ASSESSMENT OF CHANGE IN BIOMASS FROM 2006 TO 2014/2015 OF NON-FOREST WOODY VEGETATION IN DENMARK

Technical documentation

Technical Report from DCE – Danish Centre for Environment and Energy No. 178 2020

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract:	This report contains the technical documentation of the assessment of changes in biomass for formations of non-forest woody vegetation (NFW) in Denmark. National high-resolution digital terrain and surface models were applied to map formations of NFW for 2006 and for 2014/2015. NFW formation were grouped into formations, which during the studied period were unchanged, removed and emerged. For each category, volumes were calculated and, based on field measurements, converted into biomass. While estimated net-changes are relatively small, absolute changes in terms of removed and emerged formations are significant
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Preface

This study was conducted as part of the documentation concerning the Kyoto protocol, Article 3.4, for the second commitment period, 2012–2020 (SINKS), financed by the Danish Ministry of Climate, Energy, and Utilities.

The estimated changes in biomass form the basis for the reporting of carbon dioxide emissions and sinks as part of the Danish greenhouse gas emission inventory.

The authors wish to thank Mikkel Lehm Nielsen, HedeDanmark, Sune Glitrup, Hededanmark and Chresten Møller Petersen, Skovdyrkerne, for providing field measurements of wood chips for selected formations of non-forest woody vegetation and Niels Hedegaard Madsen, Fjernvarme Fyn for providing data on chips conversion to dry matter.

Sammenfatning

Denne rapport indeholder den tekniske dokumentation af opgørelsen over ændringer i biomasse i vedvegetation i det danske landbrugslandskab, som ikke er omfattet af skov (NFW). Med udgangspunkt i nationale højopløselige terræn- og overflademodeller samt anden rumlig information blev NFW elementer kortlagt for 2006 og for 2014/2015. En rumlig model, som muliggør registrering af ændringer mellem 2006 og 2014/2015 blev udviklet og NFW elementer blev grupperet i elementer som i undersøgelsesperioden var uændrede, elementer som var blevet fjernet og elementer som var fremkommet. For hver gruppe blev volumen beregnet. Baseret på målinger fra Hededanmark, blev volumen konverteret til volumen af træflis. Med udgangspunkt i eksisterende studier blev volumen af træflis konverteret til ton tør biomasse. Resultaterne viser at det samlede areal med NFW mellem 2006 og 2014/2015 steg med 6,7 procent og den samlede biomasse med 6,1 procent. Denne mindre stigning dækker imidlertid både over områder med et betydeligt tab på 392 kiloton (5,5 procent i forhold til 2006) og områder med en gevinst på 826 kiloton (11,6 procent i forhold til 2006.

Summary

This report contains the technical documentation of the assessment of changes in biomass for formations of non-forest woody vegetation (NFW) in the Danish rural landscape. Based on high-resolution digital terrain and surface models together with additional spatial land use information, formations of NFW for 2006 and for 2014/2015 were mapped. A spatial model, enabling detection of changes from 2006 to 2014/2015 was developed and NFW formation were grouped into formations, which during the studied period were unchanged, removed and emerged. For each category, volumes were calculated. Based on field measurements provided by Hededanmark, NFW volumes were converted into volume of wood chips. Finally, based on existing studies, wood chip volume was converted to tons of dry biomass. Results show that between 2006 and 2014/2015 the total area of NFW increased by 6.7 percentage and total biomass by 6.1 percentage. However, with a loss of 392 kilotons (5.5 percent of 2006) and a gain of 826 kilotons (11.6 percent of 2006), absolute changes where significant.

1 Introduction

According to the United Nation's (UN) framework convention on climate change (European Commission, 2013) countries are obliged to report greenhouse gas emissions from Land Use, Land-Use Change and Forestry (LULUCF). This obligation includes reporting emissions originating from changes in woody vegetation, which does not comply with the convention's definition of forest. These areas of non-forest woody vegetation (NFW) comprise smaller woodlots, groups of trees, single trees with an area <0.5 hectares as well as linear wooded elements like hedgerows and lines of trees with a width of maximum twenty meters (Penman et al., 2003) . Furthermore, NFWs are part of the agricultural landscape, i.e. they are located within or at the edge of cropped land or grassland. The aim of this study was to assess changes in biomass caused by the spatio-temporal dynamics of NFW. In order to achieve that, LiDAR data from 2006 and from 2014 / 2015 were utilized as they provide detailed input to assess the change in vegetation volume. By using LiDAR data from two different point in time, it was possible to delineate formations of NFW, assess their temporal dynamics and finally estimate change in biomass.

This report contains the technical documentation of the assessment of changes in biomass for formations of NFW for Denmark. The structure of the report is as follows: Chapter 2 contains a description of applied data. In Chapter 3, the applied methods are described. Results are presented and discussed in Chapter 4.

In the report, the following terminology is applied:

- A *dataset* is a collection of data, originating, produced and supplied by one institutional body
- A *layer* refers to a map layer, containing specific spatial information, such as land use or land cover
- *Raster data* are spatial data, organized in raster cells
- *Cell size* refers to the dimensions (length and width) of a single cell contained in a raster
- *Resampling* refers to the method of changing the cell size of a raster
- The term *overlay* refers to the spatial combination of two or more layers into one layer, where information from all applied layers are contained
- *Feature* refers to a representation of a real-world object in a map

2 Applied data

2.1 ALS datasets

Airborne LiDAR (Light Detection and Ranging) is a remote sensing technology that uses light in the form of laser pulses to measure the range between a sensor and the Earth's surface. Raw airborne LiDAR data (ALS) come in the form of point clouds with X, Y, Z coordinates, where each point refers to one laser return after the pulse interacted with the land surface. The pulses might penetrate certain land cover types, depending on the characteristics of both the laser pulse and the land cover (i.e. penetration of an open vegetation canopy) resulting in more than one return per pulse.

A time delay between emitting a pulse and recording its return to the sensor after reflection from the Earth's surface is used to determine the distance between the sensor and the surface. Based on return order and filtering algorithms, digital surface models (DSM), providing elevation for above ground objects (such as vegetation) as well as digital terrain models (DTM), providing elevation of the ground, can be created.

DSM and DTM are frequently interpolated in raster formats with cell sizes set proportionally to the density of the original point cloud data. For this study, the DSM and DTM from 2006 provided by COWI (2007) and for 2014/2015 provided by the Agency for Data Supply and Efficiency (2015) were applied. The 2014/2015 dataset uses Jonathan Richard Shewchuks Triangle to triangulate the point cloud (Agency for Data Supply and Efficiency, 2017). Information about the interpolation method for the 2006 datasets is not available. The 2006 ALS dataset has a point density of 0.5 points per m^2 with a maximum distance between points of 1.5 meters. The horizontal accuracy (X, Y) of the dataset is 60 cm while the vertical (Z) accuracy is 7 cm. The newer ALS acquisition from 2014/2015 provides data with a point density of 4 to 5 points per m^2 with 0.47 meters of maximum distance between points. The horizontal accuracy is 15 cm while the vertical accuracy is 6 cm. The resulting elevation models of 2006 have a cell size of 1.6 x 1.6 meters and the 2014/2015 models a cell size of 0.4 x 0.4 meters. By subtracting the DTM from the DSM, a normalised DSM (nDSM or also frequently termed as Canopy Height Model) was created, containing information about any objects' height above the ground for both dates. In order to enable later comparison of the two raster datasets, the nDSM for 2006 was resampled from the original cell size of 1.6 x 1.6 meters to 0.4 x 0.4 meters.

2.2 Aerial photos

For quality control of the NFW width estimation from 2006 and 2014/2015 nDSMs as well as for the accuracy estimation of the changes in the location of NFWs orthorectified aerial photos (orthophoto) from 2006 and 2015 (Agency for Data Supply and Efficiency, 2006 and 2015b) were used. The photos have a spatial resolution of 40 centimetres for 2006 and 25 centimetres for 2015.

2.3 Additional spatial data

Since our study only concerns NFW within the agricultural landscape, categorical spatial information was applied to exclude areas from the nDSM, which do not comply with this requirement. Information on agricultural land use was extracted from the national Integrated Administration and Control Systems (IACS) database. IACS was set up by the European Commission following the 1992 reforms (Commission of the European Communities, 1992) demanding member states to adopt the system in order to document agricultural subsidies. The applied data consist of a field parcels map for the year 2015, containing specific information about the agricultural land use (Ministry of Environment and Food 2015 a) and a field block map for 2015, containing general land use information within field blocks (Ministry of Environment and Food 2015 b). Furthermore, thematic layers of the features: buildings, lakes and forest from the Danish topographic database (Agency for Data Supply and Efficiency, 2015c) were utilized.

2.4 Field Data from Hededanmark and Skovdyrkerforeningen

As part of their business, the Danish company Hededanmark and Skovdyrkerforeningen (The Danish association of foresters) provides the service to remove hedgerows and small lots of woody vegetation. Removed vegetation, which includes both above-ground vegetation, is sold as wood chips and thus measured in cubic meters. For the period from 2016 to 2018, for 18 locations, comprising 103305 m^2, Hededanmark and Skovdyrkerforeningen provided the exact delineation and wood chip volume in cubic meters of removed hedgerows and woodlots. This information was applied to convert of vegetation volume derived from the nDSMs into wood chip volume and hence to total carbon stock.

3 Method

3.1 Definition of non-forest woody vegetation (NFW)

Corresponding with the FAO definition of land use categories dominated by woody vegetation (Food and Agriculture Organization of the United Nations, n.d.), for this study, NFW is defined as vegetation formations of woody vegetation with heights equal to or exceeding two meters and smaller than 0.5 hectares or with a width of maximum twenty meters. Formations of NFW thus include small lots of woody vegetation as well as hedgerows and lines of trees. Furthermore, NFW is located within or at the border of agricultural land, including cropland and grassland. Finally, agricultural land use, which is associated with woody vegetation, such as Christmas trees, orchards or energy trees are by definition not included in NFW.

3.2 General approach

Figure 3.1 illustrates the general approach, which was applied to assess dynamics in biomass for formations of NFW. The approach includes following processing and modelling steps:

1. From the nDSMs for 2006 and for 2014/2015, surface heights equal to or exceeding 2 meters were extracted.
2. Based on the field parcel and field block layers as well as specific features from the topographical database, a mask, representing the potential area, where NFW can be located, was created.
3. Surface heights equal to or exceeding two meters and located within the mask of potential NFW were extracted, resulting in layers for delineations of NFW for 2006 and for 2014/2015.
4. The layers of NFW delineation for 2006 and for 2014/2015 were overlaid and spatially adjusted, resulting in a layer containing changes in delineation of NFW.
5. By multiplying the cell sizes with heights, layers of NFW volume were created for 2006 and for 2014/2015.
6. Field data of biomass measurement were applied to transform NFW volume to biomass and change in biomass.

In the following paragraphs, the single processing steps are described in further detail.

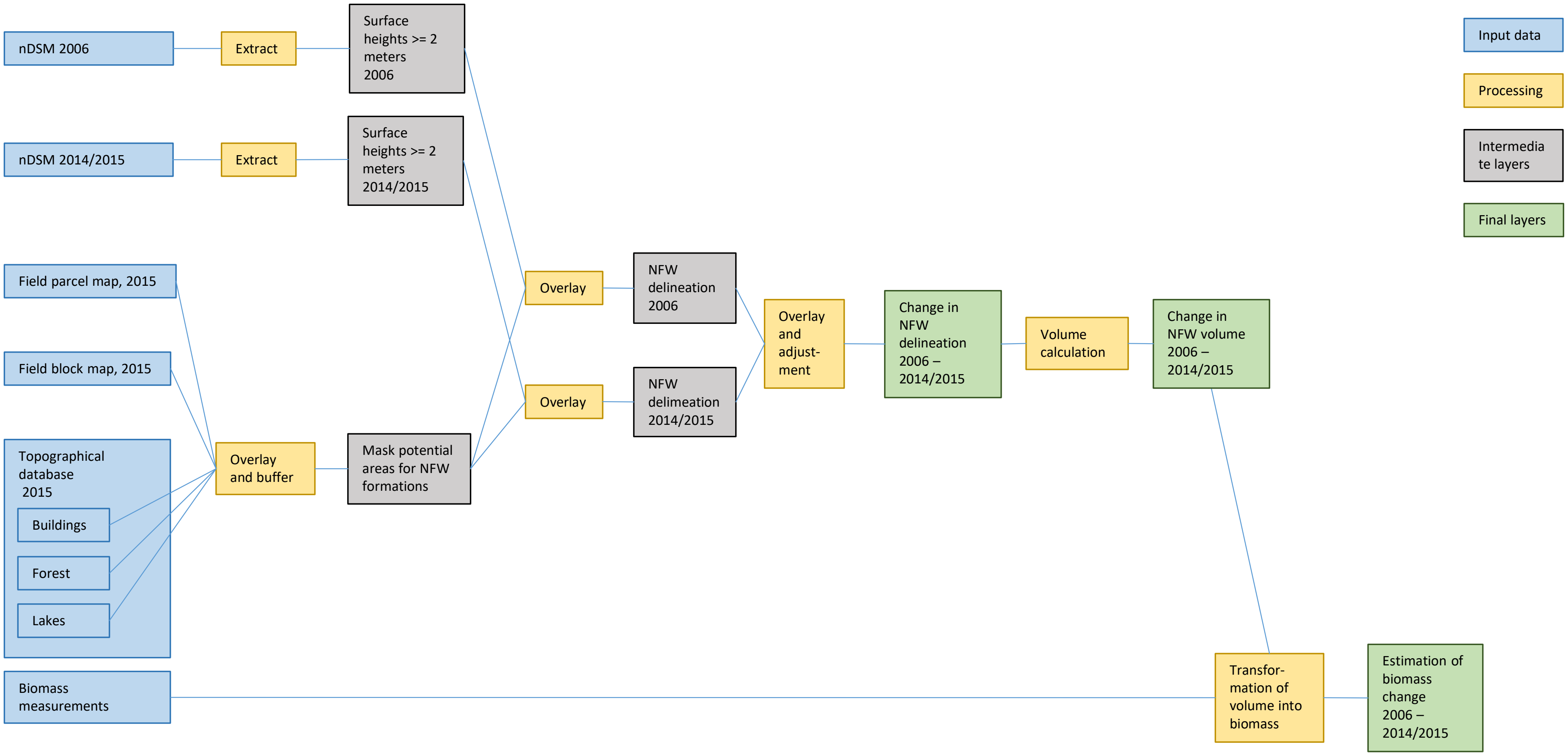

Figure 3.1 Flow diagram of the applied methodological approach.

3.3 Localising NFW

The first part of the assessment of change in biomass within formations of non-forest woody vegetation comprised the localisation and delineation of formations of NFW. This was done for both 2006 and for 2014/2015.

Extraction of surface heights equal to or exceeding two meters.

In agreement with the definition of NFW, from the nDSMs for 2006 and for 2014/2015, cells with surface heights equal to or exceeding two meters were extracted as illustrated in Fig 3.2.

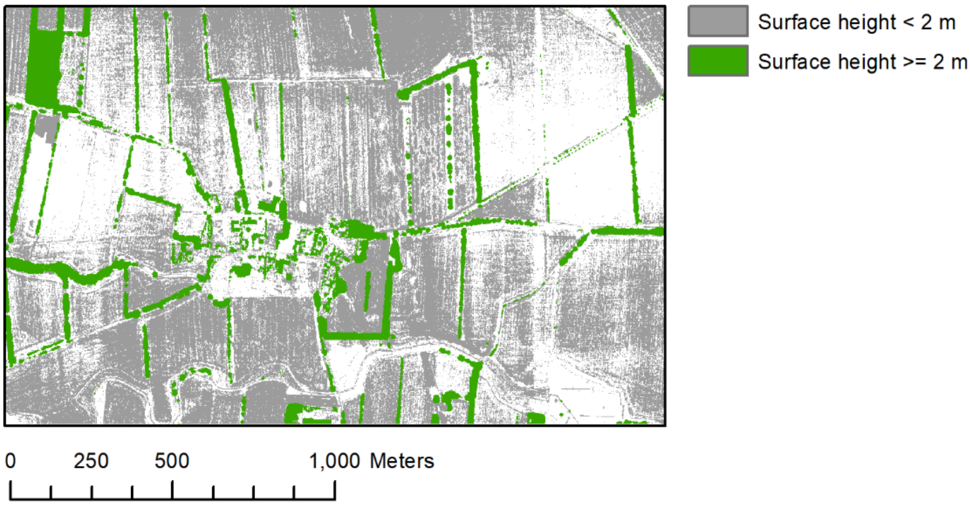

Figure 3.2 Illustration for a map extract of extraction of surface heights >= 2 meters from the 2014/2015 normalised digital surface model.

3.3.1 Initial masking of potential NFW formations

In agreement with the definition of NFW, a mask comprising potential areas, where NFW can be localised, was created. The mask was based on the 2015 field parcel map, the 2015 field block map and selected features from the 2015 topographical database. The mask includes field parcels and field blocks, which contain cropland or grassland. Features, which by definition are not in agreement with NFW, including buildings and forests from the topographic database as well as forest, afforestation areas, energy forest and orchards from the field parcel and the field block map, were excluded from the mask. In order to also include NFW formations located at the fringe of agricultural land, a buffer of twenty meters width was added to the mask. However, features, which are inconsistent with the definition of NFW (buildings, forests, orchards, energy forest) were excluded from the buffer.

From the nDSMs for 2006 and 2014/2015, cells with surface heights equal to or exceeding two meters and located within the mask of potential NFW were extracted. Although the potential area, which can contain NFW may have changed over the study period, for both 2006 and for 2014/2015, the mask was based on input layers for 2015. I.e. changes from NFW located within agricultural land in 2006 to areas, which were not agricultural land in 2015, were not included. The process of initial masking of potential NFW formations is illustrated in figure 3.3.

Figure 3.3 Illustration for a map extract for 2014/2015 of the applied extraction of non-forest woody vegetation within agricultural land.

3.3.2 Detailed adjustment of NFW delineations

The initial mask of NFW formations includes areas, which in reality are part of larger formations of woody vegetation, such as forests or fields with energy forest or orchards, which are located at the boundary of agricultural land. In order to reduce the bias form these, so called "slivers", boundaries between NFW formations and other areas of woody vegetation were adjusted. This detailed adjustment is described in Figure 3.4.

In several locations, extracted surface heights, equal to or exceeding two meters include forest edges (Fig 3.4 a). In order to detect and exclude these edges, forests were extended twenty meters into the extracted surface heights and removed from these (Fig 3.4 b). As this extension also includes parts of e.g. hedgerows, which are connected to forest, the remaining surface heights were again extended twenty meters into the extended forest (Figure 3.4 c). The final delineation of NFW thus excludes areas along forest edges (Figure 3.4 d).

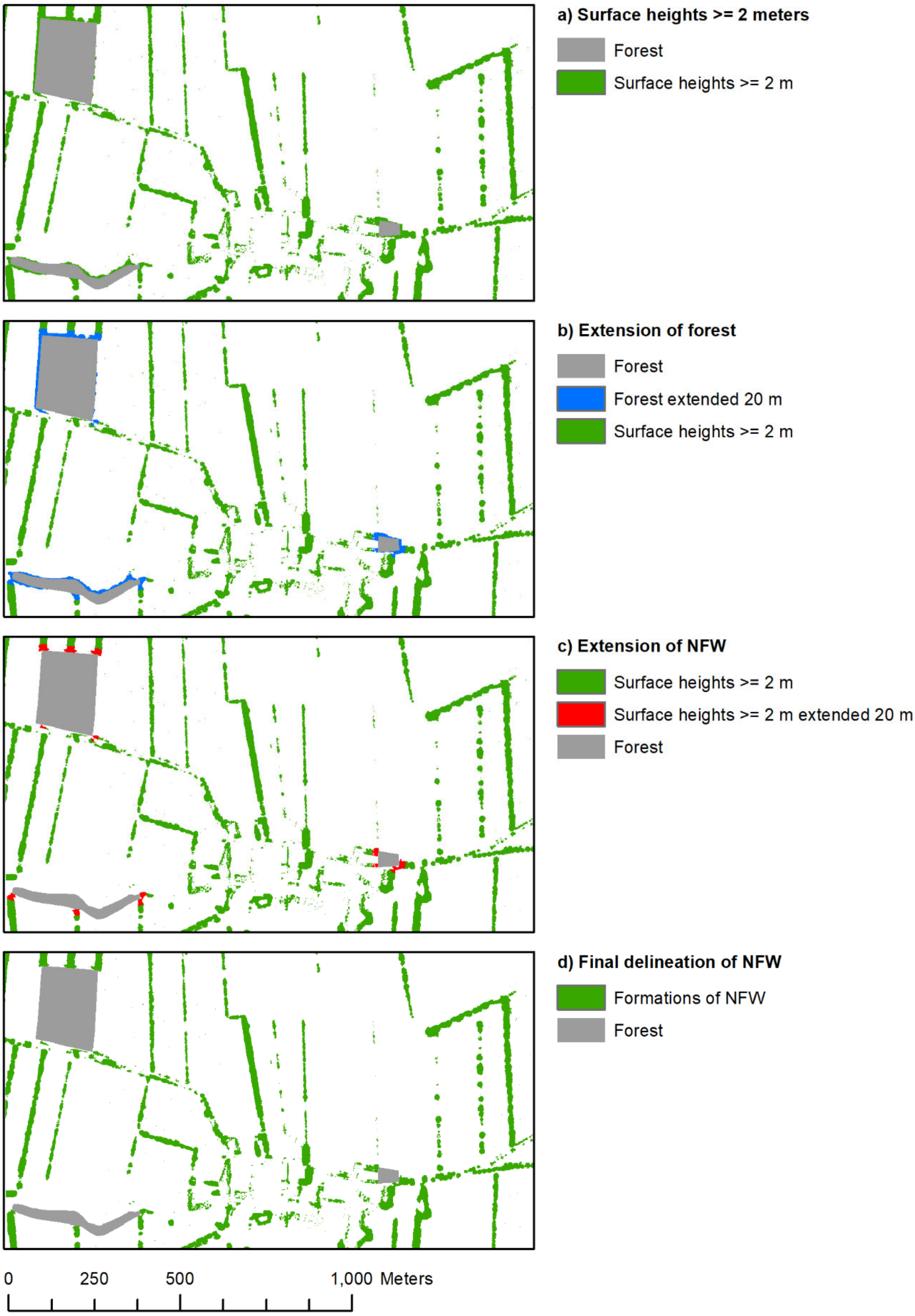

Figure 3.4 Illustration for a map extract for 2014/2015 of the applied method for detailed adjustment of delineations of formations of non-forest woody vegetation.

3.4 Assessment of spatial dynamics in location of NFW

The localisation and delineation of formations of NFW was done for both 2006 and for 2014/2015. In order to map dynamics, in the next processing step, extracted formations of NFW for 2006 and for 2014/2015 were overlaid and grouped into three types of change:

- Unchanged: Present in both 2006 and in 2014/2015
- Removed: Present in 2006 only
- Emerged: Present in 2014/2015 only

The overlay showed discrepancies between the boundaries of NFW in 2006 and 2014, which are unlikely to reflect real changes but most likely are biased by differences in boundaries due to differences in point densities of the ALS data and resulting cell sizes of the applied nDSMs. For a stratified sample composed of 385 formations, which were mapped as unchanged, the accuracy of the delineation for 2006 and for 2014/2015 was assessed through visual interpretation of aerial photos. Results showed while 98.83 percent of the mapped NFW area for 2014/2015 are located within the delineation visually mapped on aerial photos, 98.9 percent of NFW area for 2006 are located at distances up to four meters from the delineation visually mapped on aerial photos (Fig. 3.5). Therefore, the delineation of the 2006 NFW-formations was moved to the border of 2014/2015 formations, if it was located within 4 meters from NFW in 2014/2015. The method is illustrated in Figure 3.6.

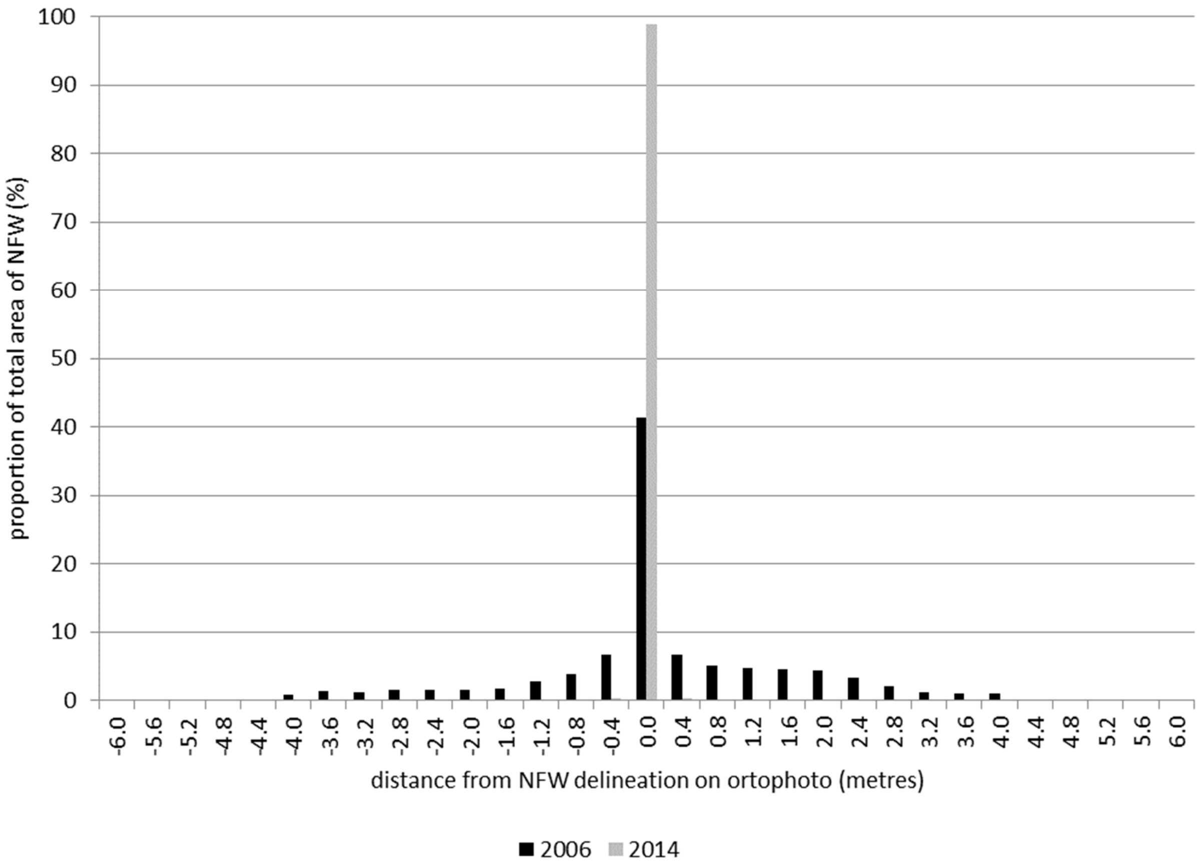

Figure 3.5 Assessed area proportion of NFW derived from nDSM for 2006 and for 2014 at different distances from delineations visually mapped from aerial photos.

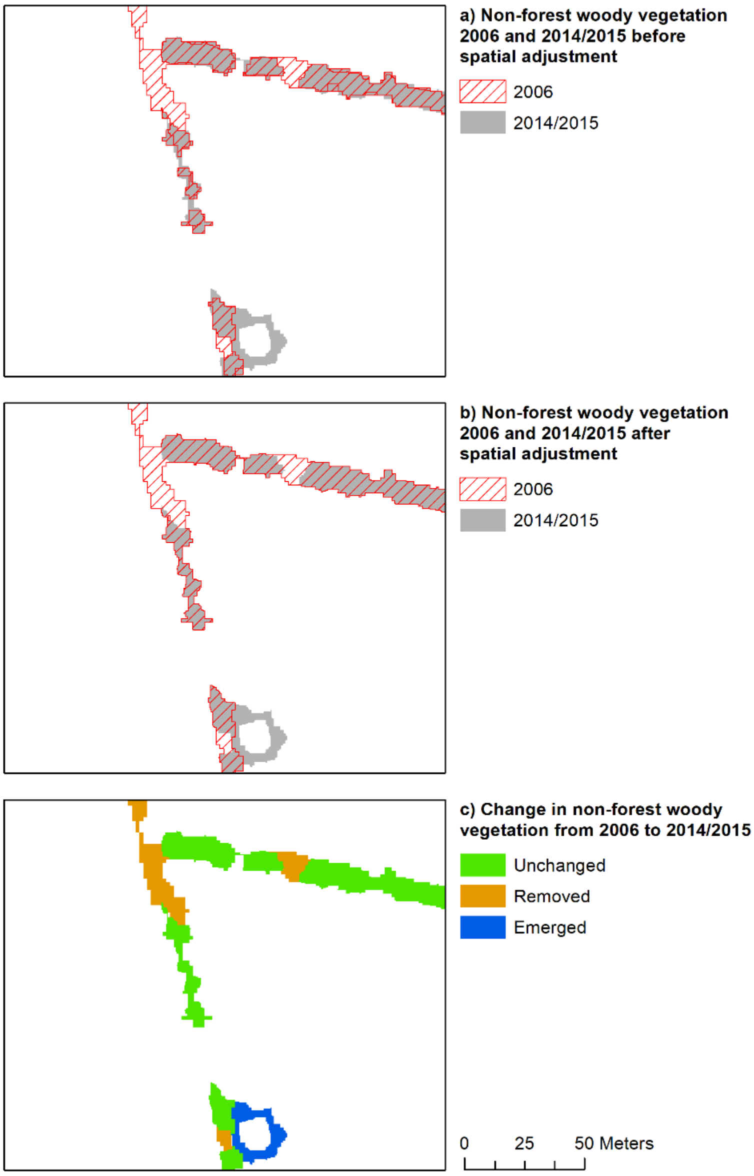

Figure 3.6 Illustration for a map extract of the applied method for adjusting the 2006 delineation of non-forest woody vegetation to the 2014/2015 delineation of non-forest woody vegetation.

3.5 Accuracy of NFW height calculations from the normalised surface model

In order to estimate the accuracy of height calculations based on the nDSM, for a sample of 23 NFW elements located on the island of east Zealand, heights derived from the nDSM were compared to field measurements, carried out with a Nikon DTM 310 Total Station. Results, which are shown in Figure 7.3, reveal a mean average error (MAE) of 0.48 m and a root mean square error (RMSE) of 0.62 m (relative RMSE of 7.9% against the actual average) between the nDSM estimated and observed heights. The linear fit reached a determination coefficient of 0.97 indicating a good fit between reference and estimation, even though the scatter plot and the bias (0.42) pointed out a trend to underestimate the heights slightly.

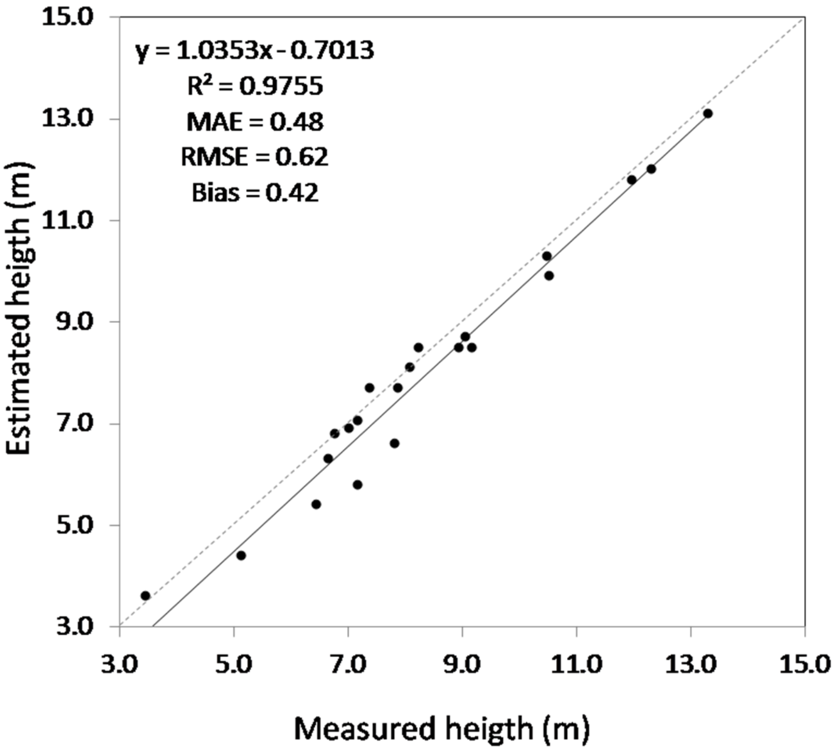

Figure 3.7 Linear fit and RMSE confronting the measures and nDSM estimated NFW heights (n=23).

3.6 Accuracy assessment of NFW delineation and mapped dynamics

In order to estimate the accuracy of NFW delineations and estimated changes, an accuracy assessment based on visual interpretation of aerial photos for 2006 and 2014 was conducted. While aerial photos do not contain information about vegetation height, NFW formations are relatively easy to demarcate from the surrounding agricultural landscape in terms of differences in colour, form and shades. The accuracy assessment was conducted for a pilot study in southern Jutland (Fig. 3.8) (Angelidis, Levin, Díaz-Varela, & Malinowski, 2017).

To assess the spatial accuracy of the NFW delineations, for each change type (unchanged, removed, emerged) a confidence level of 95 percent and a confidence interval of 5 percent was set. This resulted in a needed sample size of 385 formations or approx. 0.2 percent of the area within each group. Selected formations were sampled to represent the variability in sizes (m^3) of the full sample and were evenly distributed over the study area. For each formation in the sample, the type of change was cross-referenced using visual interpretation of the 2006 and 2014 orthophotos. If the mapped change corresponded with the reference change derived from the photos, the change was considered correct, otherwise incorrect. Based on this comparison, the percentages of correctly mapped changes against the total of validation samples were calculated.

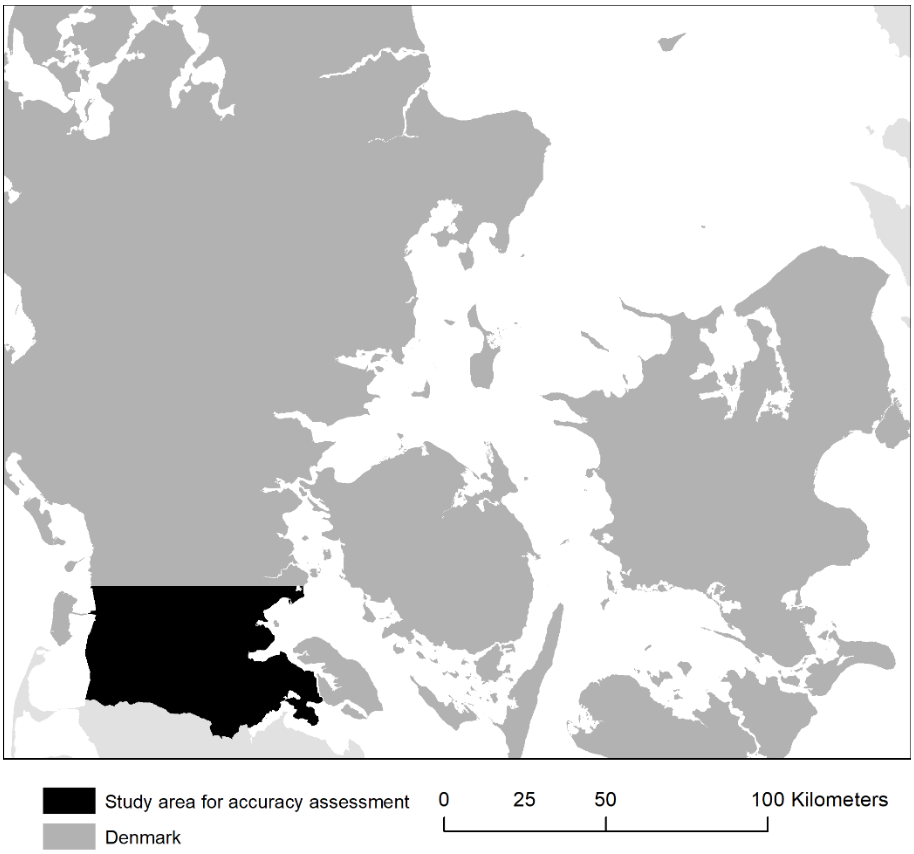

Figure 3.8 Location of study area for accuracy assessment.

Table 3.1 summarises results of the accuracy assessment of mapped NFW formations and their dynamics. Accuracy measures represent the correctly mapped area of NFW and their correctly mapped dynamics. Results indicate that the accuracy (expressed in terms of sensitivity or true positive rate) of mapped NFWs is above 97 percentage for both analysed years with a slightly higher accuracy for 2014/2015. Regarding dynamics, measured accuracy is very high (over 99 percent) for formations which between 2006 and 2014/2015 were mapped as unchanged. The accuracy is lower for formations, which were mapped as removed (approx. 90 percent), and for formations which were mapped as emerged (approx. 82 percent).

Table 3.1 Results of accuracy assessment of mapped non-forest woody vegetation and their dynamics.

	NFW mapping				
	2006	2014/2015	Unchanged	Removed	Emerged
Correctly mapped NFW (%)	97.78	98.93	99.07	90.07	81.74

3.7 Biomass calculation

3.7.1 Calculating NFW volume

In order to estimate the volume of mapped NFW, the layer of NWF dynamics was overlaid with the nDSM for 2006 and for 2014/2015. Volumes were calculated by multiplying the cell size (0.4 x 0.4 meters) with the cell height.

3.7.2 Volume corrections

Comparing NFW volumes for formations, which between 2006 and 2014/2015 had not changed in terms of area, showed a significant discrepancy between 2006 and 2014/2015. Assessed volumes for 2014/2015 exceeded 2006 volumes by an average of around 11 percent. Since particularly hedgerows are trimmed frequently, it is unlikely that this discrepancy is the result of vegetation growth. More likely, because of a lower point density and lower vertical accuracies, the applied 2006 ALS dataset underestimates vegetation height. Furthermore, comparison also reveals that the difference in assessed volumes between 2006 and 2014/2015 increases with decreasing sizes of NFW formations. I.e. the underestimation of the 2006 volume is more pronounced for small formations compared to larger formations (see Table 3.2).

Table 3.2 Discrepancies between assessed volume of NFW for 2006 and 2014/2015 for unchanged formations of NFW.

Size groups of formations of NFW*	Area	Volume 2006	Volume 2014/2015	Volume 2014/2015 as proportion of volume 2006
m²	hectares	m³	m³	%
< 150	8,243	266,585,351	334,222,094	125.4
150 - 360	8,499	366,837,113	419,759,911	114.4
360 - 610	8,076	383,868,027	428,518,506	111.6
610 - 920	8,404	421,048,245	466,354,858	110.8
920 – 1,290	8,199	428,818,288	473,051,813	110.3
1,290 – 1,750	8,229	444,121,616	489,343,010	110.2
1,750 – 2,370	8,180	456,810,517	501,840,686	109.9
2,370 – 3,350	8,246	473,500,747	518,566,938	109.5
3,350 – 5,380	8,270	488,486,648	533,859,275	109.3
> 5,380	8,362	532,580,368	572,316,116	107.5

*Each size group contains approx. the same area of NFW.

Therefore, for this study it was assumed, that for unchanged formations of NFW, volume has not changed between 2006 and 2014. Furthermore, it can be expected that volumes are also underestimated for formations, which between 2006 and 2014/2015 had been removed. Consequently, for these formations, volumes were adjusted. This adjustment was based on the relative difference between volumes for 2006 and volumes for 2014/2015 for different sizes of unchanged formations. The adjustment of 2006 volumes for removed NFW formations appears from table 3.3.

Table 3.3 Measured and adjusted volume for different sizes of formations of NFW, which between 2006 and 2014/2015 were removed.

Size groups of formations of NFW	Volume 2006	Adjustment factor	Adjusted volume 2006
m²	m³		m³
< 150	94,228,187	1.2537	118,135,306
150 - 360	47,956,661	1.1443	54,875,265
360 - 610	24,247,904	1.1163	27,068,354
610 - 920	15,637,311	1.1076	17,319,953
920 – 1,290	11,483,055	1.1032	12,667,557
1,290 – 1,750	8,654,979	1.1018	9,536,247
1,750 – 2,370	7,418,450	1.0986	8,149,725
2,370 – 3,350	6,626,061	1.0952	7,256,707
3,350 – 5,380	6,142,631	1.0929	6,713,183
> 5,380	12,747,192	1.0746	13,698,259

3.7.3 Distribution on regions and soil types

From 1930 and up to 1970 most of the subsidies for hedgerow establishment was given for sandy soils in Jutland to reduce sand erosion and to improve the microclimate. In the later years, subsidies have mostly been given to clayey sandy soils in Jutland. As growth rates and maximum size depends on the species, climate and soil type, there could be differences in the hedges size between regions and soil types in NFW.

Figure 3.7 shows a map with the average wind density at 50 meters altitude over Denmark (Global Wind Atlas, 2019). The map clearly shows a difference in wind force, which has an impact on how the hedges are growing and how tall they become.

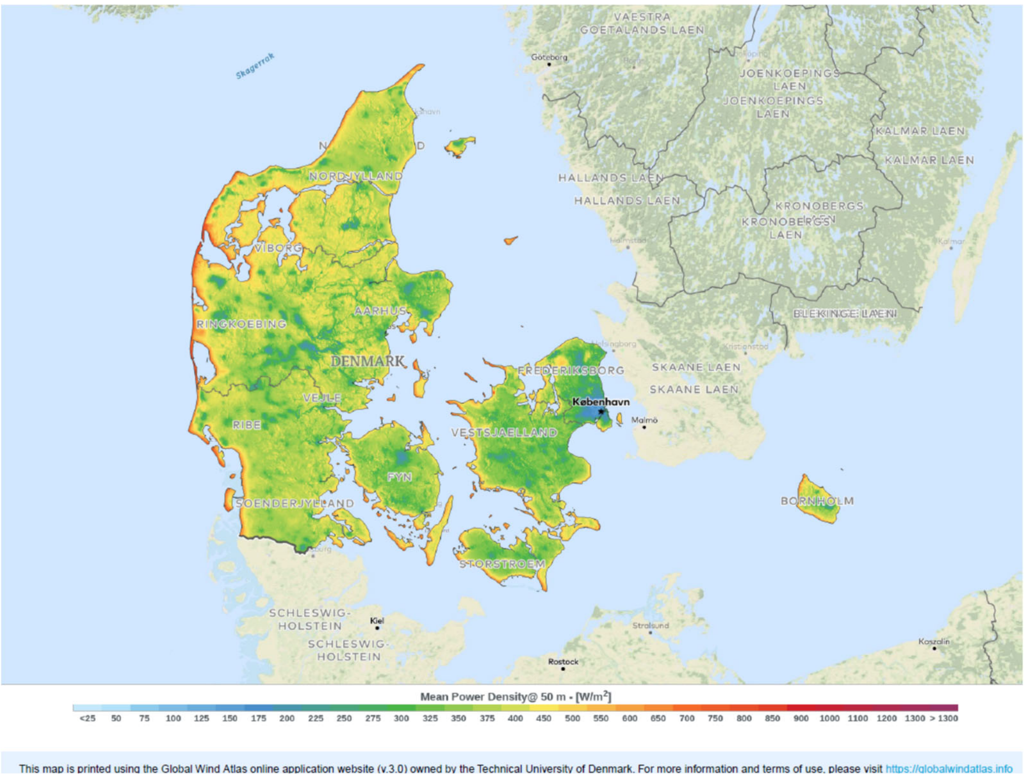

Figure 3.8 Average wind density at 50 meters altitude for Denmark. The prevailing wind is western which clearly is shown on the map. This may result in low and wind-damaged hedges in the landscape (Global Wind Atlas, 2019).

Table 3.4 shows the area of mapped NFW for 2014 / 2015 over regions and soil types (a), the total area on different soil types (b) and the percentage of the area with NFW (c). The figures indicates that there are a higher share of NFW on the more sandy soils and in the western part of Denmark (South Jutland and Western Mid-Jutland). North Jutland is vulnerable for wind erosion from the North Sea, but the share of agricultural land out of the total land area (not shown) is lower in this region, and the need for NFW is less on the coarse sandy soils. The effect of this harsh environment can be seen in Table 3.5 where the hedges in North Jutland has the absolute lowest average height.

Table 3.4 Distribution of NFW on regions and soil types in Denmark in 2014/2015.

a) NFW per region and soil type (km²)

Region	Coarse Sandy soil	Fine Sandy soil	Clayey Sandy soil	Sandy Clayey soil	Clayey soil	Organic soil	Total
Copenhagen and North Zealand	0.3	0.6	22.9	9.2	2.0	3.2	38.1
Bornholm	0.2	0.0	1.1	7.8	2.1	0.2	11.3
Funen	1.7	1.1	31.9	48.9	3.2	3.9	90.7
Eastern Mid-Jutland	25.3	7.0	58.8	34.5	5.2	13.8	144.6
Southern Jutland	94.7	2.2	69.9	37.5	9.0	18.1	231.4
Western Mid-Jutland	109.2	16.7	42.9	7.7	1.2	21.4	199.3
Zealand	1.4	2.3	28.9	83.1	26.5	10.1	152.3
North Jutland	21.3	71.1	40.5	7.7	2.7	16.8	160.2
Total, Denmark	254.1	101.0	296.9	236.5	52.1	87.4	1,028.0

b) Total area of soil type per region (km²)

Region	Coarse Sandy soil	Fine Sandy soil	Clayey Sandy soil	Sandy Clayey soil	Clayey soil	Organic soil	Total
Copenhagen and North Zealand	12.4	19.5	875.5	753.8	94.7	114.7	1,870.6
Bornholm	9.6	0.5	120.8	332.3	118.7	4.6	586.5
Funen	63.3	44.8	1,133.1	1,949.0	117.7	133.5	3,441.4
Eastern Mid-Jutland	1,189.7	286.1	2,672.1	1,702.5	258.8	425.4	6,534.6
Southern Jutland	3,509.6	82.9	2,280.2	1,535.0	539.2	609.7	8,556.6
Western Mid-Jutland	3,854.8	520.1	1,682.6	391.7	95.8	557.6	7,102.6
Zealand	74.8	87.3	1,268.2	4,035.6	1,293.7	387.2	7,146.9
North Jutland	1,374.6	2,516.5	1,888.7	423.4	153.0	727.1	7,083.3
Total, Denmark	10088.7	3557.6	11921.1	11123.4	2671.6	2959.9	42322.4

c) Percent area with NFW per region and soil type

Region	Coarse Sandy soil	Fine Sandy soil	Clayey Sandy soil	Sandy Clayey soil	Clayey soil	Organic soil	Total
Copenhagen and North Zealand	2.3	2.8	2.6	1.2	2.1	2.8	2.0
Bornholm	1.8	2.1	0.9	2.4	1.8	3.4	1.9
Funen	2.8	2.5	2.8	2.5	2.7	2.9	2.6
Eastern Mid-Jutland	2.1	2.4	2.2	2.0	2.0	3.2	2.2
Southern Jutland	2.7	2.7	3.1	2.4	1.7	3.0	2.7
Western Mid-Jutland	2.8	3.2	2.6	2.0	1.3	3.8	2.8
Zealand	1.8	2.6	2.3	2.1	2.1	2.6	2.1
North Jutland	1.5	2.8	2.1	1.8	1.8	2.3	2.3
Total, Denmark	2.5	2.8	2.5	2.1	1.9	3.0	2.4

Table 3.5 shows the average height, StDev in meters and the number of the individual NFW formations. The table does not show any major differences in heights between the different landscapes and all of them have a StDev of 50% although the windy North Jutland has the lowest average height of 2.9 meter. This indicates that, when estimating the total carbon stock in NFW, a simpler model for the national scale can be used, neglecting regions and soil types. One of the reasons for the lack of regional differences may be that normal species for planting on the sandy soils were single-rowed conifers (*Picea sitchensis)* or broad-leaved (*Sorbus intermedia*) which currently are being replaced by 3- or 6-rowed mixed broad-leaved hedgerows. The old conifer hedgerows are tall and may even out the larger extent of thin and low hedges in the windy areas in the calculated heights. Furthermore, the 2-meter extraction limit in the DEM for identification of hedges may also have an effect on the resulting heights.

Table 3.5 Height and StDev of the NFW in 2014/2015 on regions and soil types. (n= number of LiDAR samples).

Region	Coarse Sandy Soil	Fine Sandy Soil	Clayey Sandy Soil	Sandy Clayey Soil	Clayey Soil	Organic Soil	Average, m
Copenhagen and North Zealand	3.3 ±1.7 (2065)	3.3 ±1.8 (4099)	3.5 ±1.9 (148989)	3.4 ±1.9 (68670)	3.5 ±2.1 (14354)	3.1 ±1.8 (22569)	3.4
Bornholm	3.3 ±1.7 (1000)	3 ±1.6 (92)	3.4 ±1.8 (6570)	3.4 ±1.7 (44820)	3.5 ±1.7 (12857)	3.2 ±1.7 (655)	3.3
Funen	3.1 ±1.8 (12527)	3.1 ±1.8 (7898)	3.3 ±1.9 (215980)	3.4 ±1.9 (324041)	3.3 ±1.8 (21218)	3.1 ±1.7 (26768)	3.2
Eastern Mid-Jutland	3.4 ±1.8 (169522)	3.3 ±1.8 (46132)	3.5 ±1.8 (410342)	3.6 ±1.9 (252947)	3.5 ±1.8 (39422)	3.2 ±1.6 (100350)	3.4
Southern Jutland	3.1 ±1.5 (606756)	3.0 ±1.4 (14604)	3.1 ±1.5 (463773)	3.2 ±1.6 (272095)	3.1 ±1.6 (69008)	2.8 ±1.3 (145707)	3.0
Western Mid-Jutland	3.3 ±1.6 (615875)	3.2 ±1.6 (111105)	3.2 ±1.6 (289024)	3.0 ±1.6 (59604)	3.0 ±1.8 (10701)	3.0 ±1.4 (169932)	3.1
Zealand	2.8 ±1.4 (13467)	3.1 ±1.7 (17062)	3.4 ±1.9 (214554)	3.5 ±1.9 (608142)	3.4 ±2 (203922)	3.1 ±1.8 (72290)	3.2
North Jutland	3.0 ±1.5 (163621)	3.2 ±1.7 (466369)	3.1 ±1.7 (297275)	2.6 ±1.4 (71115)	2.6 ±1.4 (24116)	2.9 ±1.5 (129986)	2.9

3.7.4 Converting volume to biomass

Measures of biomass in terms of cubic meters of wood chips were applied to convert NFW volume derived from the nDSM to volume of wood chips. For 18 removed areas, comprising 103,305 m² (10.3 hectares) the company Hededanmark and Skovdyrkerforeningen provided information on the wood chip volume removed (only above ground biomass) and the exact delineation of the formations. For each area, the ratio between nDSM volume and the measured wood chips volume was calculated. The 18 formations vary in size from 3477 m² to 10,973 m² and with a length up to 830 meter. Removals of more than 10 ha are included in the analysis. In order to reduce biases from the different formation sizes, an area weighted average ratio was calculated. The area rated average ratio between nDSM volume and wood chips volume was 100:1.37 percent (Table 3.6). I.e., in average, wood chips volume comprises 1.37 percentage of the volume derived from the nDSM. To convert nDSM volume to wood chips volume and further to kilogram of dry matter (DM), the nDSM volume was multiplied by 0.0137 and 185 kg DM / m3 wood chips. In concordance with the IPCC guidelines (IPCC, 2014), to convert from kg / DM to C a factor of 0.47, was used.

Table 3.6 Biomass removed from 18 NFW areas, in total 10.3 hectares.

Site No.	Area (m2)	Average height (m)	Volume nDSM (m3)	Volume wood chips (m3)	Ratio (volume wood chips, fraction of volume nDSM)	DM per m3 chips, kg/m3[a]	Kg DM/m3	Kg C/m3
1	10,632	4.3	46,242	681	0.0147	185	2.724	1.308
2	14,171	6.0	84,782	1,100	0.0130	185	2.400	1.152
3	3,937	5.0	19,504	275	0.0141	185	2.608	1.252
4	3,477	9.0	31,406	324	0.0103	185	1.909	0.916
5	9,545	3.5	33,495	400	0.0119	185	2.209	1.060
8	7,324	4.4	31,873	499	0.0157	185	2.896	1.390
12	10,973	7.4	81,000	1,140	0.0141	185	2.604	1.250
13	7,124	8.6	61,324	840	0.0137	185	2.534	1.216
14	8,302	8.2	28,598	232	0.0081	185	1.501	0.720
15	8,646	5.4	46,554	531	0.0114	185	2.108	1.012
16	4,691	7.7	35,956	480	0.0133	185	2.470	1.185
17	5,875	8.1	47,542	879	0.0185	185	3.420	1.642
18	8,607	7.1	60,701	973	0.0160	185	2.965	1.423
Total, Average (Weighed Avg)	103,305 (7,947)	6.3	608,976	8,354	0.0137 (± 0.003469)	185 (±23.5)[b]	2.538 (±0.471)	1.218 (±0.226)

[a]DM content is not known from the samples. DM weight is based on wood chips delivered to "Dalum Kraftvarme".

[b]Based on 1463 truck loads with chips.

The conversion of chips volume to dry matter and further to carbon content was based on information from chips delivered to Dalum Kraftvarme, Fjernvarme Fyn. Dalum Kraftvarme is a power plant on Funen, only fuelled by Danish wood chips.

For the year 2018-2019, for 1463 truckloads arriving at the plant with > 50 m^3 chips, the chip volume and net weight of the chips was registered. In total, this composed 131,339 m^3 chips. For each lorry load, samples were taken to determine the chips humidity. The 131,339 m^3 chips had a total dry matter (dm) content of 24.27 kt dm. On average, the dry matter content was 185.1 ±23.5 (StDev) kg dm / m3 wood chips. Unfortunately, the origin of the wood chips was not registered as derived from forests or from hedgerows. Forest wood chips may have another composition of species, a different distribution between trunks and thin branches than designated hedgerows, and it may have been stored on site before chipping.

Table 3.7 shows the humidity in the chips delivered during 12 months and the number of truck loads. The most wet chips are delivered in winter and the driest in late summer and early autumn. In the estimation of the dry matter density, the annual average humidity of 34.6 % is used. For conversion from dry matter to carbon the default value of 0.48 from the IPCC (2014) is used. Several of the 18 biomass removal areas were composed of conifers and were cut during summer. Hence, it is assumed that the total removed biomass includes biomass from both leaves and needles. To include biomass in roots the default root-shoot factor for forestry of 0.192 is used (IPCC, 2019).

Table 3.7 Average humidity in wood chips, %.

Month	Average humidity, %	Number of truck loads
1	35.3	493
2	37.5	383
3	39.1	375
4	35.8	473
5	35.3	335
6	32.1	11
7	32.6	102
8	30.9	382
9	31.1	508
10	33.6	377
11	34.6	3439
12	35.3	493
Weighted Average	37.5	383

4 Results and discussion

Results (Table 4.1) show that between 2006 and 2014/2015, the total area of NFW increased by 6.7 percent (about 6,500 hectares). The total volume (in terms of volume derived from the nDSM) and consequently biomass increased by 6.1 percent (about 305 million m³; 434 kt C). Yet, this relatively small net change covers a significant increase and decrease. Results show that between 2006 and 2014/2015 about 14,000 hectares of NFW where removed (14.4 percent of the NFW area in 2006) while about 20,400 hectares emerged (21.1 percent of the NFW area in 2006). Removed volume is estimated to about 275 million m³ and removed biomass about 392 kt C (5.5 percent of 2006) while emerged volume is estimated to about 580 billion m³ and emerged biomass is estimated to 826 kt C (11.6 percent of 2006).

Table 4.1 Estimated change in area, volume and biomass of NFW in Denmark for the period from 2006 to 2014/2015.

	2006	2014/2015	Net change		Unchanged		Removed		Emerged	
	Total	Total	Total	(% of 2006)	Total	(% of 2006)	Total	(% of 2006)	Total	(% of 2006)
Area (ha)	96,660	103,105	6,445	6.7	82,709	85.6	-13,951	-14.4	20,396	21.1
nDSM volume (1000 m³)	5,013,254	5,318,714	305,461	6.1	4,737,833	94.5	-275,421	-5.5	580,881	11.6
Wood chip volume (1000 m³)	68,768	72,959	4,190	6.1	64,990	94.5	-3,778	-5.5	7,968	11.6
AGB (kt dm)	12,722	13,497	775	6.1	12,023	94.5	-699	-5.5	1,474	11.6
BGB (kt dm)	2,443	2,591	149	6.1	2,308	94.5	-134	-5.5	283	11.6
Total Carbon Stock, kt C	7,127	7,562	434	6.1	6,736	94.5	-392	-5.5	826	11.6
AGB, t C/ha	61.9	61.5	56.5		68.3		-23.5		34.0	
BGB, t C/ha	11.9	11.8	10.9		13.1		-4.5		6.5	
Total living biomass, t C/ha	73.7	73.3	67.4		81.4		-28.1		40.5	

AGB = Above Ground Biomass.
BGB = Below Ground Biomass.

The average total C Above Ground Biomass (ABG) per hectare has been estimated to around 62 ton C/ha and the below ground biomass to app. 12 C/ha. The slight decrease from 2006 to 2014/2015 may be due to the uncertainty in the measurements caused by different resolution in the LiDAR measurements but also that a larger replacement of old conifers has taken place over the last decades. Currently it is not clear why the removed NFW has a low average C stock/ha compared to the average. Further analyses is needed before conclusions can be drawn.

Very little data can be found in the literature on volumes and carbon stocks in NFW and hedgerows. In England, UK, Axe et al. (2017) found average C stocks of 32-42 ton ABG C/ha in hedgerows mainly constituting of Hawthorn/Blackthorn (*Crataegus monogyna, Prunus spinosa*) with the largest value for a 3.5 meter tall hedgerow. The Danish hedgerows consist of many different species and a direct comparison is therefore not possible. Axe et al. (2017) did not estimate the dry matter content per volume of hedge. We have converted the data in Axe et *al*. (2017) to kg DM/m3 hedge. This gives a volume density of 3.0 kg DM/m³ (2.1-3.9 kg DM/m³) for hedgerows with the largest value for the lowest hedgerow and the lowest for the (1.9-3.5 m height). In our study, we found an average of 2.538 kg DM/m³ hedge (Table 3.5) which is similar to Axe et *al*. (2017) but in our measurements the hedges are taller. Lingner et *al*. (2018) measured three hedgerows in Northern Germany with an Unmanned Aerial Vehicle (UAV). They did not provide detailed data on hedgerow structure, total volume etc. For the three hedgerows, they found a density of 1.42, 1.94 and 2.43 kg DM/m³. The methodology used in their study is similar to our study although we may expect that their UAV measures a more exact 3-

D volume of hedgerows compared to our 3-D measurements based on LiDAR measurements taken from 500 m height. Lingner et *al*. (2018) measured, similar to Axe et *al*. (2017), highest densities for the lowest hedgerows, which we could not see from our data. Based on photos in Lingner et al. (2018) the three hedgerows included in their study are similar to typical Danish broadleaved hedgerow types. One reason for the difference can be that we in our measurements has included coniferous hedgerows, which may have a higher density.

As hedgerows tend to be rounded and as LiDAR measurements have returns from the whole surface, the height estimated by Axe et al. (2017) may be higher than if it was analysed from LiDAR, but overall the three methodologies gives similar values of approximately 2-2.5 kg DM / m3 hedge volume.

In Ireland, Black et al. 2014 used LiDAR to estimate the biomass in hedgerows. They found an average AGB carbon stock of approximately 38 t C / ha equivalent to what Axe et *al*. (2017) found and lower than our findings. Black et al. did not indicate heights and species composition in their calculations so it is not possible to directly compare the results.

Further verification is needed. The most uncertain figures in our estimates is probably:

- many hedges are broadleaves and some of our ground truth measurements are from conifers
- the origin of the chips to Dalum Kraftvarmeværk is mainly based on forest biomass. If the forest biomass gives a different volume of chips compared to chipping of hedges we may have an overestimation of the conversion rate
- As the dry matter measures are mainly from forest plots, these may have another humidity content than biomass from hedges. In the current database the average moisture content is 34.6 % yielding 185 kg DM / kg chipped biomass. We have a few data with known hedges where 165 kg DM / kg was measured.

Overall, the use of LiDAR-based normalised surface models to estimate NFW volumes is useful. However, assessing dynamics based on two, LiDAR-derived normalised surface models is challenging due to different spatial resolutions (1.6 m for 2006 and 0.4 m for 2014 / 2015). Comparisons of volumes for NFW formations, which, between 2006 and 2014 / 2015 have not changed location, shows that volumes derived from the 20016 surface model are in average 11 percentage lower than volumes derived from the 2014 / 2015 surface model. Furthermore, this difference increased with decreasing sizes of NFW formation. As 11 percentage increase in volume is unlikely to be the result of natural succession / growth, and the fact that differences in volume are biased by formation sizes indicates that normalised surface models from different years and with different spatial resolutions are, as such, not suitable for assessments of volume dynamics. Consequently, we chose to correct 2006 volumes as described in section 3.5.2. Currently, updated surface models with the same spatial resolution as the 2014 / 2015 surface model are under preparation. Once a countrywide updated surface model is available, new approaches to assess volume and hence biomass dynamics should be developed.

Our C stock data is based on removal of 10 hectares of hedges / small biotopes (Table 3.6). It can always be discussed if these 10 hectares are representative for the whole of Denmark, but as similar data has been found in Northern

Germany, England (UK) and Ireland has been found, a reasonable carbon stock in living biomass in Cropland, Grassland and Wetlands not qualifying as Forest Land, is within a range of 7,562 kt C ±20% in 2015.

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ASSESSMENT OF CHANGE IN BIOMASS FROM 2006 TO 2014/2015 OF NON-FOREST WOODY VEGETATION IN DENMARK

Technical documentation

This report contains the technical documentation of the assessment of changes in biomass for formations of non-forest woody vegetation (NFW) in Denmark.
National high-resolution digital terrain and surface models were applied to map formations of NFW for 2006 and for 2014/2015. NFW formation were grouped into formations, which during the studied period were unchanged, removed and emerged. For each category, volumes were calculated and, based on field measurements, converted into biomass. While estimated net-changes are relatively small, absolute changes in terms of removed and emerged formations are significant.

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