data recorded as the volume barrels of seeds was were converted to cropland area in Sweden and Norway before 1875. By comparison comparing between statistics and census in 1999, cropland area data from statistics was were validated and calibrated. After time points selectingselection, missing data were interpolated, and the cropland area of each administrative unitat the parish/municipality/countyparish and county levels in Scandinavia from 1690 to 1999 was developed (Figure 2).



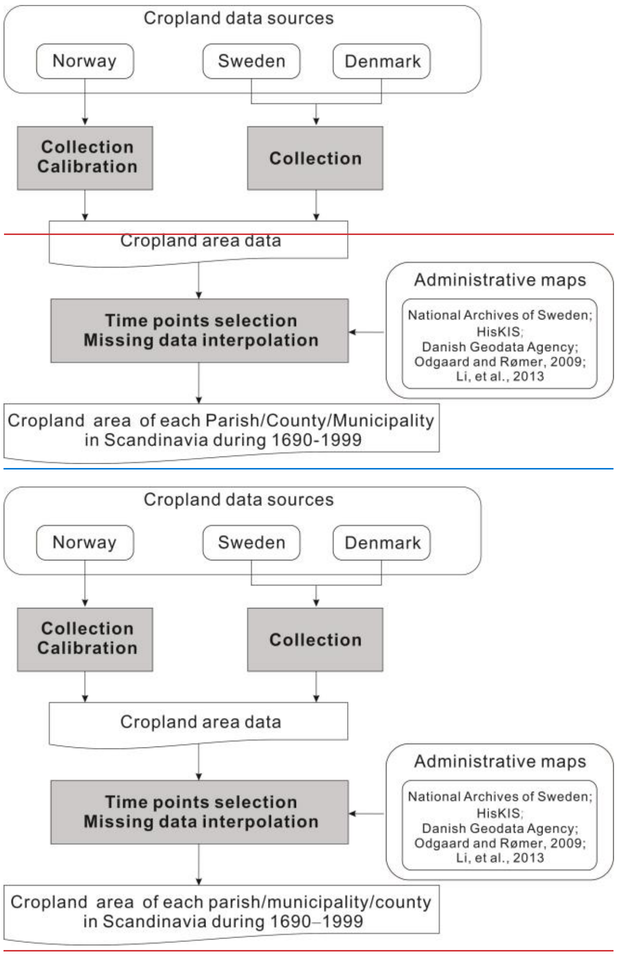


Figure 2 ~~The f~~Flow chart of reconstructing the cropland area at the parish/municipality/county~~parish and county~~ levels

3.1.1 Cropland ~~Data~~ data collection and calibration

The category "“Cropland"” defined by FAO (http://www.fao.org/) was used ~~for the cropland~~ in this study. Thus, our cropland ~~The "“Cropland"”~~ includes arable land (areas under temporary crops, temporary meadows and pastures, land ~~with~~ temporarily fallow)~~,~~ and areas under permanent crops. Non-cropland area~~data~~, such as permanent meadows, were excluded.

Because the unit of Swedish data in 1690, 1750, and 1810 from SND ~~only provided the~~was ~~number~~ barrels of seeds ~~sowed into the land~~~~but~~and not area~~unit~~, we used the formula of 1 barrel of seeds = 4936m^2 of cropland = 0.4936 hectare (ha) of cropland (Cardarelli, 2003) to obtain the cropland area of each parish. The Norwegian data in 1665, 1723, and 1809 also ~~showed~~ provided the volume of seeds but not the cropland area. We collected the relationships between the volume of seeds and the cropland area from four sources (Table 2). The values of liter per *maal* (1 *maal* = ~~10~~ 0.1 ~~hectare~~ha) ~~regarding~~ for seven types of seeds were close to each other, except for the value from NSD. The closest year to the three time points of 1665, 1723, and 1809 was 1835. ~~Since~~ Because agricultural development reduced the use of seeds per *maal* gradually, we chose the values of liter per *maal* in 1835 from *Statistiske Oversigter 1914* (Aschehoug, 1914). ~~1835 was the closest year to the 3 time points of time, 1665, 1723 and 1809.~~ For data sources in the remaining years and in Denmark, ~~cropland areas~~area units were ~~recorded~~used, and we unified the area units to ~~hectare (~~ha~~)~~.

Table 2 ~~The r~~Relation of *maal* to liter from different sources in Norway

Sources	*Oversigt over det norske landbruks utvikling siden 1750* (Klokk, 1920)			*Norges Landbrug i Dette Aarhundrede* (Smitt, 1888)	*Statistiske oversigter 1914* (Aschehoug, 1914)		NSD
Liter per maal\Year	1896–1900	1901–1905	1907	1866–1875	1835	1865	1907
Hvete (wheat)	29.0	27.8	28.2	26.4	25.0	25.2	39.2
Rug (rye)	20.4	20.8	22.5	19.5	19.5	19.3	31.2
Byg (barley)	32.8	31.9	32.2	33.4	34.8	34.7	44.8
Havre (oats)	46.9	45.5	45.2	51.4	52.8	53.2	62.9
Blandkorn (mix)	42.6	40.5	40.2	47.3	47.3	47.0	55.9
Erter (peas)	30.4	26.8	30.9	29.2	30.6	30.9	42.9
Poteter (potato)	302.2	306.8	302.7	290.5	290.5	290.3	420.7

Cropland data from SND ~~was~~ were based on tax records, historical maps, land survey records, and farmer inventories ~~of farmers~~. Cross-validation of data from multiple sources ensured data reliability. However, ~~fallow land and~~ land under permanent crops were excluded in SND's data ~~and statistics~~, which underestimated the total cropland area before 1875 in Sweden. ~~But~~ However, no ~~more~~ additional historical records ~~was~~ were found ~~about~~ regarding the size of ~~fallow land and~~ land under permanent crops ~~in history~~. Using the same coefficient in different years to estimate ~~the~~ land area ~~of fallow land and land~~ under permanent crops will increase the discrepancy of the cropland area. Moreover, ~~Based~~ based on the Farm Structure Survey (FSS, https://ec.europa.eu/) in 1999 and 2010, the total ~~size of fallow land and~~ land size under permanent crops accounted for only approximately ~~less than 10~~~~about~~ 0.1% of ~~the total~~all cropland area in Sweden. Thus, we used the converted area from the ~~volume~~ barr~~a~~aels of seeds ~~records~~ as the cropland area before 1875 in Sweden~~, without the size of fallow land and land under permanent crops estimating~~. For the collected cropland area data after 1875 in Sweden, Li et al. (2013) has evaluated ~~their used~~the statistics employed and ensured the data accuracy. Cropland area data of Denmark in 1688, 1800, and 1881 were also validated using historical maps when they were generated (Dam and Jakobsen, 2008; Odgaard and Rømer, 2009). As the census from the FSS showed that the area under permean~~mae~~nt crops accounted for less than 1% of ~~the total~~all cropland in Denmark, we used “ager” and “agerjord” as cropland in 1688. 1800, 1881, and 1998. Danish ~~S~~statistics ~~of in Denmark~~ recorded the land use areas of all crops, temporary meadows and pastures, and fallow land. Therefore, we selected the land area ~~of lands that belongs to~~categorized as cropland ~~defined by~~according to the FAO and calculated ~~their~~its total area. ~~We then compared the cropland area based on statistics in 1999 with FSS census in 2000 for Sweden and Denmark. Their difference was less than 1%, which reflected the accuracy of official statistics during the 20th century.~~

~~Statistics of Norway in 1999 were also compared with FSS census in 2000.~~ The total cropland area collected by Li et al. (2013) from statistics in Norway was 1.04 × 10^6 ha in 1999, which was 38% larger than the total area of arable land and land under permanent crops in 2000 from the FSS census, but was the same as the total ~~agricultural land area~~area of arable land, land under permanent crops, and land under permanent grassland and meadow from the FSS. ~~Li et al. (2013) included permanent grassland and meadow area in the total cropland area.~~ Thus, we re-collected the ~~the area of~~ arable land area and ~~the~~ land area under permanent crops from the 1999 statistics (NSD kommunedatabase, https://kdb.nsd.no/kdbbin/kdb_start.exe) used by Li et al. (2013)~~, in 1999~~. We found the total cropland area provided by the FSS census in 2000 was 1.18 times larger than ~~that from~~our collected statistics. Thus, a ~~C~~calibration coefficient of 1.18 was used to compensate for estimating the cropland area in Norway from official statistics from 1665 to 1999~~, as shown in Figure 2~~.

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3.1.2 Time points selection and data interpolation

~~According to~~Based on the years when cropland area data are available in Sweden, Norway, and Denmark, we selected ~~9~~ nine times to re~~points of time that could ~~present the cropland change trend from 1690 to 1999. Compared to the data sources in Norway and Denmark, the ~~numbers of~~ cropland data from ~~the data sources of~~ Swed~~en~~ish data sources were the most abundant and complete. Thus~~,~~, the ~~9~~ nine time points ~~of time~~ were based on the data sources in Sweden, which were 1690, 1750, 1810, 1875, 1910, 1930, 1950, 1980, and 1999. The years of 1690, 1750, and 1810 correspond to 1665, 1723, and 1809 from the data sources in Norway. In Denmark, 1690, 1810, 1910, 1930, 1950, 1980, and 1999 correspond to 1688, 1800, 1881, 1912, 1936, 1950, and 1998, respectively. ~~from the data sources in Denmark.~~

To map the spatial patterns of cropland distribution in Sweden before 1875, we used the parish level administrative map ~~at the parish level in~~from 1750. We linked the datasets ~~in~~ during 1690–~~-~~1810 to the base map in 1750 based on parish code. Four cities (*stad*) in the datasets failed to ~~be~~ connect~~ed~~ with the corresponding base map, and ~~14~~ fourteen parishes on~~in~~ the base map ~~were~~ also ~~without~~ lacked cropland data. After checking their administrative codes, a relationship between the four cities (*stad*) and ~~14~~ fourteen parishes was found. Then, all the 2390 parishes ~~found~~ were associated with their corresponding cropland area data.

For Denmark, cropland area data in 184 (total 8083) ~~"~~"*ejerlavs*~~"~~" ~~was~~ were missing in 1688. We assumed that neighboring "*ejerlavs*" with similar terrain had the same cropland fraction and cropland growth rate. Then, ~~The~~ the missing data were interpolated based on the cropland fractions of their neighboring ~~"~~"*ejerlavs*~~"~~" in 1688 and the cropland area changes from 1688 to 1800. Using the same method, we also interpolated 56 (total 1705) missing data in 1800 and 2 missing data (total 1719) in 1881. We selected the administrative map in 1688 from the HisKIS network as the cropland data base map. ~~for cropland data.~~ Cropland area data in 1800, 1881, and 1999 also had ~~their~~ corresponding base maps (Odgaard and Rømer, 2009). The base maps for data in 1936, 1950, and 1980 were from the *Danish Geodata Agency* (https://eng.gst.dk/). There was no cropland area record ~~for the cropland area~~ of Denmark in 1750. Therefore, we assumed that the cropland area change rate from 1690 to 1810 was constant and computed each ~~P~~parish~~'~~'s cropland area in 1750.

Because the cropland data before 1875 was at the ~~County~~ county (~~*Amt*~~*amt*) level and the administrative division did~~n'~~~~t~~ not change dramatically from 1690 to 1875 in Norway, the administrative map in 1875 from NSD's kommunedatabase was used for data in 1690~~-~~–1810 as the base map. Following the above steps, the cropland area of each administrative unit at~~in~~ the ~~9~~ nine time points was connected to the corresponding administrative maps.

3.~~3~~ 2 Cropland area allocation into grid cells~~Cropland area allocation~~

As the cropland area data of each ~~administrative unit~~parish/municipality/county cannot be used as input for the climate and environment simulations directly, we developed cropland area allocation models and allocated the cropland area into 1 km × 1 km grid cells. The allocation process include~~ds~~ two e~~n~~ssential parts, cropland distribution factors and the maximum extent constraints. In this work, ~~-~~elevation and slope were selected as the distribution factors, and the maximum extent ~~constratins~~constraints ~~are~~were defined based on the CLC2000 data.

We analyzed the factors affecting ~~the~~ cropland distribution ~~of cropland~~. In previous studies, elevation, slope, climate, soil, water, and population were used as causes related to the change ~~of the~~in cropland spatial distribution ~~of cropland~~ (Klein Goldewijk et al., 2011; Li et al., ~~2015~~2016; Paudel et al., 2017). People tend to ~~be more inclined to~~prefer starting from areas with lower elevations and gentler slopes when cultivating the land. Land with high elevations and slopes has negative characteristics that constrain cropland cultivation~~,~~; therefore it ~~which~~ will only be used after low-elevation and gentle-slope land has been cultivated. In Scandinavia, there is little climate difference in each Parish/Municipality/County. We assumed the impact of climate ~~for~~ on cropland distribution had been included in the effects of elevation and slope in each ~~Parish~~parish/~~Municipality~~municipality/~~County~~county. Soil properties such as texture, fertility, and organic-matter content impact suitability for growing crops, but it is not a limitation for land cultivation in most areas. According to statistics, Scandinavia's population constantly increased from the 17th century to the present (SCB, SSB, and Statistics Denmark), while the cropland area decreased after 1950. Population growth was an important reason for cropland area increase before 1950, especially in Sweden and Denmark. However, the spatial distribution of population data before 1950 at a high spatial resolution is

~~rather~~ hard to obtain. Thus, elevation and slope were selected as the factors in the cropland area allocation model. ~~Used~~ Using the NASA ~~Shuttle Radar Topographic Mission (~~SRTM~~)~~ 90 m ~~digital elevation data (~~DEMs~~)~~, we resampled the DEMs in Scandinavia to 1-km resolution. The values of elevation and slope ~~was~~ were normalized using the following formulas:

$$E'(i)=\frac{E_{\max}-E(i)}{E_{\max}-E_{\min}} \quad (1)$$

$$S'(i)=\frac{S_{\max}-S(i)}{S_{\max}-S_{\min}} \quad (2)$$

~~$E'(i)=\frac{E_{\max}-E(i)}{E_{\max}-E_{\min}}$ (1)~~

~~$S'(i)=\frac{S_{\max}-S(i)}{S_{\max}-S_{\min}}$ (2)~~

where E' (i) and S' (i) are the normalized elevation and slope value of grid *i*~~;~~, $E(i)$ and $S(i)$ are original elevation and slope value of grid *i*~~;~~, E_{max} and S_{min} are the maximum elevation and slope value of grid *i* in Scandinavia~~;~~, and E_{min} and S_{min} are the minimum elevation and slope value of grid *i* in Scandinavia.

~~t~~The value of land cultivation suitability *Suit(i)* of grid *i* is calculated using the following formula:

$$Suit(i)=Mcrop(i)\times E'(i)\times S'(i) \quad (3)$$

~~W~~where *Mcrop(i)* refers the maximum extent of cropland, which is

~~In cropland allocation models, the maximum extent of cropland of gird i (Mcrop(i)) is~~ a crucial component for allocation models. In this study, *Mcrop(i)* is defined using the CLC2000 data.

	~~$Suit(i)=Mcrop(i)\times E'(i)\times S'(i)$~~	~~(3)~~

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~~The total weight of each administrative unit for cropland area allocation was is as 1.~~ The weight of grid i for cropland area allocation ($w(i)$) and the cropland area of grid i ($Crop(i)$) become:

$$w(i)=\frac{Suit(i)}{\sum_{i=1}^{n} Suit(i)} \qquad (4)$$

$$Crop(i)=w(i)\times Crop(p_n) \qquad (5)$$

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	~~$w(i)=\frac{Suit(i)}{\sum_{i=1}^{n} Suit(i)}$~~	~~(4)~~
	~~$Crop(i)=w(i)\times Crop(p_n)$~~	~~(5)~~

where $Crop(P_n)$ is the total cropland area of administrative unit (~~of~~ P_n). The total weight of each administrative unit for cropland area allocation ~~was~~ is ~~as~~ 1.

In previous studies, the maximum extents of cropland (*Mcrop*) in modern times ~~were~~ have been used to allocate ~~the~~ historical cropland area ~~in history~~ (Li et al., ~~2015~~2016; Wei et al., 2019) because usually the area of cropland in modern times is larger than that ~~of~~in historical periods.~~,~~ However, ~~which~~ this ~~was~~is a source of error in Scandinavia ~~since~~ as many croplands were converted to the forest during the 20th century. Beyond the maximum extent of modern cropland ~~in modern times~~, more marginal lands may have been cultivated. Considering Scandinavia'’s agricultural history and urbanization development, we used different maximum extents of cropland during 1690–~~-~~1950, in 1980, and 1999~~, respectively~~.

~~Since~~ Because urban land is usually built on rural and cultivated land, urban land cover maps ~~were~~ from CLC2000 were also used to build the maximum cropland cover extent map. In Scandinavia, although industrialization ~~took off from~~accelerated after 1870, the urbanization rate was still less than 30% before 1930. After 1960, urbanization was even faster, and its rate reached over 50% in 1990 (Clark, 2009). Thus, the urban land cover map was only used during 1690–~~-~~1950. The cropland area was allocated to grid cells ~~followed~~ following the process ~~showed~~ shown in Figure 3.

(1) The maximum extent of cropland in the first step allocation is defined as the sum of ~~"~~“Arable land~~,"~~”~~,~~ ~~"~~“Permanent crops~~,"~~” and ~~"~~“Discontinuous urban fabric~~"~~” ~~of~~ ~~in~~from CLC2000. *Mcrop_I(i)* and $Mcrop\_I(P_n)$ refer~~ence~~s to the maximum extent of cropland ~~of~~in grid *i* and the administrative unit P_n, respectively.~~First of all,~~ ~~we~~ We compared our collected cropland area ~~($Crop(P_n)$)~~ of administrative unit P_n ($Crop(P_n)$) with $Mcrop\_I(P_n)$. ~~with the total area of "Arable land", "Permanent crops" and "Discontinuous urban fabric" of P_n ($Mcrop\_I(P_n)$) from CLC2000 in each time point before 1950.~~ If $Crop(P_n)$ <= $Mcrop\_I(P_n)$, $Crop(P_n)$ was allocated into grid cells using the formulas (3), (4) and (5) mentioned above, where *Mcrop_I(i)* is *Mcrop(i)* in the formula (3).~~. The total area of "Arable land", "Permanent crops" and "Discontinuous urban fabric" of grid i (Mcrop_I(i)) was used as Mcrop(i) in the formula (3).~~ Otherwise if $Crop(P_n) > Mcrop\_I(P_n)$, $Mcrop\_I(P_n)$ was allocated and the rest (~~,~~ $Rest1(P_n)$, calculated as $Crop(P_n)$ - $Mcrop\_I(P_n)$~~$Crop(P_n)$ – $Mcrop\_I(P_n)$~~), went~~goes~~ into the next step (Figure 3).

~~Secondly~~In the second step, ~~the rest (~~$Rest1(P_n)$~~, calculated as $Crop(P_n)$ – $Mcrop\_I(P_n)$)~~ was compared with $Mcrop\_II(P_n)$. If $Rest1(P_n)$ <= $Mcrop\_II(P_n)$, $Rest1(P_n)$ was allocated into grid cells using ~~the~~ formulas (3), (4), and (5~~).~~), where *Mcrop_II(i)* ~~was used as~~is *Mcrop(i)* in the formula (3). Otherwise, $Mcrop\_II(P_n)$ was allocated. T~~. The~~he rest (~~-~~$Rest2(P_n)$, calculated as $Rest1(P_n)$ - $Mcrop\_II(P_n)$), was compared with $Mcrop\_III(P_n)$ and allocated following the same ~~steps~~ procedure as the first and second ~~areas~~steps. *Mcrop_IV(i)* and *Mcrop_V(i)* ~~was~~ were used in ~~the~~ formula (3) in turn~~ to allocate the rest if $Rest2(P_n)$ > $Mcrop\_III(P_n)$~~, until the cropland areas in all administrative units were ~~assigned~~ allocated to grid cells.

~~In~~ For the cropland area in 1980, ~~since~~as the urbanization rate reached ~~about~~ approximately 50%, more cropland was converted to urban land and~~,~~ the maximum extent of cropland in the first ~~step~~ allocation step ~~is~~was defined as the sum of “Arable land” and “Permanent crops” from CLC2000. ~~the area of "Discontinuous urban fabric" was excluded from $Mcrop\_I(P_n)$ and~~ $Crop(P_n)$ was allocated to grid cells using the allocation model in Figure 3. For cropland area~~In~~ in 1999, following the allocation steps in Figure 3, $Crop(P_n)$ was allocated to *Mcrop_I(i)* (defined as all “Arable land” and “Permanent crops” of grid *i*), *Mcrop_II(i)* (defined as “Complex cultivation patterns” of grid *i*) and *Mcrop_III(i)* (defined as “Land

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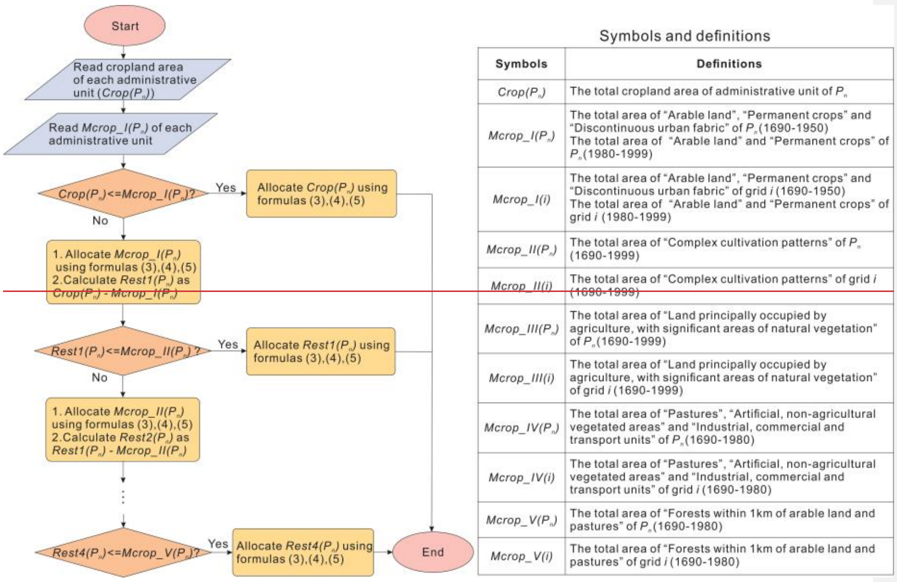
principally occupied by agriculture, with significant areas of natural vegetation" of grid *i*) in turn.grid cells in the extent of "Arable land" and "Permanent crops", "Complex cultivation patterns", and "Land principally occupied by agriculture, with significant areas of natural vegetation" in turn.



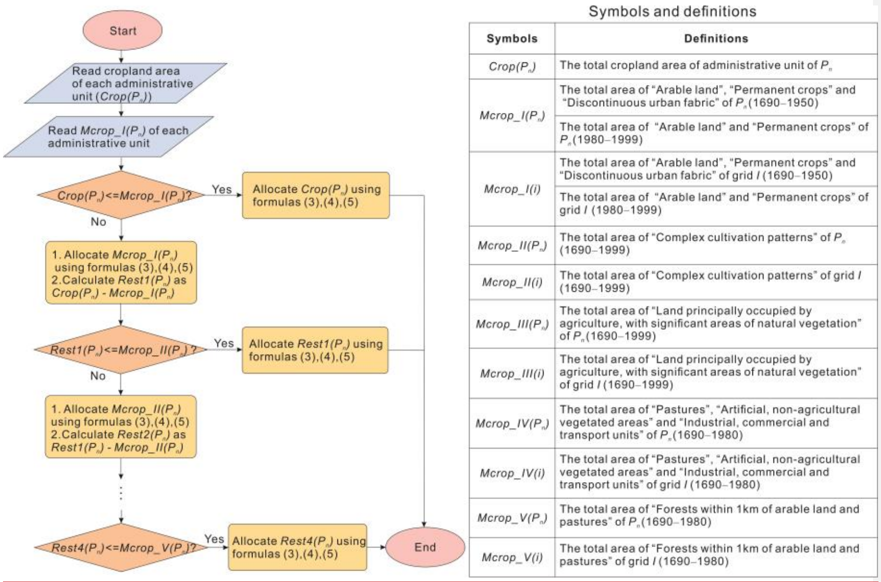


Figure 3 Flow chart of cropland area allocation model

3.~~4~~ 3 ~~Allocation method validation~~Cropland data comparison

~~Since~~Because global datasets were produced based on national level cropland area while cropland areas at the parish/municipality/county levels were used to spatialize cropland distribution by us, cropland datasets from this study could be used for assessing the accuracy of global datasets. As the total cropland area is small in Scandinavia, the relative difference ratio (*RD*) was used to identify the differences between different datasets as follows: ~~global datasets was produced based on cropland area at the national level while cropland area at the parish and county levels were used to spatialize cropland distribution by us, cropland datasets from this study could be used for assessing the accuracy of global datasets. As the total cropland area is small in Scandinavia, relative difference ratio (RD) was used to identify the differences between different datasets, and the formula is as follows:~~

$$RD = \frac{C_{globe}(t) - C(t)}{C(t)} \times 100\% \qquad (6)$$

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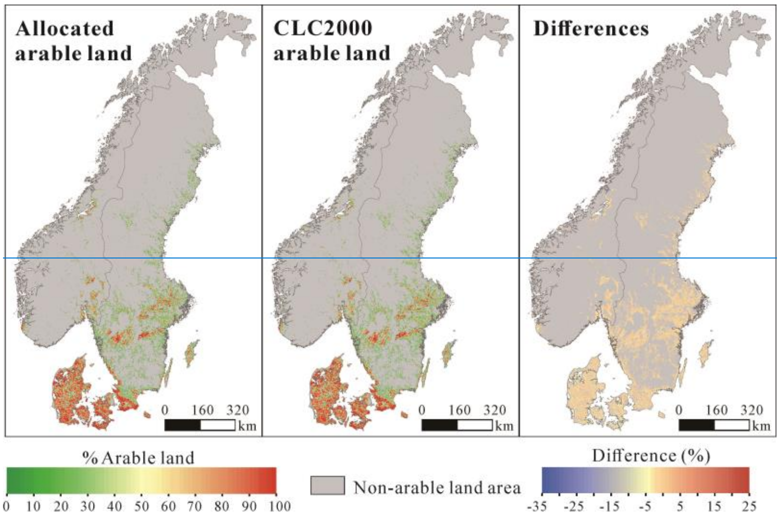
where $C_{globe}(t)$ is the cropland area from global datasets and~~,~~ $C(t)$ is the cropland area from this study.

~~Since cropland area in "Complex cultivation patterns" and "Land principally occupied by agriculture, with significant areas of natural vegetation" from CLC2000 is hard to compute, we selected "Arable land" as an example to validate our allocation method. Comparing our allocated "Arable land" in 2000 using formulas (3), (4) and (5) with CLC2000 data, the differences were distributed between -34% and 21%. Grid cells with differences between -5% and 5% accounted for 98% of the total grid cells with arable land, reflecting the reliability of the allocation model (Figure 4).~~



~~Figure 4 Comparison between the allocated arable land in 2000 and CLC2000~~

4 Results

~~Since~~ Because the cropland area only accounted for less than 8% of Scandinavia''s total land area in 2000, small changes were ~~hard~~ difficult to ~~be~~ observe~~d~~ from the 1 km × 1 km resolution cropland maps, especially in northern Scandinavia. However, we found the total cropland area from 1690 to 1999 showed a phased change. Significant changes in the spatial distribution of cropland in southern Scandinavia and northern cropland expansion were also shown~~of cropland in northern were also showed~~ ~~apparent~~ clearly on our maps.

4.1 Changes in the total cropland area in Scandinavia~~Changes of cropland area~~

~~4.1.1 Changes in the total cropland area in Scandinavia~~

The total cropland area change in Scandinavia during 1690–1999 is shown in Figure ~~5~~4. ~~As an o~~Overall~~trend~~, cropland area developed slowly before 1810, and kept developing rapidly or even increas~~inge~~ until the beginning of the 20th century, then remained stable for around 40 years before dropping in 1999. The cropland area change process ~~can~~ could be divided into four stages: (1) ~~slight~~ Slight increase in 1690–1810, with an annual growth rate of 0.37% on average. In 1690, the cropland area ~~stood at~~was 1.82 million ha, accounting for 2.07% of the land area. The cropland area rose steadily to 2.84 million ha in 1810. (2) ~~rapid~~ Rapid increase during 1810–1910, with a growth rate of 0.82% on average annually. After 1810, the cropland area rose dramatically for ~~over~~ the next century, reaching 6.43 million ha in 1910. 3) ~~steady~~ Steady rise in 1910–~~-~~1950, with 0.10% average annual growth rate. Between 1910 and 1950, ~~experienced~~ a slight ~~rise~~ increase in the cropland area was experienced~~,~~ and the cropland area reached 6.71 million ha. (4) ~~gradual~~ Gradual decrease in 1950–~~-~~1999, with -0.26% average annual growth rate. After 1950, the cropland area declined and dropped to 5.90 million ha in 1999, constituting 6.71% of the land area.

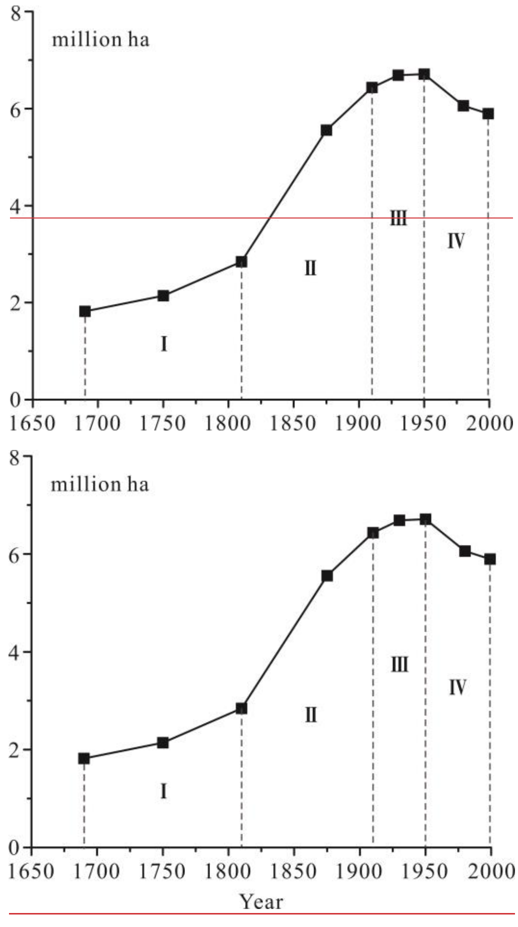


Figure ~~5~~ 4 Changes ~~of~~ in the total cropland area in Scandinavia during 1690–~~-~~1999

4.~~1.~~2 Changes at the country level

For Sweden, the cropland area was just 0.68 million ha in 1690 and rose slowly to 1.21 million ha in 1810. After 1810, Sweden had the largest cropland area in Scandinavia, growing from 2.89 million ha in 1875 to around 3.60 million ha in 1910. The next 40 years witnessed a ~~experienced a~~ slight growth in cropland area, ~~which~~ reachinge~~ed~~ a peak in 1950 ~~with~~ of 3.66 million ha and ~~represented~~ representing 52.57% of the total cropland area in Sweden. Then, the cropland area declined to 2.75 million ha ~~in~~ by 1999.

For the first three time points, Denmark~~'~~'s cropland area grew gradually and accounted for 58.53%, 59.44%, and 52.17% of ~~the total~~all cropland area in 1690, 1750, and 1810, respectively. The cropland area continued to rise ~~with~~ at an average annual growth rate of 0.36% until 1950 ~~and~~ when it reached its highest~~,~~ area of 2.68 million ha. After that, the figure slowly dropped ~~by~~ to 2.63 million ha in 1999.

The cropland area difference between Sweden and Denmark narrowed ~~from~~ after 1980. Compared with Sweden and Denmark, Norway had the smallest cropland area, which ~~made up~~comprised only 6% of Scandinavia~~'~~'s total cropland area, on average~~ly~~. After a slow increase from 1690 to 1810, there was ~~also a~~ noticeable growth between 1810 and 1910. During 1690~~-~~–1910 the cropland area increased by 4.5 times. Despite some slight fluctuations, the cropland area rose from 0.35 million ha in 1910 to 0.65 million ha in 1999, with an average annual growth rate of 0.70% (Figure ~~6~~5).

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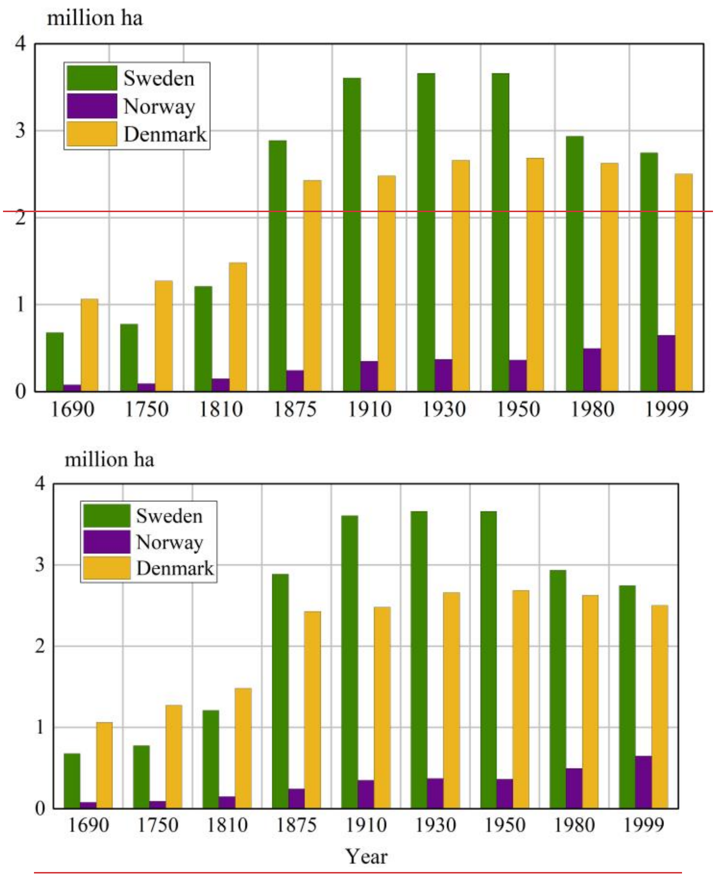


Figure ~~6~~ 5 Changes ~~of~~ in the total cropland area during 1690~~–~~–1999 in Sweden, Norway and Denmark

4.~~2~~ 3 Spatial ~~patterns of~~ cropland distribution patterns

The spatial patterns of cropland distribution from 1690 to ~~2015~~ 1999 in Scandinavia are shown in Figure ~~7~~6. Denmark and southern Sweden already had extensive cropland cover in 1690, which reflected ~~they~~ their ~~had had a~~ long ~~history~~ historical ~~of~~ agricultural practices. Before 1810, cropland cover expanded in southern Scandinavia and remained stable in the north. Grid cells with more than 5% cropland accounted for 9.79% and 12.58% of the total ~~number of~~ grid~~s~~ cells in 1690 and 1810, respectively, while the number of grid cells with more than 60% cropland increased ~~about~~ approximately ~~4~~ four times. After 1810, cropland in northern Scandinavia experienced slight expansion, and the cropland fractions increased rapidly. In 1910, grid cells with more than 5% cropland represented a proportion of around 17.05%, while the percentage of grid cells with more than 60% cropland grew to 6%. During 1910–-1950, cropland area changed gentlygradually, cropland fraction proportion changes in most grid cells were between -20%~% and 20%. After 1950, cropland areas began to decrease in most regions, especially in eastern Scandinavia. In western Scandinavia, the cropland area increased gradually and expanded to the north. Grid cells with more than 60% cropland accounted for 5.53% of the total number of grid cells and 28.43% of the grid cells that have had cropland in 1999.

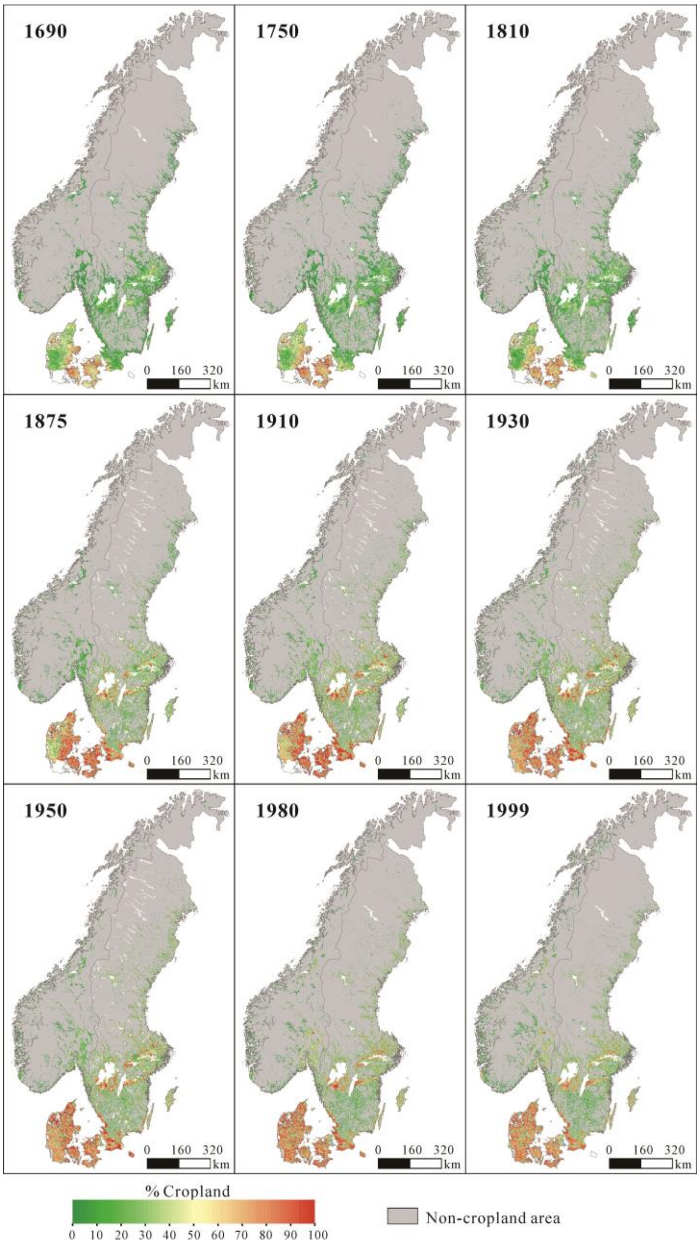


Figure 7 6 The sSpatial distribution of cropland area during 1690-1999 in Scandinavia

4.~~2~~3.1 Sweden

In Sweden, about half of the area is covered by forest. Mountains, marshes, and lakes together cover approximately one third of the area. The cropland area has accounted for 1.50%–8.13% of Sweden’s total land area over the past 300 years. In 1690, croplands were especially dense in southern Sweden, especially around the lakes of Vänern, Vättern, Mälaren and Hjälmaren ~~and~~ as well as in Skåne, reflective of the long cultivation history ~~of cultivation~~. After that, the cropland spatial patterns ~~of cropland~~ became more intensive in southern Sweden and began to spread ~~to the~~ northward. ~~A large number of~~Several grid cells with more than 80% cropland were ~~seen~~ observed and increased in 1910. During 1910–1950, spatial patterns of cropland distribution remained stable, except for slight increases in Västerbotten and Norrbotten counties in the north, and ~~gentle~~ minor changes in Skåne (Malmöhus and Kristianstad counties) and Gotland. In the following years, the cropland area declined in most regions and the percentage of grids cells with more than 80% cropland dropped ~~to~~ in 1980 and 1999. However, the coastal areas of Halland and Skåne still maintained high cropland fractions.

4.~~2~~3.2 Norway

Mountains, forests, open heathlands, and grasslands dominate Norway’s landscapes, and only about 3% of the land surface is suited for cultivation or arable farming (FAO, http://www.fao.org/family-farming/detail/en/c/358178/). In 1690, a small amount of cropland in Norway was distributed around the two agricultural centers, Olsofjorden and Trondheimsfjorden. From 1750 to 1810, the cropland spatial patterns ~~of cropland~~ around the two fjords expanded and cropland appeared in Nordland County in northern Norway. Then, the cropland fraction increased in the two agricultural centers ~~over~~ during 1810–1910, and cropland began to appear in the northernmost county, Finnmark. Cropland in the two agricultural centers stabilized and even decreased, but increased in other regions from 1910 to 1950. After 1950, cropland around Olsofjorden and Trondheimsfjorden started growing again. The dramatic growth ~~was~~ occured in the southwestern area of Rogaland. Cropland area in low-elevation ~~the~~ coastal ~~area~~ regions ~~with low elevation~~ also increased.

4.23.3 Denmark

Denmark is among the most intensively cultivated countries in Europe. The long land cultivation history of land cultivation broughthas included widespread cropland cover since 1690 in Denmark. Most high-fraction grid cells were distributed in eastern Denmark since as soil conditions were more suitable for crop planting than in the western part of the country. The period between 1690 and 1810 experienced a gradual growth, and the most rapid cropland increase occurred in eastern Denmark. During 1810 and 1910, we saw a sharp increase in cropland area in both eastern and western Denmark was observed. Grid cells with more than 20% and 60% cropland accounted for 83.42% and 71.24% of the total number of grid cells in 1910. Since 1910, we saw negative rates of change of in cropland areas have dominated in northern and eastern Denmark, and positive rates in the western part, including Ribe, Ringkjøbing and Viborg Countiescounties. But However, the changes of in cropland areas of most grid cells were less than 20%. Although cropland areas in South Jutland, Ribe, Ringkjøbing, Viborg, and South Nouth Jutland Counties counties increased moderately, those in other Danish counties of Denmark declined from 1950 to 1999.

5 Discussion

5.1 Validation of the dataset developed in this study

To validate the newly created dataset, we used the satellite-based modern cropland cover data. Two sets of global land cover maps at 30-m resolution, from the Global Food Security Analysis-Support Data at 30 Meters (GFSAD30, https://croplands.org/app/map?lat=0&lng=0&zoom=2) Project and GlobeLand30 maps were found. However, GFSAD30 provides land cover map at 30-m resolution only for 2015 whereas GlobeLand30 has 30-m resolution maps in 2000, 2010, and 2020. Although there are differences among satellite-based maps of multiple time points in modern times, compared to the past 300 years, the period of 1985–2000 can be regarded as one time point. Thus, we choose the GlobeLand30 map for 2000 to validate our 1999 cropland dataset.

The images for land cover development classification and update of GlobeLand30 were mainly 30-m multispectral images, including TM5 ETM+ and OLI multispectral images from Landsat (USA) and HJ-1 (China Environment and Disaster Reduction Satellite).

GlobeLand30 includes ten land-cover classes in total (Chen, et al., 2014); namely cultivated land, forest, grassland, shrubland, wetland, water bodies, tundra, artificial surface, bare land, and perennial snow and ice. Cultivated land refers to the land used for cultivating crops. Paddy fields, irrigated upland, rainfed upland, vegetable land, cultivated pasture, greenhouse land, land mainly planted with crops and rarely with fruit trees or other trees, tea plantations, coffee plantations, and other economic croplands are included in this category (Chen, et al., 2014). However, cropland in our datasets only includes arable land (areas under temporary crops, temporary meadows and pastures, land temporarily fallow) and areas under permanent crops.

We compared the cropland area at the parish and county levels in 1999 in this study with cultivated land area from the 2000 GlobeLand30 map to validate our statistics. Then, we aggregated the 30-m resolution GlobeLand30 to 1 km and compared the result with our 1999 gridded cropland dataset to validate our allocation method. Comparing the cropland area at the parish and county levels in 1999 in this study with the cultivated land from the 2000 GlobeLand30 map shows that the cultivated land area from GlobeLand30 is 1.4 times that of our cropland area (Figure 7).

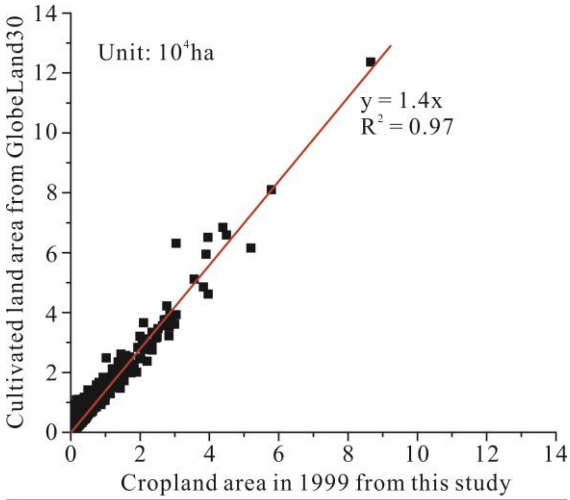
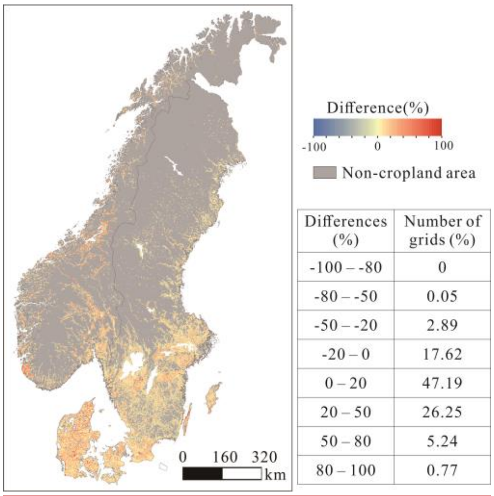


Figure 7 Comparison of the area at the parish and county levels between GlobeLand30 and this study

Comparison of the gridded cropland area at 1 km resolution between GlobeLand30 and this study shows grids with differences between -20% and 20% account for 64.81% of the total number of grids with the cropland area > 0 (Figure 8). Because cultivated pasture, greenhouse land, gardens, and so on are included in cultivated land from GlobeLand30, whereas only arable land and permanent crops comprise cropland in this study, among all grids with cultivated land > 0, 79.44% of grids from GlobeLand30 have more cultivated land than this study.



Differences (%)	Number of grids (%)
-100 – -80	0
-80 – -50	0.05
-50 – -20	2.89
-20 – 0	17.62
0 – 20	47.19
20 – 50	26.25
50 – 80	5.24
80 – 100	0.77

Figure 8 Comparison of the gridded cropland area between GlobeLand30 and this study

Because CLC2000 provides more agricultural (cultivated) land classes (Büttner, 2014), we used CLC2000 to further validate our cropland dataset. In Scandinavia, CLC2000 divides agricultural areas into four categories: “Arable land” (including one class, “Non-irrigated arable land”), “Permanent crops” (including one class, “Fruit trees and berry plantations”), “Heterogeneous agricultural areas” (including two classes, “Complex cultivation patterns” and “Land principally occupied by agriculture, with significant areas of natural vegetation”), and “Pastures”. Comparison of the gridded cultivated land area and agricultural areas at 1-km resolution between GlobeLand30 and CLC2000 shows the consistency of these two datasets. We compared the total area of “Arable land,” “Permanent crops,” and “Complex cultivation patterns” from CLC2000 with our cropland area for each parish and county (Figure 9). Figure 9 shows that the area from CLC2000 is 1.17 times that of our cropland area. Removing some marginal roads and natural lands included in “Arable land,” “Permanent crops,” and “Complex cultivation patterns” from CLC2000, our cropland areas at the parish and county levels are close to those from CLC2000.

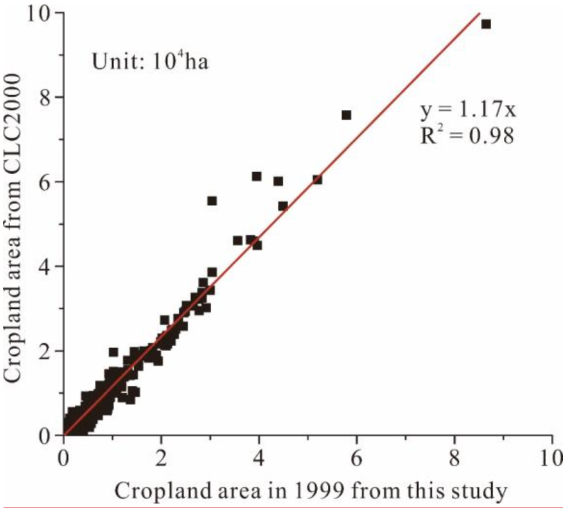
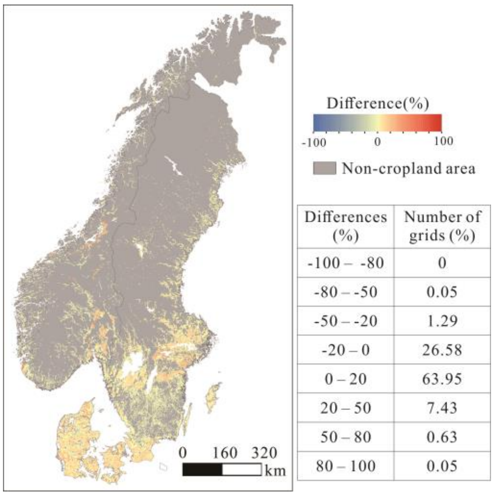


Figure 9 Comparison of the cropland area at the parish and county levels between CLC2000 and this study

Comparison of the gridded cropland area at 1-km resolution between CLC2000 and this study shows grids with differences between -20% and 20% account for 90.54% of the total number of grids with the cropland area > 0 (Figure 10). Our gridded cropland area is close to that in CLC2000 overall, which indicates the reliability of our cropland dataset. However, around Stockholm and Trondheim, in southeastern Norway and northern Denmark, respectively, our cropland areas are slightly less than those from CLC2000.



Differences (%)	Number of grids (%)
-100 – -80	0
-80 – -50	0.05
-50 – -20	1.29
-20 – 0	26.58
0 – 20	63.95
20 – 50	7.43
50 – 80	0.63
80 – 100	0.05

Figure 10 Comparison of the gridded cropland area between CLC2000 and this study

~~To validate the newly created dataset, we found there were two global land cover maps at 30m resolution, Global Food Security Analysis Support Data at 30 Meters (GFSAD30, https://croplands.org/app/map?lat=0&lng=0&zoom=2) Project and GlobeLand30 maps. But GFSAD30 provides land cover map at 30m resolution only in 2015. GlobeLand30 has maps at 30m resolution in 2000, 2010 and 2020. Although there are differences between satellite-based maps of multiple time points in modern times, compared to the history over the past 300 years, the period of 1985~2000 can be regarded as one time point. Thus, we choose GlobeLand30 map of 2000 to validate our cropland dataset in 1999.~~

~~GlobeLand30 includes 10 land cover classes in total, namely cultivated land, forest, grassland, shrubland, wetland, water bodies, tundra, artificial surface, bare land, perennial snow and ice. Cultivated land refers to the lands used for cultivating crops. paddy fields, irrigated upland, rainfed upland, vegetable land, cultivated pasture, greenhouse land, land mainly planted with crops rarely with fruit trees or other trees, tea garden, coffee garden, and other economic cropland and so on are included in this category (Chen, et al., 2014). However, cropland in this study only includes arable land (areas under temporary crops, temporary meadows and pastures, land with temporary fallow) and areas under permanent crops.~~

~~We compared the cropland area at the parish and county levels in 1999 of this study with cropland data from GlobeLand30 map of 2000 to validate the statistics. Then, we aggregated~~

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the 30m resolution GlobeLand30 to 1km and compared with our gridded cropland dataset in 1999 to validate our allocation method. Compared the cropland area at the parish and county levels in 1999 of this study with cultivated land from GlobeLand30 map of 2000, cultivated land area from GlobeLand30 is 1.4 times of our cropland area (Figure 8).

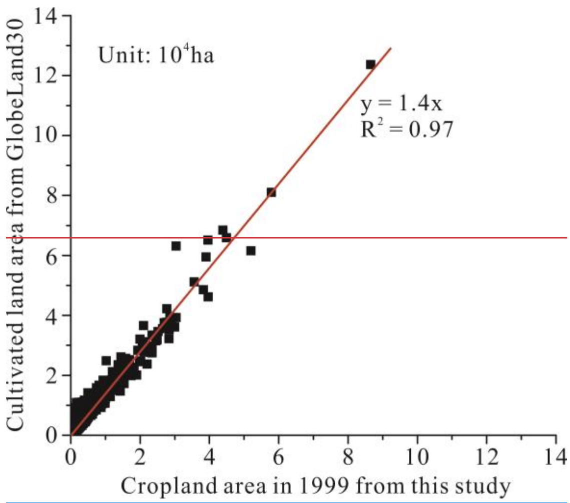

Figure 8 Comparison of the area at the parish and county levels between GlobeLand30 and this study

Comparison of the gridded cropland area at 1km resolution between GlobeLand30 and this study shows grids with differences between -20%~20% account for 64.81% of the total number of grids with the cropland area more than 0 (Figure 9). Because cultivated pasture, greenhouse land, garden and so on is included in cultivated land area from GlobeLand30, whereas only arable land and permanent crops compose cropland in this study, 79.44% grids from GlobeLand30 have cropland area which is more than those from this study.

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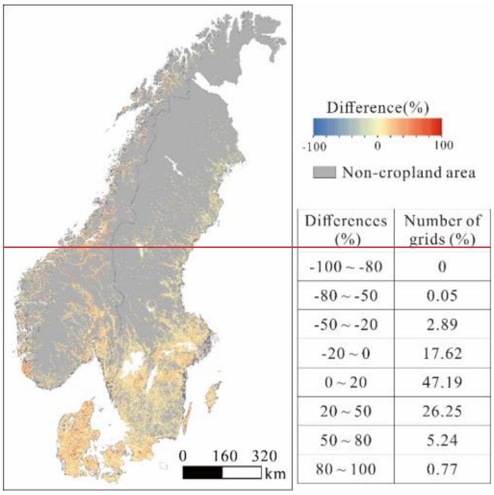

Differences (%)	Number of grids (%)
-100～-80	0
-80～-50	0.05
-50～-20	2.89
-20～0	17.62
0～20	47.19
20～50	26.25
50～80	5.24
80～100	0.77

Figure 9 Comparison of the gridded area between GlobeLand30 and this study

Since CLC 2000 provides more classes of agricultural land (Büttner, 2014), we used CLC 2000 to further validate our cropland dataset. In Scandinavia, CLC 2000 divides agricultural areas into 4 categories: "Arable land" (include 1 class, "Non-irrigated arable land"), "Permanent crops" (include 1 class, "Fruit trees and berry plantations"), "Pastures" and "Heterogeneous agricultural areas" (including 2 classes, "Complex cultivation patterns" and "Land principally occupied by agriculture, with significant areas of natural vegetation"). Comparison of the gridded cultivated land area and agricultural areas at 1km resolution between GlobeLand30 and CLC 2000 shows the consistency of these two datasets. We compared the total area of "Arable land", "Permanent crops" and "Complex cultivation patterns" from CLC2000 with our cropland area of each parish and county (Figure 10). Figure 4 shows data from CLC 2000 is 1.17 times of our cropland area. Removing some marginal roads and natural lands are included in "Arable land", "Permanent crops" and "Complex cultivation patterns" from CLC2000, our cropland area at the parish and county levels is close to that from CLC2000.

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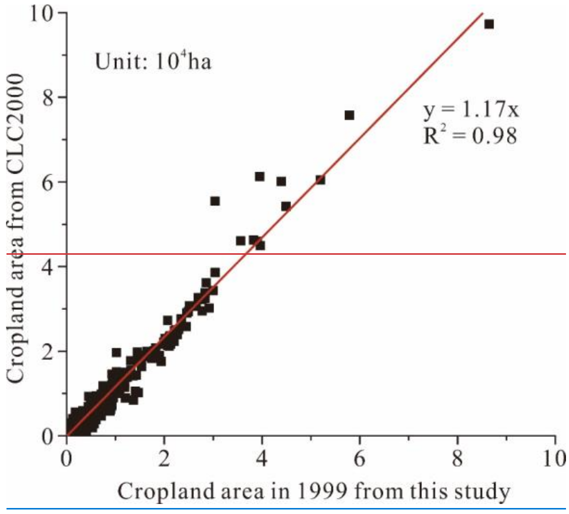

Figure 10 Comparison of the cropland area at the parish and county levels between CLC2000 and this study

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Comparison of the gridded cropland area at 1km resolution between CLC2000 and this study shows grids with differences between -20%~20% account for 90.54% of the total number of grids with the cropland area more than 0 (Figure 11). Our gridded cropland area is close to CLC2000 on the whole, which indicates the reliability of our cropland dataset. However, around Stockholm and Trondheim, in southeastern Norway and northern Denmark, our cropland area is slightly less than that from CLC2000.

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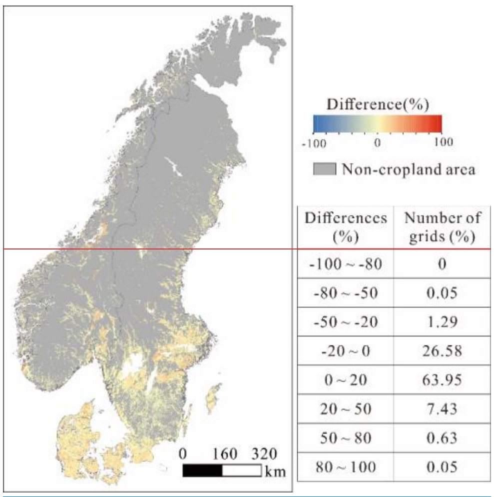
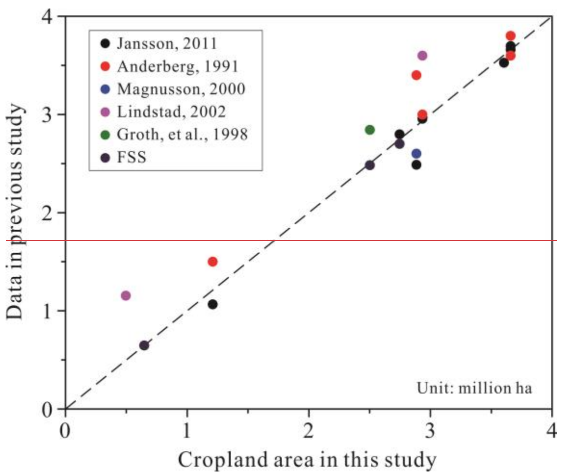


~~Figure 11 Comparison of the gridded cropland area between CLC2000 and this study~~

~~To validate the newly created dataset, w~~We also compared the total country level cropland area ~~at the country level~~ with ~~the data~~that from previously published studies. ~~Since~~ Because many studies ~~on~~ of historical agriculture in Norway and Denmark were also ~~based on statistic~~statistically based~~s~~, cropland areas before 1980 were available only in Sweden. This study’’s cropland area is ~~close~~ similar to the data from previous studies (R^2 = 0.967, slope = 1.05), which ~~shows~~ indicates the reliability of ~~this~~ the results in this study~~’s results~~ (Figure ~~8~~1~~2~~1). ~~Since~~ Because the studies of Anderberg (1991), Lindstad (2002) and Groth, et al. (1998) provided the cultivated land area but not the cropland area, their data ~~is~~ show slightly larger areas than the data observed in this study.



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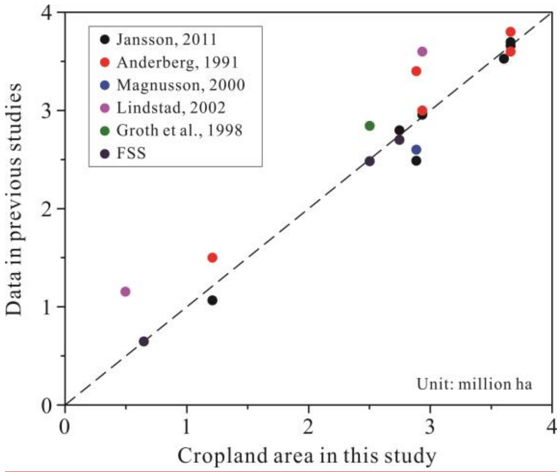

Figure 8 121 Comparison of the cropland data from previous studies and this study

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Several missing data were interpolated in Denmark in 1688, 1750, 1800, and 1881 using the cropland fractions of their neighbors and the linear interpolation method. These interpolation methods were also used by Ramankutty and Foley (1999), Ye, et al. (2015), Wei, et al. (2016); He, et al. (2017), Li, et al. (2018), and Yu and Lu (2018); however, their interpolated data did not reduce the credibility of their datasets. As satellite-based data and survey data at the parish level were unavailable from 1688 to 1881, the interpolated data were impossible to validate using direct fitted observations. Based on the study of Fang et al. (2020), three methods could be used to assess the credibility of historical land cover datasets, including accuracy assessment (quantitative assessment based on quantitatively reconstructed regional land cover data), rationality assessment (qualitative assessment, including the regional historical facts-based rationality assessment and the expertise-based rationality assessment), and likelihood assessment (the credibility of the land cover data for given spatial or temporal units is inferred according to the degree of consistency in land cover data extracted from multiple datasets). Because apart from the data sources we used, other quantitatively reconstructed regional land cover data in Denmark from 1688 to 1881 were unavailable, we employed a regional historical facts-based rationality assessment to analyze the reliability of our interpolated data in Denmark. The following Danish history suggests that linearly interpolated data are reasonable. The national tax system stipulated that each household in Denmark had

50 acres of cropland, no more and no less. The population of Denmark grew steadily from 1690 to 1881. During this period, wars did not cause sudden changes in cropland area in Denmark. The agricultural reform that began in 1789 changed the relationship between landlords and tenant farmers but did not cause a sudden change in cropland area (Jespersen, 2018).

~~5.1 Comparison with global datasets~~5.2 Comparison with global datasets

To show the improvement made by our dataset, three widely used global datasets HYDE 3.2 (Klein Goldewijk et al., 2017), PJ (Pongratz et al., 2007), and KK10 (Kaplan et al., 2011) were selected to compare with our results. As~~Widely used global datasets HYDE 3.2 (Klein Goldewijk et al., 2017), PJ (Pongratz et al., 2007) and KK10 (Kaplan et al., 2011) were selected to compare with our results. Since~~ KK10 only provided the sum of cropland and pasture area data, it ~~is~~ was much larger than the total cropland area from other studies (Figure ~~9~~1~~3~~2). For Scandinavia, the total cropland area from this study ~~is~~ was between that from the HYDE 3.2 and PJ results. However, differences are apparent at the country level, especially in Norway and Denmark. For Sweden, though cropland areas ~~are~~ were close to those from different datasets before 1810, the PJ results ~~are~~ were far less than ~~the~~ those ~~data~~ from HYDE 3.2 and this study after 1875.

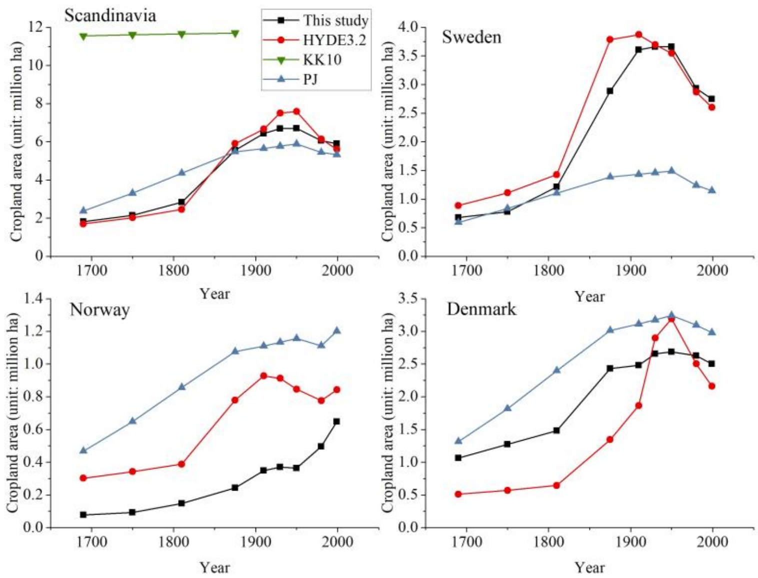

Figure ~~9~~ 1~~3~~2 Comparison of the total cropland area ~~between~~ among HYDE3.2, PJ, KK10 and this study

~~As the total cropland area is small in Scandinavia, relative difference ratio (RD) was used to identify the differences between different datasets, and the formula is as follows:~~

$$RD=\frac{C_{globe}(t)-C(t)}{C(t)}\times 100\% \quad (6)$$

~~where $C_{globe}(t)$ is the cropland area from global datasets, $C(t)$ is the cropland area from this study.~~

Compared with HYDE 3.2, large differences ~~are~~ were found during 1690–1875 in Sweden and Denmark, and ~~in~~ at all time points in Norway. ~~Though~~ Although the RD between PJ and this study ~~is~~ was close before 1810 in Sweden and after 1875 in Denmark, it ~~is~~ was even larger than that between HYDE 3.2 and this study in Norway. PJ datasets overestimated the total cropland area in Norway and Denmark, and after 1875 in Sweden. HYDE 3.2 also overestimated the total cropland area in Norway, but underestimated it before 1910 and after 1980 in Denmark, compared with this study (Table 3). Different definitions of cropland in

Norway caused ~~the~~ cropland area overestimation ~~of the cropland area~~ in Norway by HYDE 3.2 and PJ. Based on the ~~data from~~ FSS data, we inferred that ~~part of the~~some permanent meadow area was ~~added~~ included in the cropland land area by HYDE 3.2 and PJ.

Tabel 3 Relative difference ratio (RD, unit: %) between global datasets and this study

Time points	Sweden		Norway		Denmark	
	RD(HYDE3.2)	RD(PJ)	RD(HYDE3.2)	RD(PJ)	RD(HYDE3.2)	RD(PJ)
1690	30.81	-12.51	290.74	504.51	-52.04	23.59
1750	42.97	7.67	269.80	599.98	-55.40	42.73
1810	17.84	-8.89	162.50	479.01	-56.62	61.85
1875	31.16	-51.98	220.43	342.24	-44.67	24.08
1910	7.40	-60.32	166.00	218.16	-24.79	25.42
1930	1.02	-60.10	146.19	205.73	9.00	19.44
1950	-3.12	-59.30	132.50	217.46	18.83	20.67
1980	-2.32	-57.71	56.38	124.03	-4.67	17.88
1999	-5.25	-58.33	30.04	85.42	-13.59	19.06

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We selected time points with RDs ~~less than~~≤ 30% to compare spatial patterns of cropland distribution from PJ, HYDE 3.2, and this study. PJ ~~has~~ had a spatial resolution of 0.5° × 0.5°, but HYDE 3.2's resolution ~~is~~ was 5′ × 5′. To reduce the ~~error of~~ resampling error, cropland area data from this study were aggregated to 0.5° × 0.5° and 10 km × 10 km to compare with PJ and the resampled HYDE 3.2, respectively. For Sweden, although the differences ~~of~~ in the total cropland area during 1690–1810 from PJ and this study ~~are~~ were small, the spatial patterns of cropland distribution varied ~~greatly~~substantially. Based on the PJ dataset, more cropland ~~is~~ was showned in northern Sweden and Skåne, but the cropland area around the lakes Vänern, Vättern, Mälaren and Hjälmaren in southern Sweden ~~is~~ was less than that in this study. For Denmark, more cropland area ~~is~~ was allocated in western and southeastern Denmark by PJ, but cropland area in northern and southwestern ~~is~~ was scarce (Figure ~~10~~143), which is inconsistent with the facts. Because the land in the eastern of Denmark was more conducive to ~~cultivating~~ cultivation than that in the West, the eastern cropland ~~in the east in history~~area gradually decreased with urbanization development. Increased afforestation and the need for urban expansion had steadily reduced the agricultural area in eastern Denmark (Pedersen and Møllenberg, 2017).

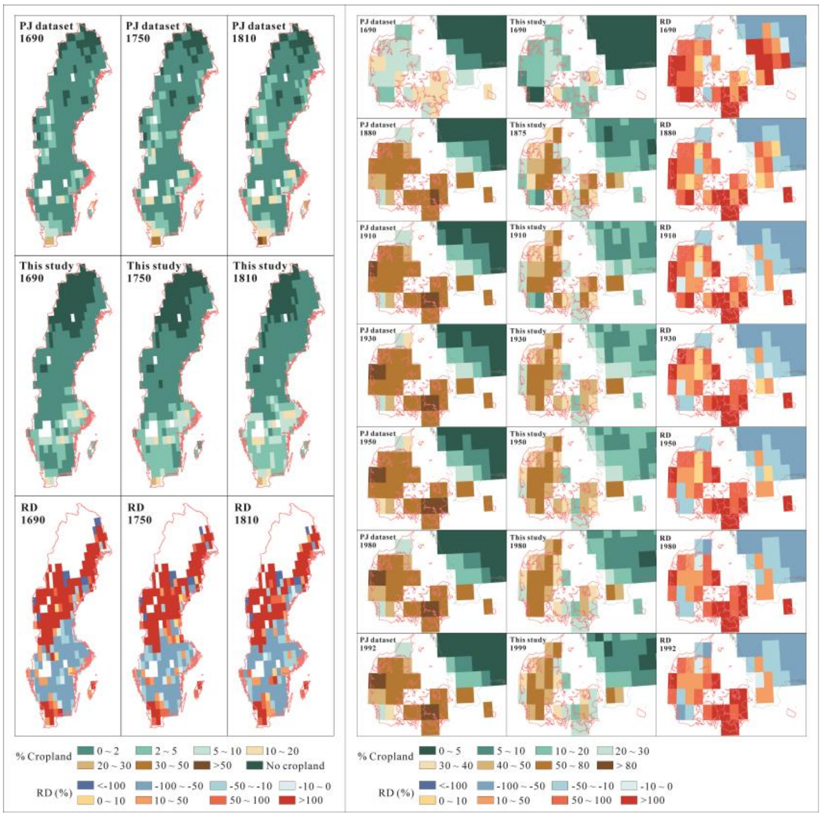

Figure ~~10~~ 143 Comparison of the spatial distribution of cropland area between PJ and this study (The left figure is the comparison ~~of~~ in Sweden and the right one is the comparison in ~~for~~ Denmark)

Although spatial cropland patterns ~~of cropland are~~were in agreement in Sweden between HYDE 3.2 and this study, around the lakes Vänern, Vättern, Mälaren, Hjälmaren and in the northeast coastal area, there were significantly more cropland areas ~~from~~ in HYDE 3.2 ~~are significantly more~~ than in this study. However, in Blekinge, Hallands, Jönköping, Kalmar and Kronoberg ~~Counties~~ counties in ~~the~~ southern of Sweden, there were fewer cropland areas ~~from~~ in HYDE 3.2 ~~is lower~~ than in this study. Moreover, no cropland area ~~is~~ was allocated in northern Sweden from HYDE 3.2, but statistics show ~~these areas have~~ that this area has cropland. The number of grid cells with RD more than 50% or less than -50% accounted~~s~~ for

53%_ ~64% of the total grid cells from 1810 to 1999 (Figure 11154). There is was little difference in the spatial patterns of cropland from 1910 to 1999 for Denmark between HYDE 3.2 and this study (Figure 12165). Relative difference ratios (RD) s of most grid cells are were between -50%~% and 50%. The number of grid cells with RDs between -10%_~10% even accounteds for about approximately 40% of the total grid cells in 1980 and 1999 b. Because Denmark has a small land area and most lands have has been cultivated intensely. Moreover, the topographical differences within Denmark are relatively small. Thus, although HYDE 3.2 used the national cropland area, the cropland area allocation errors were little small in Denmark.

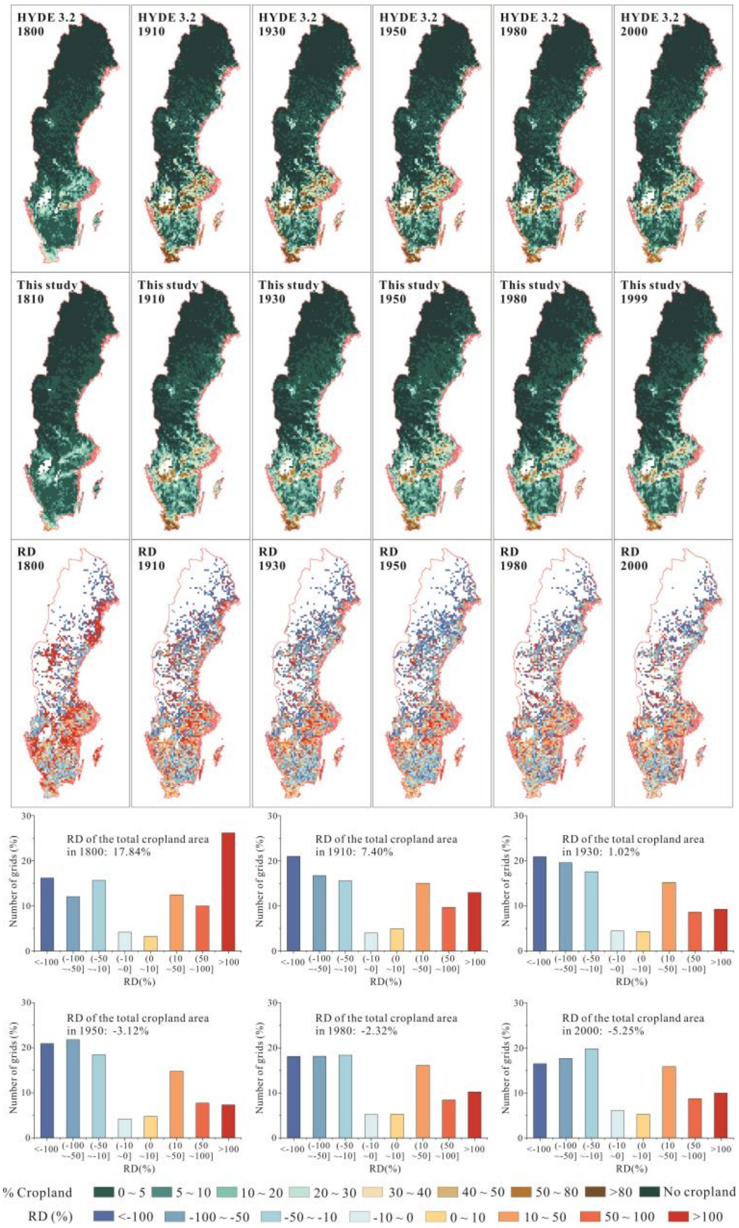

Figure 11 154 Comparison of the spatial distribution of cropland area between HYDE 3.2 and this study in Sweden

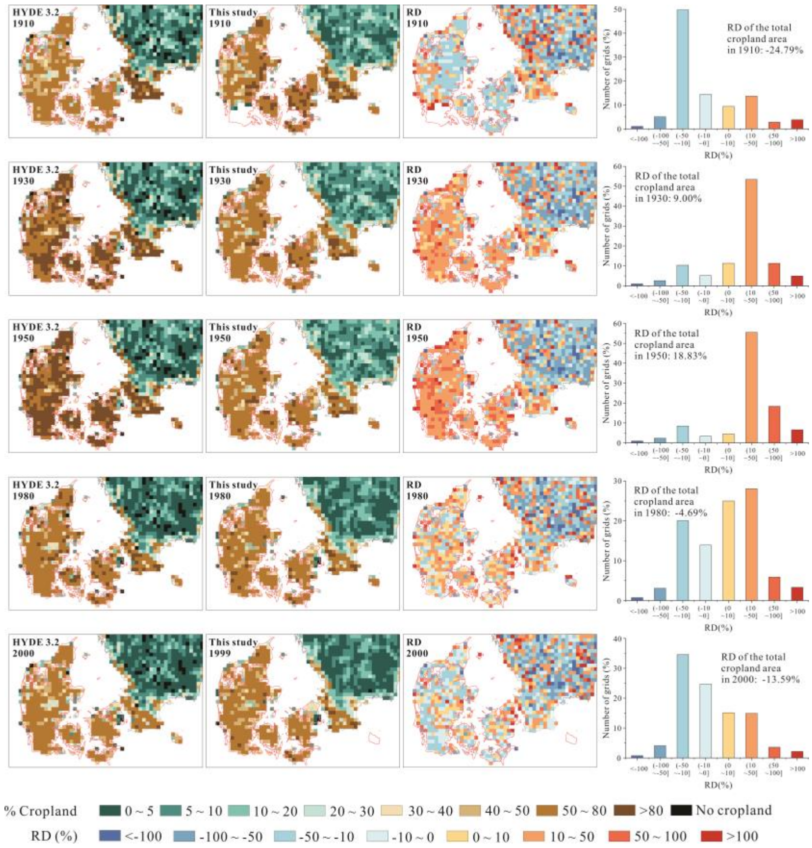

Figure ~~12~~ 165 Comparison of the spatial distribution of cropland area between HYDE 3.2 and this study in Denmark

5.~~2~~ 3 Uncertainties

To develop the cropland area dataset in Scandinavia from 1690 to 1999, we have used many methods to ensure data accuracy. However, there are still uncertainties in this work. Our cropland is defined as the sum of arable land and land under permanent crops. Arable land comprises areas under temporary crops, temporary meadows and pastures, and land ~~with~~ temporarily fallow. Although the ~~areas of~~ temporarily fallow and permanent crops areas account for a small ~~ratio~~ proportion of the total cropland area, the ~~lack~~ absence of records about the size of fallow land makes our cropland before 1875 in Sweden and Norway smaller than the real value. Moreover, we used elevation and slope as factors that affect the spatial distribution of cropland, which may allocate a smaller amount of cropland area to grids that should not have cropland ~~in~~ historically~~y,~~ and make the spatial patterns of cropland insufficiently concentrated. Failure use of settlements in the cropland area allocation model also ~~brought~~ introduced errors in our gridded dataset.

6 Data availability

All cropland data cover for 1690, 1750, 1810, 1875, 1910, 1930, 1950, 1980, and 1999 with a spatial resolution of 1km are available in https://doi.pangaea.de/10.1594/PANGAEA.926591 (Wei et al., 2021).

7 Conclusions

Based on the collected cropland data of each administrative unit from statistics and previous studies, and using a range of data processing and cropland area allocation methods, we developed the cropland area dataset at a spatial resolution of 1km in Scandinavia from 1690 to 1999. Our reconstruction indicated that the cropland area developed slowly before 1810, then increased rapidly until the beginning of the 20th century and~~,~~ remained stable for around 40 years before ~~dropping~~ declining in 1999. At the country level, the cropland area change trends in Sweden and Denmark were almost ~~the same as~~identical to that in Scandinavia. The cropland areas of both Sweden and Denmark reached a peak in 1950. Norway had the least cropland area, which increased gradually from 1690 to 1999. The spatial patterns of cropland distribution showed that Denmark and southern Sweden already had extensive cropland cover in 1690. In the following 100 years, cropland expanded in southern Scandinavia and remained stable in the north. During 1910-1950 the cropland area changed ~~gently~~ slightly but began to decrease in southern and eastern Scandinavia after 1950.

The statistically based accuracy of our gridded cropland dataset has been validated by comparison with satellite-based data (GlobeLand30 and CLC2000) in 2000, although our cropland area is slightly smaller than that from satellite-based data. Comparing our dataset and global datasets shows that KK10 ~~is~~ has much larger total cropland area than this study ~~for the total cropland area~~ in Scandinavia. Although the total cropland area is in agreement in Scandinavia among HYDE 3.2, PJ and this study, more considerable differences are found in cropland areas at the country level. The differences in cropland spatial patterns are also

~~unneglectable~~non-negligible, even ~~in~~ at time points ~~that~~ where the total cropland area differences are small in Sweden and Denmark between PJ and this study. HYDE 3.2 allocates more cropland area ~~in~~ to highly cultivated regions in Sweden but has a lower cropland area between the highly cultivated regions in southern Sweden.

Although some cropland area allocation errors ~~brought~~ introduced uncertainties with our reconstruction, this study improved descriptions of historical cropland change in Scandinavia. Our cropland dataset is an essential reference for a better understanding of the complex climate system.

Acknowledgments

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Author Contribution

WX, WM and LB designed the work. WX wrote the manuscript. FX, YY and CT provided suggestions on structure and methods. ZC helped with downloading the data for cropland allocation. All the authors contributed to the review of the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

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