# Land-use mapping 2022

## Documentation of adjustments in the applied methodology for assessment of land-use changes

Scientific note from DCE – Danish Centre for Environment and Energy

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# Data sheet

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# Summary

Due to Denmark's ratification of the United Nations Framework Convention on Climate Change (UNFCCC) Denmark is obliged to document annual sequestration and emission of carbon dioxide from land use and land cover (LULC) and changes in these. For Denmark, estimation of LULC change is done as a wall-to-wall mapping in raster format for the periods 1990 to 2005 and 2005 to 2011 and annually since 2011. This scientific note describes three methodological adjustments, which were introduced for the inventory of LULC changes for the inventory year 2022 (submission 2024) and which also necessitate adjustment over the whole assessment period from 1990 to 2022.

The first is an adjustment of the method for mapping of roads and subsequent re-estimation of the settlement area which includes roads. Due to changes in the road definition in the applied input data, a backward adjustment is applied, where roads also are mapped in the preceding years (1990 to 2021) if they were included in the respective versions of the input data from these years. As a result, over the whole period from 1990 to 2022, the settlement area is adjusted upwards by 2.2 % or around 11,000 hectares.

The second is a visual control of deforestation and re-estimation of forestland. To reduce an overestimation of deforestation (conversion from forestland to other land uses), all areas, which between 1990 and 2022 were mapped as deforestation, where inspected visually on basis of aerial photos. Based on this inspection, the total area of deforestation between 1990 and 2022 was reduced from 11,592 to 5,215 hectares.

The third is a re-mapping of wetlands. New input data and an improved understanding of wetland restoration data from the Danish Agricultural Agency necessitated a remapping of the wetland category for the whole inventory period from 1990 to 2022. Based on the re-mapping, the total mapped wetland area has been adjusted upwards until around 2006 and downwards after 2006. For the whole period from 1990 to 2022, the area of partly water covered wetland was adjusted downwards by at average around 5,300 hectares and the area of fully water covered wetland was adjusted upwards by at average around 5,600 hectares.

# Sammenfatning

Som følge af Danmarks ratificering af FN's Klimakonvention (UNFCCC), er Danmark forpligtet til at dokumentere binding og udslip af kuldioxid fra arealanvendelse og arealdække samt fra arealændringer. For Danmark er estimeringen af arealændringer foretaget som en væg-til-væg-kortlægning i rasterformat for perioderne 1990 til 2005 og 2005 til 2011 og årligt siden 2011. Dette videnskabelige notat beskriver tre metodiske justeringer, som blev indført for opgørelsen af arealændringer for opgørelsesåret 2022 (indsendelse 2024), og som også nødvendiggør justering over hele opgørelsesperioden fra 1990 til 2022.

Den første er en justering af metoden til kortlægning af veje og efterfølgende genberegning af settlement-arealet, som omfatter veje. På grund af ændringer i vejdefinitionen i de anvendte inputdata foretages en bagudrettet justering, hvor veje også kortlægges i de foregående år (1990 til 2021), hvis de var inkluderet i de respektive versioner af inputdata fra disse år. Resultatet er, at settlement over hele perioden fra 1990 til 2022 er justeret op med 2,2 % eller omkring 11.000 hektar.

Den anden er en visuel kontrol af skovrydning og genberegning af skovarealet. For at reducere en overvurdering af skovrydning (konvertering fra skov til andre arealanvendelser) blev alle områder, der mellem 1990 og 2022 blev kortlagt som skovrydning, inspiceret visuelt på baggrund af luftfotos. Baseret på denne inspektion blev det samlede areal af skovrydning mellem 1990 og 2022 reduceret fra 11.592 til 5.215 hektar.

Den tredje er en ny kortlægning af vådområder. Nye inputdata og en forbedret forståelse af data om genopretning af vådområder fra Landbrugsstyrelsen nødvendiggjorde en ny kortlægning af vådområdekategorien for hele opgørelsesperioden fra 1990 til 2022. Baseret på genkortlægningen er det samlede kortlagte vådområdeareal blevet justeret opad indtil omkring 2006 og nedad efter 2006. For hele perioden fra 1990 til 2022 er arealet af delvist vanddækket vådområde blevet nedjusteret med i gennemsnit omkring 5.300 hektar, og arealet af fuldt vanddækket vådområde er blevet opjusteret med i gennemsnit omkring 5.600 hektar.

# 1 Introduction

Due to Denmark's ratification of the United Nations Framework Convention on Climate Change (UNFCCC), Denmark is obliged to document sequestration and emission of carbon dioxide from land use and land cover (LULC) and changes in these. According to the IPCC guidelines (IPCC, 2006), estimation of LULC must cover following categories: settlement, cropland, grassland, wetland, which is fully water covered, wetland, which is partly water covered, forestland and other land. For Denmark, estimation of LULC change is done as a wall-to-wall mapping in raster format with a resolution of 25x25 meters and is based on available categorical and spatially explicit LULC information. The first LULC inventory was made for the periods 1990 to 2005 and 2005 to 2011 (Levin et al., 2014). Since 2011, the LULC inventory has been updated annually (Levin and Gyldenkærne, 2022).

This scientific note describes three methodological adjustments, which were introduced for the inventory of LULC changes for the inventory year 2022 (submission 2024) and which also necessitate adjustment over the whole assessment period from 1990 to 2022. The first is an adjustment of the method for mapping of roads and subsequent re-estimation of the settlement area. The second is a visual control of deforestation and re-estimation of forestland. The third is a re-mapping of wetlands.

# 2 Adjusted mapping of roads

Settlement is defined as developed land including transportation infrastructure and human settlements. For the Danish inventory, information on transportation infrastructure is derived from the Danish topographical database GeoDanmark (SDFI, 2005-2022) for the period from 2005 to 2022 and from Danish Areal Information System (AIS) (Miljø- og Energiministeriet, 2000) for the year 1990. These include railway lines and roads. Since the road layer in the topographical database includes various types of roads, including paths and small roads, in the LULC inventory, only larger roads are included. In the initial inventory, these comprised highways (motorvej), motorways (motortrafikvej) and roads with a width exceeding six meters (Levin et al., 2014). After 2017, the attribute "road width" was phased out of the topographic database. Therefore, from 2018, roads included in the inventory were traffic roads (trafikvej) and local primary roads (lokalvej primær) (Levin and Gyldenkærne, 2022). By 2021, also this definition was phased out and therefore replaced by main route (hovedrute), thoroughfare route (gennemfartsrute), distribution route (fordelingsrute) and large road (stor vej).

These three different categorisations of roads are not fully consistent. I.e., multiple roads, which were e.g., categorised primary road in 2018 and in later years, were also registered in the topographic database for 2017 and earlier but were not categorised as highway, motorway or road with a width exceeding 6 meters. A simple overlay would result in an increase in the road area of 11,097 hectares or 17.8 % between 2017 and 2018 (Fig. 1, grey line). To reduce this increase, in the earlier version of the LULC mapping, a forward adjustment was applied, where only new roads, which were not earlier registered in the topographic database are included (Fig. 1 dotted line). However, applying this forward adjustment, numerous larger roads established during the inventory period, are not included. Therefore, to include all larger road and to future-proof the inventory, from the year 2022, a backward adjustment is applied. All included roads (throughfare, distribution route, and large road) from the topographical database from 2022 are included and mapped as roads in the preceding years, if they were included in the respective versions of the topographic database from these years (Fig. 1, stippled line). Compared to the former inventory, applying the backward adjustment, over the whole period from 1990 to 2022, at average the road area is adjusted by around +11,000 hectares or +18 %. The total Settlement area is at average adjusted by +2.2 % (Fig. 2).

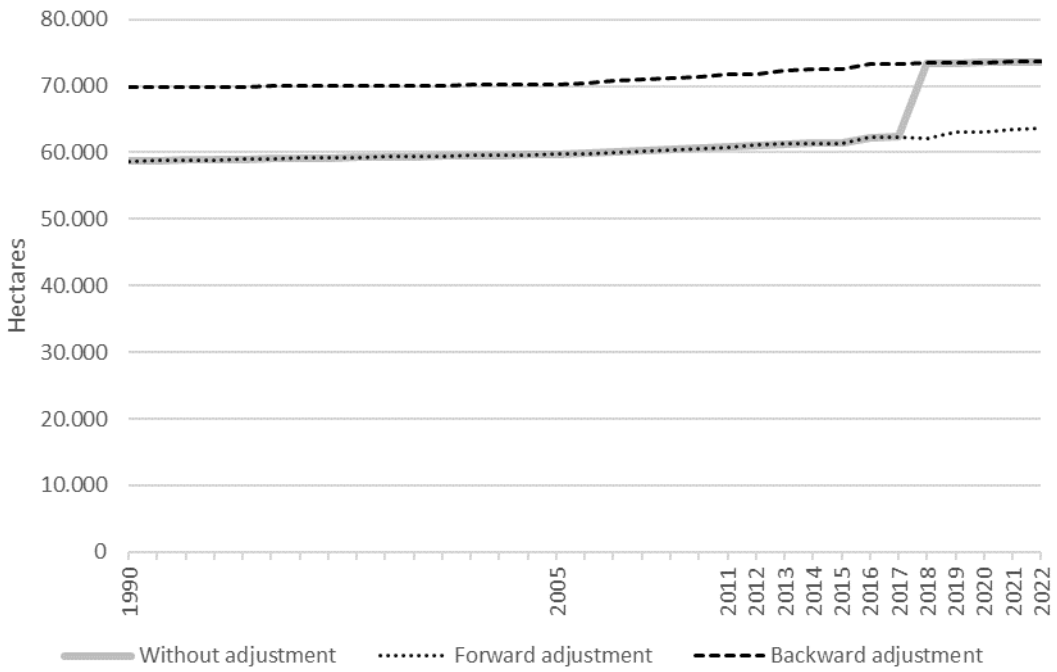


Figure 1 Total reported road area from 1990 to 2022 without adjustment, with forward adjustment and with backward adjustment of roads.

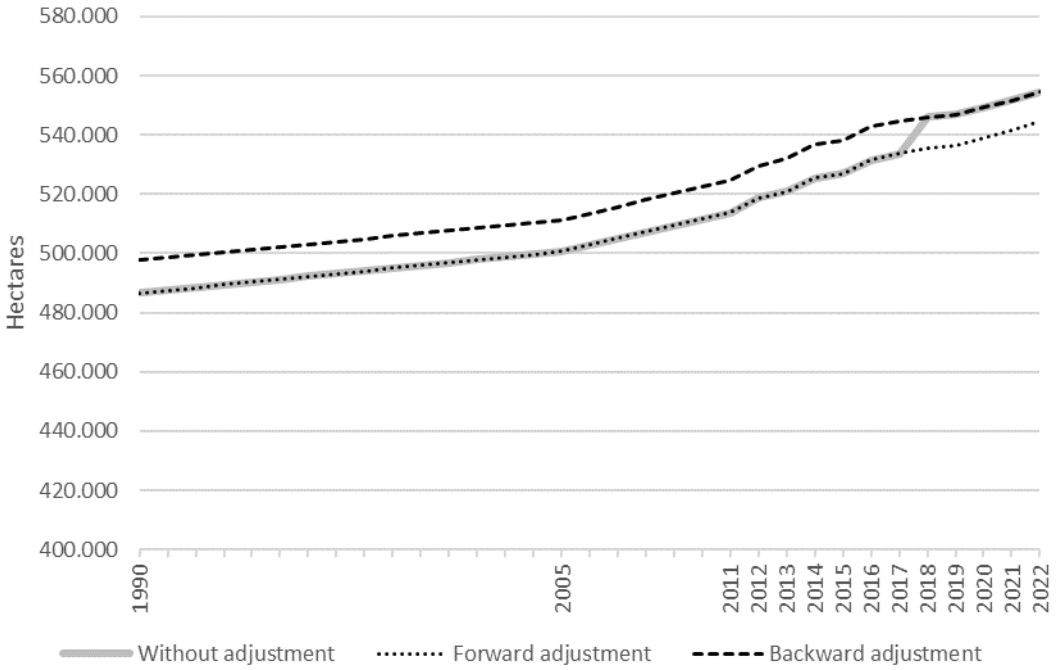


Figure 2 Total reported settlement area from 1990 to 2022 without adjustment, with forward adjustment and with backward adjustment of roads.

# 3 Inspection of deforestation

Forestland is defined as woody vegetation having a minimum tree crown cover of 10 %, a minimum area of 0.5 hectares, a minimum width of 20 meters and a minimum value for tree height, which must be able to reach a minimum height of 5 m at the site. In addition, the forestland includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes and fire breaks. Forests in national parks, reserves, or areas under special protection are included. Conifers for production of Christmas trees as well as forest for energy production, except willow plantations, are also reported under forestland.

Change from forestland to other LULC categories, i.e., deforestation, is mapped, where a new LULC category, e.g., settlement, cropland or grassland replaces forestland. In principle cropland and grassland preclude forestland since agricultural subsidies necessitate removal of shrub and tree vegetation. Consequently, a change from forestland to cropland or grassland is mapped as deforestation. However, for 14 land use categories from the field parcel maps (Danish Agricultural Agency, 2023a), removal of shrub and woody vegetation is not compulsory. Change from forestland to one of these categories, which are listed in Table 1, is therefore not mapped as deforestation but is kept as forestland.

Table 1 Crop types from the field parcel map, where mapping of forestland is possible.

| Crop code | Crop name (DK) | Crop name (EN) |
|---|---|---|
| 250 | Permanent græs, meget lavt udbytte | Permanent grass, very low yield |
| 251 | Permanent græs, lavt udbytte | Permanent grass, low yield |
| 252 | Permanent græs, normalt udbytte | Permanent grass, normal yield |
| 254 | Miljøgræs MVJ-tilsagn (0 N), permanent | Environmental grass (0 N), permanent |
| 271 | Rekreative formal | Areas for recreation purposes |
| 276 | Permanent græs og kløvergræs uden norm, under 50 % kløver | Permanent grass/clover grass without N-norm, <50% clover |
| 286 | Permanent græs og kløvergræs uden norm, over 50 % kløver | Permanent grass and clover grass without N-norm, >50 % clover |
| 312 | 20-årig udtagning | 20 years set-aside |
| 316 | Udtagning med fastholdelse, ej landbrugsareal | Wetland or low-lying areas with set-aside, not agricultural land |
| 318 | MVJ ej udtagning, ej landbrugsareal | Agri-environmental scheme, no set-aside, not agricultural land |
| 319 | MFO-brak, Udtagning, ej landbrugsareal | Agri-environmental scheme, set-aside, not agricultural land |
| 321 | Miljøtiltag, ej landbrugsarealer | Environmental initiative, not agricultural land |
| 907 | Naturarealer, økologisk jordbrug | Nature area, organic agriculture |
| 908 | Naturarealer, ansøgning om miljøtilsagn | Nature area, application for environmental subsidies |

Yet, the total area of forestland, which from 1990 to 2022 was mapped as deforestation amounts to 18,512 hectares or 3.5 % of the total 1990 area of forestland. Of this deforestation, 6.921 hectares (37 %) were mapped as deforestation from Christmas trees, while 11,592 hectares (63 %) were mapped as deforestation from other forestland. Deforestation from Christmas trees, particularly to cropland or grassland, are reasonable, as Christmas trees principally

can be seen as an agricultural crop, subject to agricultural rotation. Deforestation of other forestland is associated with much greater uncertainty and can be biased by the applied methodology and data. Originally, forestland for the years 1990, 2005 and 2011 were mapped on basis of Landsat satellite imagery (Levin et al., 2014). After 2011, for some of these areas, applied field parcel data contained cropland or grassland categories, which exclude forest. These areas were thus mapped as deforestation. However, a first superior inspection pointed at part of this deforestation being an artifact, where areas were either never forested, i.e., the satellite-based forest maps were incorrect, or were still covered by forest, i.e., the registered cropland or grassland type from the field parcel map was not correct.

Therefore, for areas, which in the periods from 1990 to 2005, from 2005 to 2011 and annually from 2011 to 2022 were mapped as deforestation (except Christmas tress), a manual inspection based on visual interpretation of aerial photos was elaborated. These areas (6,509 polygons / 11,592 hectares) were categorised into: 1) Areas which were deforested (where tree cover was removed); 2) Areas, which were still forestland (were not deforested); and 3) Areas, which were not forested in preceding years. The results are listed in Table 2. For the whole period from 1990 to 2022, the total area of deforestation, except from deforestation from Christmas trees, was 11,592 hectares. 4,444 hectares (38 %) were categorised as having not been forested in preceding years, 1,933 hectares (17 %) were categorised as not being deforested and thus were mapped as forestland in the following year and 5,215 hectares (45 %) were categorised as actual deforestation.

Table 2 Results of visual interpretation of deforestation from forestland, except Christmas trees.

| Period | 1990-2005 | 2005-2011 | 2011-2012 | 2012-2013 | 2013-2014 | 2014-2015 | 2015-2016 | 2016-2017 | 2017-2018 | 2018-2019 | 2019-2020 | 2020-2021 | 2021-2022 | 1990-2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total mapped deforestation | 420 | 2,341 | 154 | 123 | 417 | 2,260 | 1,423 | 17 | 1,019 | 380 | 1,080 | 845 | 1,114 | 11,592 |
| Has not been forest in preceding years | 58 | 702 | 53 | 9 | 252 | 644 | 589 | 7 | 512 | 180 | 436 | 409 | 592 | 4,444 |
| No deforestation (remains forestland) | 29 | 286 | 14 | 5 | 104 | 1,174 | 77 | 0 | 115 | 15 | 98 | 6 | 8 | 1,933 |
| Actual deforestation | 333 | 1,353 | 87 | 109 | 62 | 443 | 757 | 10 | 391 | 185 | 545 | 430 | 513 | 5,215 |

Fig. 3 shows reported annual rates of deforestation for all periods before the adjustment based on visual inspection and after the adjustment. Particularly after 2014, reported deforestation is reduced substantially. A major cause for this reported deforestation is that a large number of field parcels, which prior to 2015 were registered as permanent environmental grass (crop code 254), and where mapping of forestland is possible (Table 1), in following years were registered as environmental grass in rotation (crop code 247), where forestland in principle is not allowed, but where the visual inspection revealed that areas are still forested. Deforestation of Christmas trees was not inspected and thus kept the same before and after adjustment.

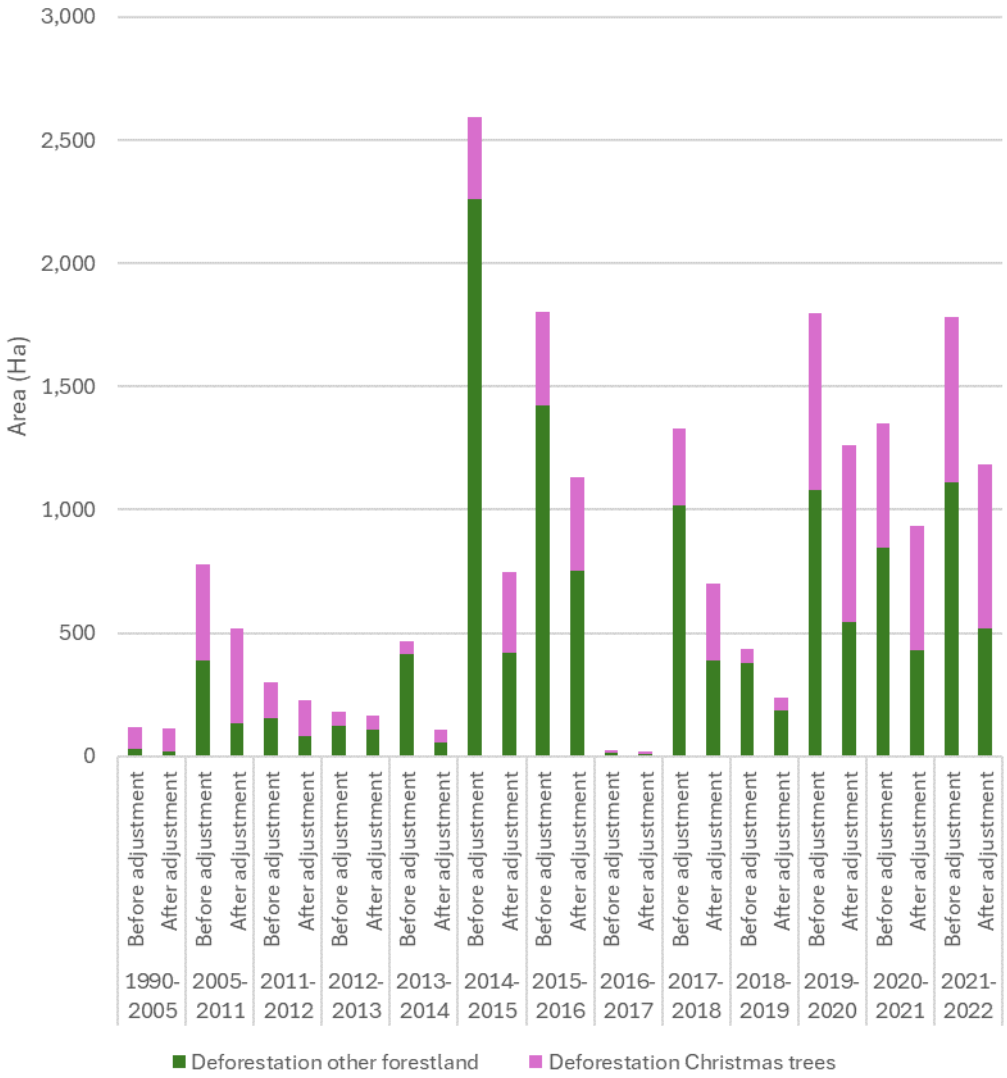


Figure 3 Annual rates of deforestation for all periods before and after adjustment based on visual interpretation.

Fig. 4 shows the change in total mapped area of forestland from 1990 to 2022 before and after adjustment. Before 2018, the total mapped area of forestland was at average reduced by 2,065 hectares or 0.36 %. Since 2018, the total mapped area of forestland was at average increased by 1,192 hectares or 0.19 %.

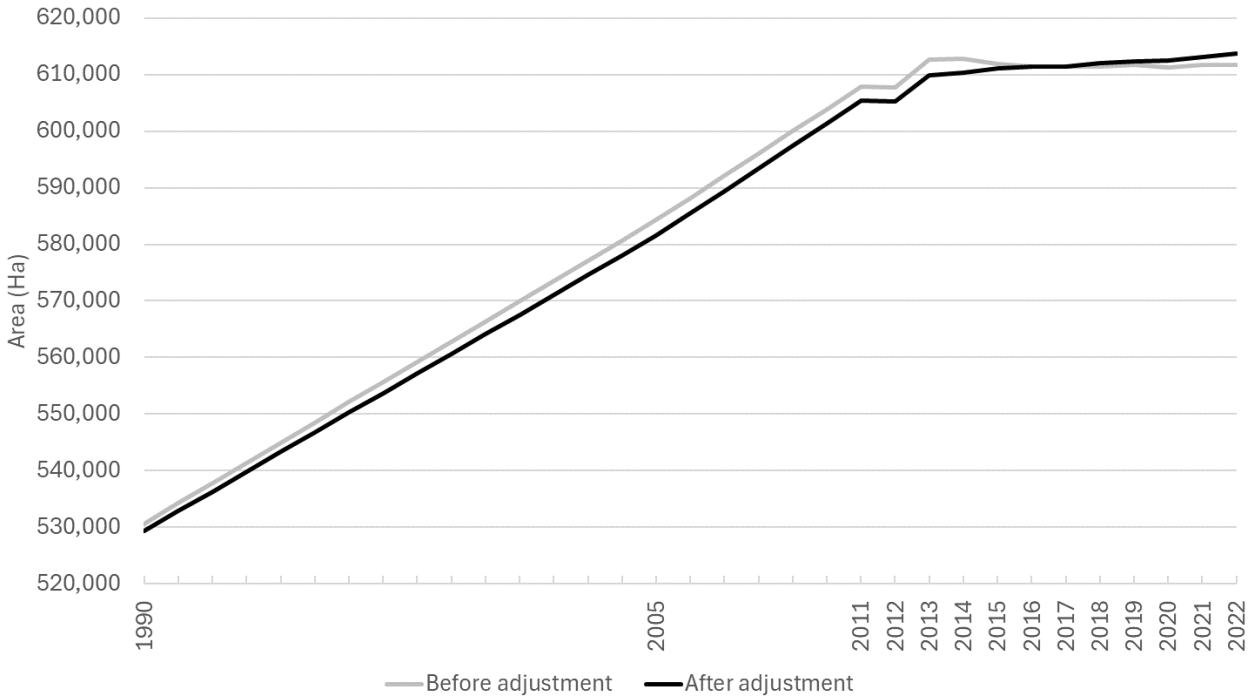


Figure 4 Total mapped area of Forestland from 1990 to 2022 before and after adjustment based on visual interpretation.

# 4 Wetland

The wetland category consists of two sub-categories: Fully water covered wetlands and partly covered wetlands. Fully water covered wetlands are defined as lakes and other permanent water bodies which are saturated by water throughout the year. For the Danish inventory, areas of open sea are not included in this category. Partly water covered wetlands are defined as land with raised water tables that flood the area in certain periods over the year. While fully water covered wetlands can be directly mapped from categorical datasets of lakes and ponds from the registration of protected habitats (Danmarks Miljøportal, 2022) and from the topographical database from GeoDanmark (SDFI 2005-2022), for partly water covered wetlands no national dataset is available. Therefore, the mapping of this category is based on a combination of maps designating wetland restoration areas from the Danish Agricultural Agency (2023b), a map of protected habitat types, where mires/bogs, freshwater meadows and coastal meadows can be categorised as partly water covered wetlands (Danmarks Miljøportal, 2022) and field parcel maps (Danish Agricultural Agency 2023a). The method applied to map partly water covered wetland is documented in Levin et al. (2014) and Levin (2022). Yet, new input data and an improved understanding of wetland restoration data from the Danish Agricultural Agency necessitated a remapping of the wetland category for the whole inventory period from 1990 to 2022.

Maps of wetland restoration from the Danish Agricultural Agency include different types of measures. Table 3 contains information on the designated area for each implementation year within each measure. The implementation year is the assigned end year (indicating when the designation was implemented) and for designations, where the end year is not assigned, the start year (indicating when the designation was approved by the agricultural agency). In total, measures contain 38,048 hectares of wetland designations. Around 12 % are not assigned a start or end year. For these designations, it is assumed that they can potentially have been implemented at any time between 1990 and 2022. I.e., these areas are mapped as partly water covered wetland in the year, where crop types from the respective field parcel map allow for mapping of wetland, as described in the section below.

Table 3 Aera of for different measures for wetland restoration from the Danish Agricultural Agency and year of implementation. Source: Danish Agricultural Agency (2023b).

| | Type of measure | | | | | | |
|---|---|---|---|---|---|---|---|
| | Water environment plans (VMP II and VMP III) | Wetlands for reduction of phosphorus leaching | Wetlands for reduction of nitrogen leaching | Wetlands for restoration of hydrology | Restoration of wetlands in low lying areas | Other wetland restoration | Total |
| Year of implementation | Area (hectares) | | | | | | |
| 1999 | 35 | | | | | | 35 |
| 2000 | 67 | | | | | | 67 |
| 2001 | 134 | | 1 | | | | 135 |
| 2002 | 433 | | | | | | 433 |
| 2003 | 1,000 | | 6 | | | 187 | 1,193 |
| 2004 | 1,029 | | | | | 274 | 1,303 |
| 2005 | 494 | | | | | 26 | 520 |
| 2006 | 1,655 | | | | | 3 | 1,658 |
| 2007 | 559 | | | | | | 559 |
| 2008 | 46 | | | | | | 46 |
| 2009 | 744 | | | | | | 744 |
| 2010 | 1,395 | | 178 | | | | 1,574 |
| 2011 | 852 | | 1,478 | | | | 2,330 |
| 2012 | 1,343 | 1 | 245 | | 35 | 7 | 1,631 |
| 2013 | | | 1,168 | | | 59 | 1,227 |
| 2014 | | 28 | 562 | 128 | | 2 | 719 |
| 2015 | | 55 | 1,418 | 236 | 12 | | 1,722 |
| 2016 | | 7 | 801 | 0 | 7 | | 815 |
| 2017 | | 32 | 1,152 | 452 | 475 | | 2,110 |
| 2018 | | | 1,875 | 748 | 614 | | 3,237 |
| 2019 | | 25 | 2,867 | 511 | 452 | | 3,854 |
| 2020 | | 60 | 3,502 | 523 | 1,762 | | 5,846 |
| 2021 | | 5 | 1,067 | 194 | 92 | | 1,358 |
| 2022 | | | 216 | 15 | 158 | | 389 |
| 2023 | | | 35 | | | | 35 |
| Year of implementation not available | 3,130 | | 8 | 1,370 | | | 4,507 |
| Total | 12,916 | 213 | 16,578 | 4,177 | 3,606 | 559 | 38,048 |
| Proportion of all measures (%) | 33.9 | 0.6 | 43.6 | 11.0 | 9.5 | 1.5 | 100.0 |

Delineations of designations of wetland restoration are relatively coarse and do include areas, which according to the field parcel map, cannot be categorised as wetland. These include cropland as well as grassland, which is regularly grazed, mowed and/or being fertilised. Therefore, wetland designations are only mapped as wetland if these do not overlap with any field parcels or with a crop type, where grazing, mowing and/or fertilisation is not allowed or possible. These crop types are listed in Table 4.

Table 4 Crop types from the field parcel map, where mapping of wetland is possible.

| Crop code | Crop name (DK) | Crop name (EN) |
|---|---|---|
| 316 | Udtagning med fastholdelse, ej landbrugsareal | Wetland or low-lying areas with set-aside, not agricultural land |
| 317 | Vådområder med udtagning | Wetland for set-aside |
| 318 | MVJ ej udtagning, ej landbrugsareal | Agri-environmental scheme, no set-aside, not agricultural land |
| 319 | MFO-brak, Udtagning, ej landbrugsareal | Agri-environmental scheme, set-aside, not agricultural land |
| 321 | Miljøtiltag, ej landbrugsarealer | Environmental initiative, not agricultural land |

In practice, for a specific year, wetland is mapped, if the year of implementation is the same as or earlier than the assigned year of implementation and if the area does not overlap with any field parcels or with one of the crop types, where mapping of wetland is not possible. Furthermore, a mapped wetland areas is categorised as fully water covered wetland if it overlaps with the lake layer from the topographic database from GeoDanmark and otherwise as partly water covered wetland.

Furthermore, there are areas which over the whole assessment period from 1990 to 2022 were not mapped in the field parcel layers but overlap with wetland categories from the map of protected habitat types. In cases, where these areas overlap with lakes in the map of protected habitat types, they were for the whole period mapped as fully water covered wetlands and in cases where these areas overlap with mires/bog, freshwater meadow or coastal meadows in the map of protected habitat types, they were for the whole period mapped as partly water covered wetlands.

Fig. 5 shows the total mapped area of wetland for the period from 1990 to 2022, for fully water covered wetland and partly water covered wetland and for the different data sources. The total mapped wetland area increased by 19,179 hectares or 17.5 % from 109,582 in 1990 to 128,766 hectares in 2022 with the largest increase taking place after 2011. Partly water covered wetlands make up 65.2 % of this increase and fully water covered wetlands 34.8 %. 17,588 hectares of wetland were mapped on basis of the designations of wetland restoration, which is around 46 % of the total area of registered wetland restoration (see Table 3). Around 20,000 hectares or 52 % of the designations of wetland restoration can, according to crop types in the field parcel maps, not be considered wetlands. Over the whole period, 103,432 hectares are mapped on basis of the map of protected habitat types. Of this area, 52.4 % are mapped as fully water covered wetland and 47.6 % as partly water covered wetland. Finally, fully water covered wetlands from other sources, i.e., lakes and ponds, which do not overlap with designations for wetland restoration or with wetlands in the map of protected habitat types increased from 3,305 hectares in 1990 to 7,741 hectares in 2022 and make up 6.0 % of the total wetland area in 2022.

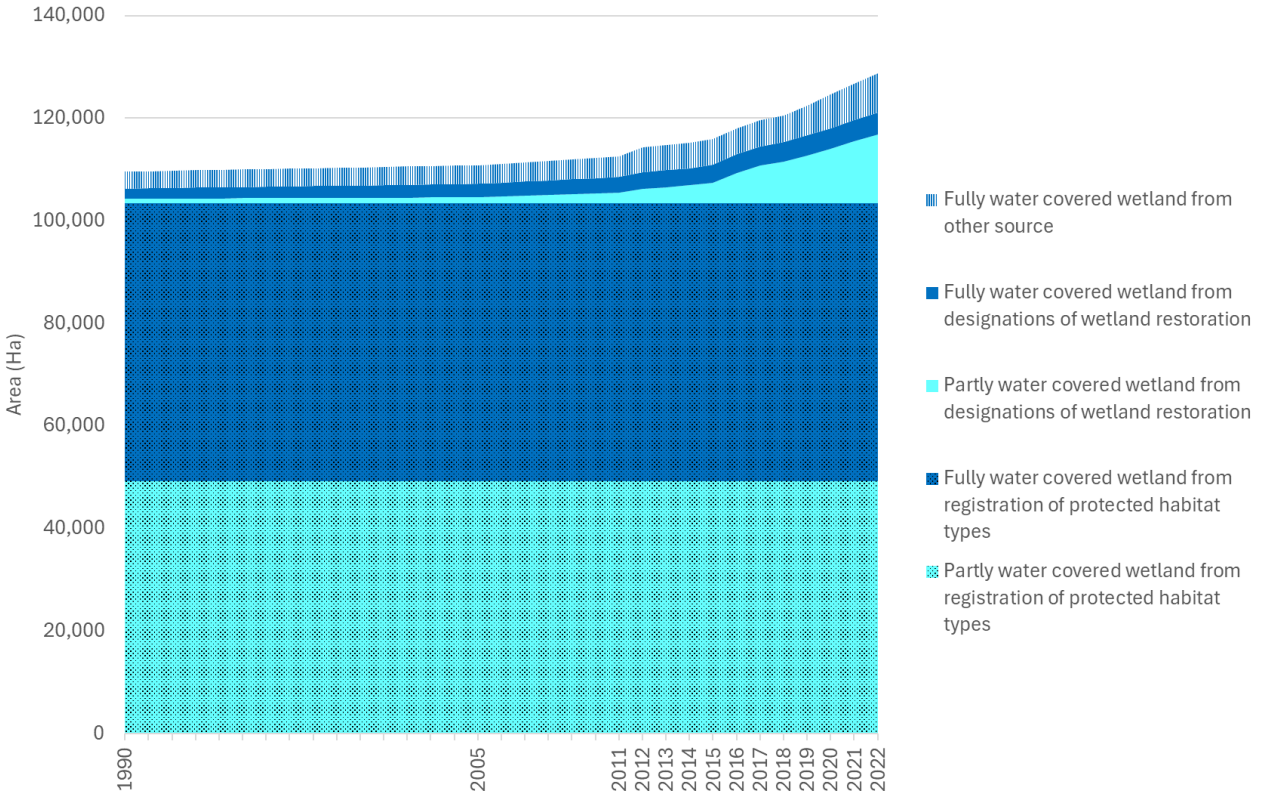


Figure 5 Mapped wetland area from 1990 to 2022, grouped into wetland categories and sources.

For the whole assessment period, Fig. 6 shows the total wetland area before and after adjusting the applied method. The total mapped wetland area has been adjusted upwards until around 2006 and downwards after 2006. For the whole period from 1990 to 2022, the area of partly water covered wetland was adjusted downwards by at average around 5,300 hectares and the area of fully water covered wetland was adjusted upwards by at average around 5,600 hectares.

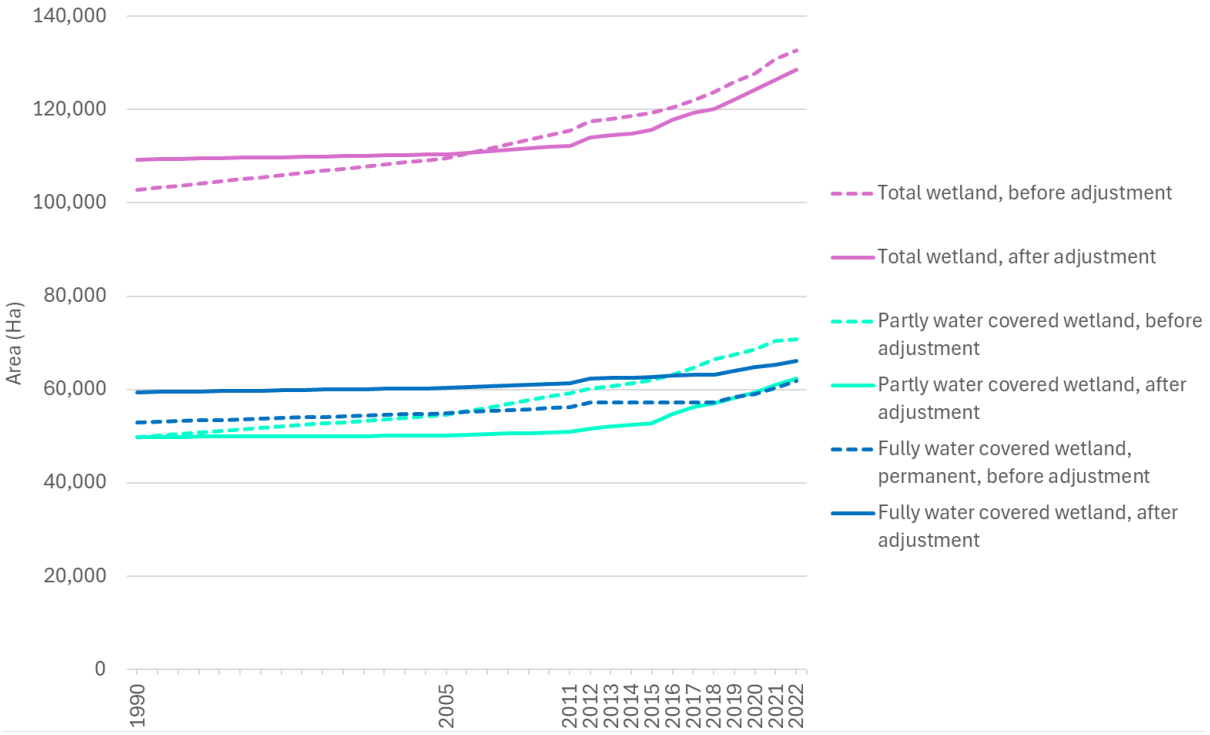


Figure 6 The mapped wetland area from 1990 to 2022 before and after adjustment of the applied method and data.

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