CLIMATE AND LAND-USE CHANGE AS DRIVING FORCES IN LOWLAND SEMI-NATURAL VEGETATION DYNAMICS

Anders Lundberg

With 11 figures

Received 31. January 2011 · Accepted 20. September 2011

Summary: In many parts of Europe, extensive changes in vegetation have taken place during recent decades. In Norway, forest expansion is a major trend, with an increase in volume of 20.3% during the period 1994–2008. The annual increase has more than doubled since 1967. This study was carried out to gain more insight into the complexity of vegetation dynamics and alterations in a lowland area on the coast of W Norway, and to identify the driving forces behind these changes. Field surveys were carried out with aerial photo interpretation and vegetation mapping. Spatial analysis was carried out using GIS. Historical sources were identified, interpreted, and used to generate information on land-use during recent centuries. Supplementary methods consisted of soil profile analysis and dendrochronology. Climate data were used to analyse climatic trends in the past 90 years since 1923. Forest expansion was a major trend during 1956–1994. In 1956, 49.5% of the area was covered by forest, and by 1994 the coverage had increased with 53.4%. Forestation continued during 1994–2003 and 2003–2007, but at rates far lower than in the previous period (4.0 and 3.8% increases, compared to 53.4%). Forest expansion was most extensive during 1956–1994, a period with no clear trend in mean July temperatures. A distinct increase in mean July temperatures occurred during the period 1994–2003 and again in 2003–2007, when the rate of forestation was far lower than in previous decades. This is an indication that a factor other than climate change is the most important driving force for vegetation change, forest expansion in particular. Forestation did not start simultaneously throughout all parts of the study area, but at different times on different landholdings. Forestation initially started on plots where livestock grazing first came to an end (in the 1930s), and lastly on plots where grazing came to an end three decades later, in the 1960s. The different starting times of forestation is reflected in the present age structure of the forest stands on the eight landholdings studied. The conclusion is drawn that changes in land-use are the major driving force behind the distinct process of forestation that occurred during the 20th century.

Zusammenfassung: In vielen Teilen Europas ist es in den letzten Jahrzehnten zu starken Veränderungen in der Vegetation gekommen. In Norwegen ist die Expansion des Waldes der Haupttrend, mit einer Volumenzunahme auf Landesebene von 20.3% im Zeitraum von 1994 bis 2008, wobei sich die jährliche Zunahme gegenüber 1967 mehr als verdoppelt hat. Ziel der vorliegenden Studie war es, die Komplexität der Vegetationsdynamik und Veränderungen in einem Tieflandbereich an der Westküste Norwegens zu untersuchen und steuernde Faktoren zu identifizieren. Zu diesem Zweck wurde die Vegetation kartiert, Luftbilder interpretiert sowie die Landnutzung für die letzten Jahrhunderte aus historischen Quellen rekonstruiert. Die räumliche Analyse der Daten erfolgte dann GIS-gestützt. Ergänzende Methoden umfassten Bodenanalysen und Dendrochronologie, darüber hinaus wurden Klimadaten der letzten 90 Jahre hinsichtlich klimatischer Trends analysiert. Die größte flächenhafte Waldzunahme im Untersuchungsgebiet erfolgte mit 53,4% zwischen 1956 und 1994. Die Wiederbewaldung setzte sich auch in den Zeiträumen 1994–2003 und 2003–2007 fort, allerdings mit gegenüber der Vorperiode deutlich niedrigeren Raten von 4% bzw. 3,8%. Für den Zeitraum der starken Waldzunahme zwischen 1956 und 1994 lässt sich in den Juli-Temperaturen kein klarer Trend erkennen. Eine deutliche Steigerung der Juli-Temperaturen erfolgte dagegen 1994–2003 und 2003–2007, also in Zeiträumen deutlich geringerer Wiederbewaldung. Dies indiziert, dass andere Faktoren als der Klimawandel die steuernde Kraft für Änderungen in der Vegetation, insbesondere die Waldexpansion, sind. Die Wiederbewaldung im Untersuchungsgebiet begann nicht zeitgleich auf allen Flächen, sondern startete zeitlich versetzt auf unterschiedlichen Teilflächen. Sie begann zuerst auf den Flächen, die bereits in den 1930er Jahren aus der Weidenutzung genommen wurden und zuletzt auf den Flächen, die erst seit den 1960er Jahren nicht mehr beweidet werden. Die unterschiedlichen Startzeiten der Wiederbewaldung spiegeln sich in der Altersstruktur der Bestände wider. Als Fazit kann festgehalten werden, dass Änderungen der Landnutzung die steuernde Kraft hinter der Wiederbewaldung im 20. Jahrhundert sind.

Keywords: Climate change, land-use change, forest expansion, GIS, historical geography

DOI: 10.3112/erdkunde.2011.04.02 ISSN 0014-0015 http://www.erdkunde.uni-bonn.de

1 Introduction

Today, vegetation change is a typical phenomenon across Europe, e.g., in grasslands (Rahmonov and Oles 2010), heathlands (Moen et al. 2006), wetlands (Bär et al. 2004), alpine areas (Löffler et al. 2004; Potthoff 2007; Rössler et al. 2008), and forests (Bryn 2008). Climate change and/or changes in land-use are often discussed as major driving forces (Hofgaard 1997; Motta et al. 2006; Bolli et al. 2007; Gehrig-Fasel et al. 2007; Albert et al. 2008; Bryn 2008; Gellrich et al. 2008; Rutherford et al. 2008).

A number of the studies of climate change and/or changes in land-use and their effect on forest expansion have been carried out across the alpine treeline. Studies of forest dynamics in lowland areas may add valuable information in determining whether the trends at high elevations have lowland parallels. The study area is situated on the island of Stord, ca. 60 km south of Bergen, in Western Norway, 0–58 m a.s.l. A major part of the area was declared a nature reserve in 1984, to protect a deciduous forest with different stands of alder (*Alnus glutionsa*), which were considered to be of international importance. The forest was understood to be an old forest, almost untouched by man (Korsmo 1975; Fylkesmannen I Hordaland 1980). The size of the study area is ca. 75 hectares (ha).

In Norway, forest expansion has been a major trend during the last 80 years. In 1933 the volume of productive forests was 322,635 m^3. This increased to 651,688 m^3 in 1994, and to 783,982 m^3 in 2008. The annual increase has more than doubled since 1967. At present, the area covered by forests is 123,840 km^2 (NORWEGIAN OFFICIAL STATISTICS 2010). This is the highest total recorded in historical times. Hence, detailed studies of how this process has proceeded at local and regional scales are of interest, in particular whether the process of forestation has been continuous and proceeded at the same rate, and which types of vegetation have been succeeded by forest, where, when, and to what extent.

All over Europe, nature and semi-natural areas have been extensively used by man and this has had an immense effect on the vegetation, its structure, function, species composition, and development (Ellenberg 1978; Goudie 2000; Emanuelsson 2009). The land has been used for livestock grazing, mowing, harvesting of fodder, timber extraction and other types of natural resources. This has also been the case in Norway, at all elevations from salt marshes to alpine meadows (Lundberg 1986; Moen 1998).

The area dealt with in this study is no exception. It was formerly used as outfields of the farm Hystad, a typical farm in western Norway. The farm had eight holdings and farmers, and until 1881 the study area was common land, mostly used for cattle grazing. Livestock grazing kept the vegetation open. Land re-allotment took place in 1881, when the land was split into eight parts of uneven size, reflecting the old land taxation of the eight holdings. Stone fences were constructed on the borderlines between the plots and from then on the land-use differed somewhat from plot to plot (Lundberg 2005b). The number and type of livestock varied among the holdings, resulting in varying levels of grazing pressure. During the 20th century agriculture decreased in importance, as in most parts of Norway (Almås and Gjerdåker 2004), and today only minor parts of the study area are used for agriculture (as arable land). Grazing has ceased altogether, as in many other parts of rural Europe. Due to such a radical change in management, vegetation response is to be expected. In summary, the study area was a semi-natural area dominated by deciduous forests that were formerly used for livestock grazing. It can be concluded that in this respect there is nothing special about the study area; it is a typical semi-natural area with a mixture of varied and interesting ecosystems which have been exposed to human impact to some extent in the past.

Land taxation papers from 1881 give detailed and interesting information about the land cover at that time. The key on the cadastral map from 1881 has four spatial signatures only: pasture, bare rock, mould pit, and arable. The latter two occupied extremely small areas, and most of the area was wet pasture and bare rock. Some seashore forest was present in 1871 but this was due to be cut within the next three years. Some alder scrub was also present in other parts of the area in 1871 but had to be cut within five years, according to the land taxation papers. When the area was mapped in 1881, no forest was left. One hundred years later the area was protected for its ‘old’, fertile and rich forests.

Field surveys since 1988 have revealed that some areas were still open with no forest, and were remnants of previous, more extensively distributed moor and/or wet pastures. In 1988, most of them were found to be invaded by juvenile alder and other young tree species, indicating that the process of forestation was ongoing. Major parts of the forest must be young first-generation forests, contrary to the information given by governmental nature conservation agencies that this was an old forest almost untouched by man (Fylkesmannen i Hordaland 1980). The interesting question is whether and to what extent this process of vegetation change is still ongoing or whether the transformation process has reached some kind of balanced state. An associated research question is whether major causes of forestation can be detected. These constitute the major research questions which will be addressed in this study. Since the study area is rather typical when it comes to land-use history and coastal climate history in Norway (Lundberg 2005b), and has a type of forest that is widespread, the findings could be a matter of principle interest, with relevance for many semi-natural and nature conservation areas in other parts of Europe.

2 Sources and methods

Field studies in the study area have been carried out annually since 1988 and changes in land cover since 1994 have been recorded. The vegetation mosaic of 1994 was used in the interpretation of the vegetation patterns of 1956. Aerial photos from 1956, 1994, 2003, and 2007 were rectified, brought to the same scale, orientation, and pixel size using Erdas Imagine software. The resulting orthophotos from 1956, 1994, 2003, and 2007 were used to produce vegetation maps/land cover maps for the same four years. The files generated were analysed using GIS, using MapFactory and ArcGis (Chrisman 2002). The output was four vegetation maps which included keys containing information on the size of each vegetation type/land-use category (in hectares).

Changes in vegetation/land-use cover were analysed using a GIS with an overlay technique (a combine function). Using this method, when one map layer is placed on top of another (combined), a new layer is generated where each pixel is assigned to a number which precisely identifies the combination of values in the corresponding cells in the other map layer. The resulting new map can be used to explore stability and change in the spatial distribution of vegetation types/land cover categories. We should keep in mind that although the size of one spatial category (vegetation type/land-use unit) may be the same for two years, the spatial distribution of that category may have changed. If so, this will be revealed by the spatial analysis. Three digital data layers (maps) were produced, showing areas with change in vegetation/land-use cover for the periods 1956–1994, 1994–2003, and 1994–2007. The size of each vegetation type/land-use category was further analysed statistically as a quantitative measure of stability and change.

Vegetation mapping in the field and aerial photo interpretation gave detailed information about vegetation patterns and change during the studied period. To provide contextual explanations for detected patterns and changes, an historical-geographical approach was applied (Lundberg 2005b, 2008). Past and present land-use has a profound impact on vegetation structure, species composition, and succession, and to provide information on past land-use, a number of historical sources were used, including a cadastral map from 1881, land taxation papers, and agricultural and population censuses (see Historical sources). Most of these are 19th century sources, although some are older and some are more recent. The historical sources provided information about the number of people living on the farm, their occupation (if they were active farmers or not), the types and number of livestock, the size, type and quality of arable, pasture, and forest (if present at the time). The type and number of livestock (cattle, sheep, lamb, and horses) was used to calculate the annual grazing pressure. The grazing pressure of one sheep roughly corresponds to the grazing pressure of five lambs on an annual basis, and a cow corresponds to the grazing pressure of four sheep. A horse corresponds to the grazing pressure of 1.5 cows, and a goat corresponds to the grazing pressure of 1.5 sheep (Lundberg 2005a). The cadastral map from 1881 and the corresponding historical description of this were vital for the analysis and understanding of past land-use and land cover. The cadastral map was also used for comparison with recent vegetation patterns and in the interpretation of historical reasons for vegetation change during the 20th century. Further, historical and topographic maps were used in the analysis of vegetation and land-cover change. Supplementary methods comprised dendrochronology (Schweingruber 1988, 1993) and soil stratigraphy analysis (Pälchen 1996).

Climate data were obtained from The Norwegian Meteorological Institute. Data from the nearest climate stations with long time series were used. Temperature data came from Slåtterøy lighthouse, ca. 30 km north-west of the study area (station 48330, 25 m a.s.l.), for the period 1923–2010. Precipitation data came from two stations at Fitjar, ca. 18 km north-west of the study area: station 48260, 20 m a.s.l., for the period 1923–1982; and station 48250, 24 m a.s.l.), for the period 1982–2009.

3 Results

The vegetation pattern for 1956 is shown in figure 1. *Calluna* heath covers the largest area (18.6 ha, 26% of the study area), followed by mixed deciduous forest (15.4 ha, 21%), and alder swamp forest (14.4 ha, 20%). These three vegetation types account for two-thirds of the area. Regarding the spatial distribution of vegetation types, *Calluna* heath is found uphill and on peninsulas on shallow soils; alder swamp forest is found in the central valley on deep, wet soils; and mixed deciduous forest is found in gentle slopes with dark, well-developed forest soils. In total, 49.5% of the area was covered by forest. The dominant role of heathland is due to land-use, particularly livestock grazing, similar to common practice in other parts of Europe (Kaland 1986; Webb 1986, 1998; Pott 1999; Vandvik et al. 2005; Moen et al. 2006). Two cattle tracks of earlier date can still be seen in the area, both connecting the study area to the infields and barns found uphill and to the west. In 1956, livestock grazing had come to an end in parts of the area, but was still practised in other parts. The mixed vegetation pattern found at that time is a reflection of this. Young forests were found in those parts where grazing had come to an end, while heathlands were found in areas where grazing was still ongoing or had recently ceased. Thus far, we have reliable information about the vegetation pattern in 1956. To understand possible vegetation change or stability, information about more recent vegetation patterns is needed.

The vegetation pattern for 1994 is shown in figure 2. By then, alder swamp forest had become the most extensive type of vegetation (19.8 ha, 26%), followed by mixed deciduous forest (15.8 ha, 21%), and pine forest (14.6 ha, 19%). *Calluna* heath had reduced to 2.2 ha, < 3%, corresponding to a decrease of 88%. Clearly, a radical change had taken place. The proportion of forest in the area had increased to 76%. During the period 1956–1994 an extensive process of forestation took place. To determine whether the process of change had come to an end or was continuing, information relating to more recent times is of interest.

The vegetation pattern for 2003 is shown in figure 3. Again, alder swamp forest was the largest type of vegetation, covering 22.1 ha (29%). Mixed deciduous forest was the second largest type of vegetation (16.3 ha, 21%), and pine forest was third largest (14.3 ha, 19%). *Calluna* heath had continued to decrease, to slightly less than 2 ha (2.6%). The expansion of forest had continued to increase, and by 2003 covered 79% of the area.

It might be considered unlikely that any major changes had occurred by 2007, compared to the situation in 2003, four years earlier. However, alder swamp forest continued to have the largest coverage (Fig. 4), and had increased to 23.2 ha (ca. 31%), followed by mixed deciduous forest (16.4 ha, 22%), and pine forest (14.6 ha, 19%). *Calluna* heath had decreased further, to 1.6 ha (2%). The proportion of the area covered by forests had increased to 81%. Even during a short period of four years, a distinct process of change can be seen.

Thus far, some of the major trends in vegetation patterns and change during the period 1956–2007 have been addressed. To achieve a proper understanding of the type of ecological change ongoing it is necessary to look in more detail at the changes in the spatial distribution of vegetation types during the years, to see which types of vegetation replaced other types of vegetation and where. This should reveal who were the 'winners' and 'losers' of terrain during the years. This type of information would be useful in the identification of driving forces in this process of recent and major ecological change.

Figure 5 shows a representation of the changes in vegetation during the period 1956–1994. In total, ca. 37.2 ha changed from one type of vegetation to another, i.e., approximately half of the area. Figures 6 and 7 show changes in land cover during the periods 1994–2003 and 1993–2007: 10.2 ha and 11.9 ha change respectively, corresponding to 13.4% and 15.7% spatial change. Extensive changes in the size and spatial distribution of different vegetation types, forest and non-forest types, had been a continuous process since 1956.

Figures 5, 6, and 7 show where changes took place, but it is also of interest to know which types of vegetation replaced which. Figure 8 shows the distribution and redistribution of vegetation types during 1956–1994, the period with the most radical alterations. Bars above the baseline give information about the type and size of vegetation with no spatial change, while bars below the baseline show the amount of land lost by each vegetation type during 1956–1994 and also which type of vegetation they lost terrain to and how much (in hectares).

Calluna heath lost the greatest area during the period 1956–1994, in total 16.3 ha, corresponding to ca. 88% of the area covered in 1956. Approximately 74% of the heath area lost transformed into pine forest (7.7 ha) and mixed pine forest (4.3 ha), typically on shallow soils uphill and on peninsulas with convex topography. Also, some of the heathland was transformed into alder swamp forest (2.8 ha), probably damp heath that was formerly present at low elevations with short distance to groundwater.

The other 'loser' during the period 1956–1994 was moor, which lost 6.6 ha, corresponding to 75% of the area covered by moor in 1956. Most area was lost to alder swamp forest (4.4 ha, two-thirds of the area lost). In 1956, moor was the dominant type of vegetation in the central part of the area, at low elevation (Fig. 1). The valley used to be a shallow sound with seawater in prehistoric times but became land due to isostatic land-uplift during the early Holocene (Lundberg 2005b).

In 1994, mixed deciduous forest and alder swamp forest were dominant vegetation types. The extensive dynamics of vegetation change are also clearly seen in figure 8, which shows that also these 'winners' lost some terrain to other types of vegetation during the process of vegetation change after 1956. Mixed deciduous forest lost 2.6 ha and alder swamp forest lost 3.5 ha. In some areas they lost terrain to types of vegetation which themselves lost terrain to mixed deciduous forest and alder swamp forest in other areas. Thus, all types of vegetation lost *and* gained terrain to and from each other in the dynamic processes of change known as succession, but some lost far more than others. Some were winners and some were losers. Possible reasons and driving forces in this process will be considered in the Discussion.

Figure 9 shows a summary of the size of each vegetation type/land-use category in 1956, 1994, 2003, and 2007. The heights of the bars show the changes that took place, and by comparing the variation in heights it is possible to gain an impression of development trends during the period studied. In general, forest types increased and open types of vegetation, such as moor and heath, decreased. Alder swamp forest increased the most, in both absolute and relative numbers, and *Calluna* heath decreased most in both respects.

The many transformations from one type of vegetation to another are also illustrated in figure 10. In addition, transformations to and from different types of vegetation from 1956 to 1994, the period with the most radical changes, are visible. In 1994, alder swamp forest accounted for the largest coverage. In figure 10, the numerous arrows pointing towards alder swamp forest are reflections of the many ways this type succeeded other types. Most area was won from moor (4.4 ha), but alder swamp forest also replaced a number of other types. When grazing successively came to an end in the eight land holdings during the 1930s to the 1960s, natural succession drove the development towards alder swamp forest, as an adaptation to on-site environment, climate, and wet soils in particular. Forest development did not start simultaneously throughout the study area but developed first in the land holdings where grazing first came to an end (in the 1930s), at times when no forest development was seen in the land holdings still grazed. This can be seen from the GIS as well as the dendrochronological analysis. The oldest trees in the study are found in the land holdings where grazing first came to an end (in the 1930s), the youngest trees are found where grazing last came to an end (in the 1960s). In the latter areas the land is still more or less open (as moor) but forestation is clearly going on (as can be seen in the central part of the study area, cf. Figs. 1–4). Further reasons for the radical changes that took place will be examined in more detail in the next section.

Mean January and mean July temperatures have varied considerably during the last 90 years or so (Fig. 11). Relatively high January temperatures during the 1930s were followed by lower temperatures in the 1960s, which then increased until the late 1990s, followed by a marked decrease until 2010. July temperatures also reached a peak during the 1930s, decreasing until the 1970s, and have been rising since then. Judging from the trend line the drop in mean July temperatures from the peak in the 1930s was ca. 1.6 °C, and the increase in mean July temperatures from the cooler summers of the 1970s to 2010 was ca. 2.6 °C. The amount of annual precipitation varied even more than mean January and July temperatures. The trend line shows a decreasing tendency from the period 1923–1924 to the mid-1940s. Thereafter, the tendency increased until 2009. Topography causes some variation in temperatures and amount of precipitation on the coastal fringe but the aforementioned periodic fluctuations can be recognised along the entire length of the coast of Norway.

4 Discussion

The analysis of vegetation change since 1956 has revealed extensive changes in the spatial distribution of vegetation. During the last 60 years or so, forestation has been continuous, contrary to what was expected when the area was declared a nature reserve. Since the area studied is rather typical in many ways, identification of major driving forces behind this radical change are of general interest.

Throughout Europe a distinction between actual natural vegetation and potential natural vegetation (PNV) can be seen (Ellenberg 1978; Bryn

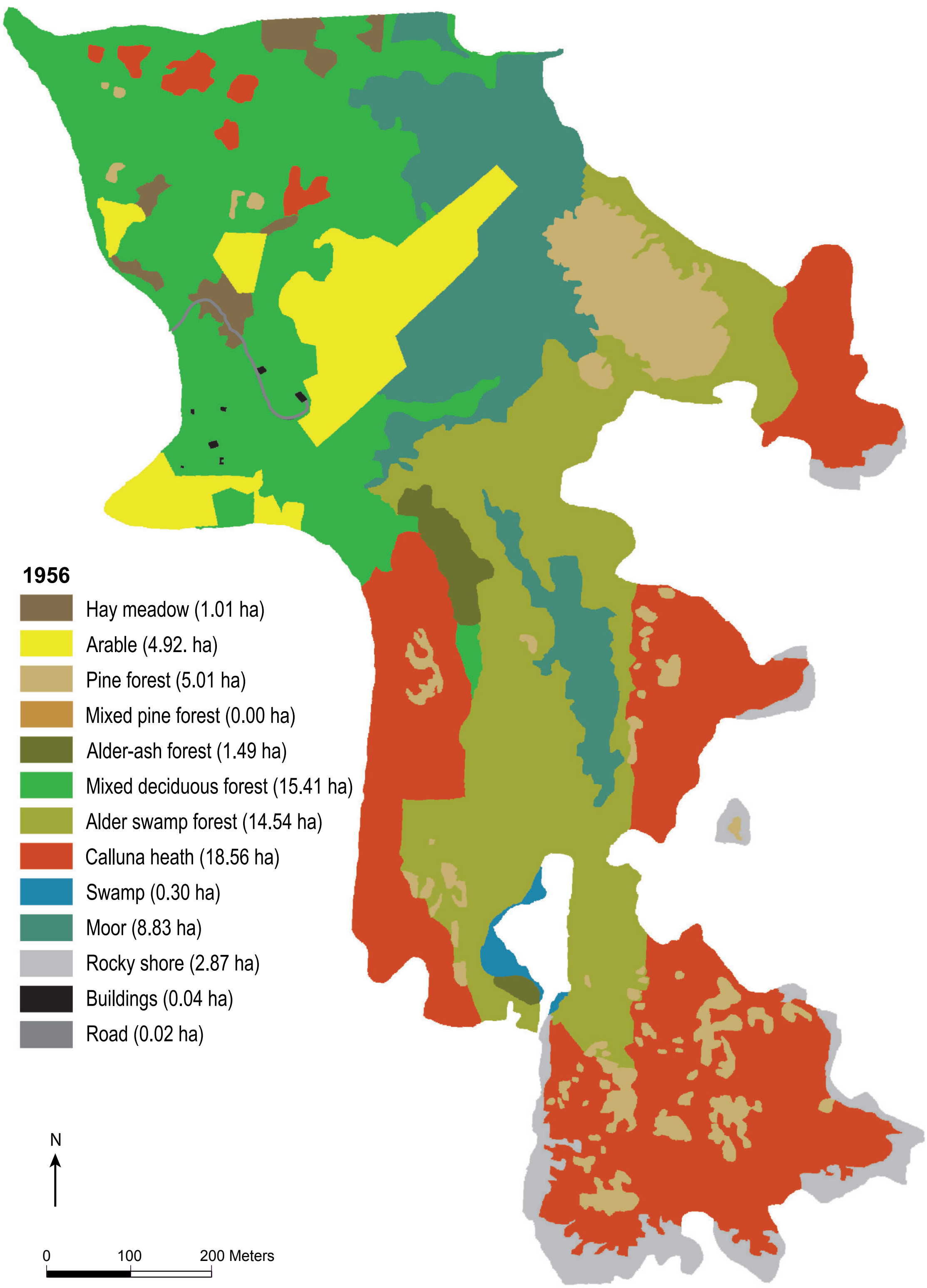

Fig. 1: The spatial distribution of vegetation in 1956

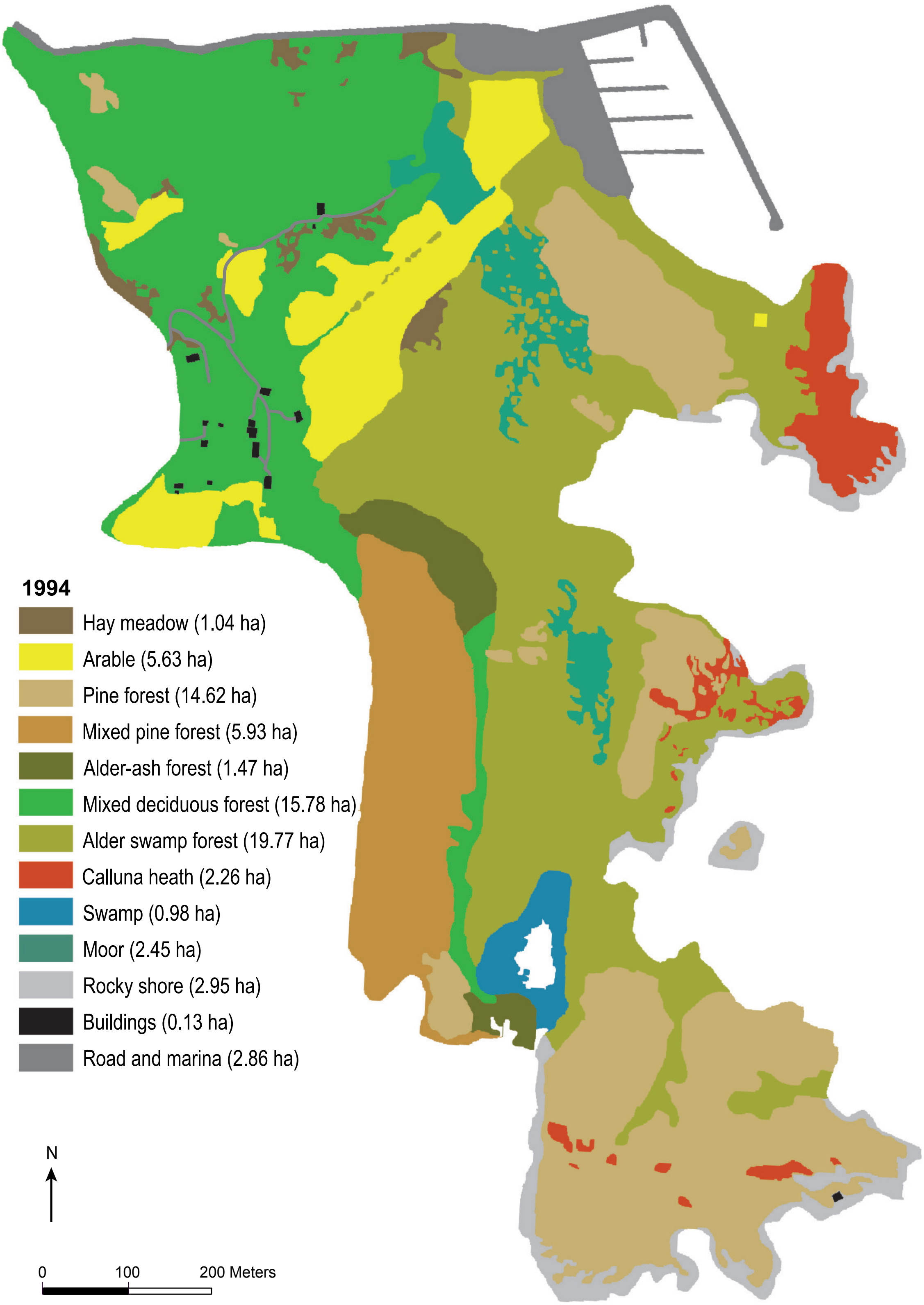

Fig. 2: The spatial distribution of vegetation in 1994. A marina was built in 1989 (upper right)

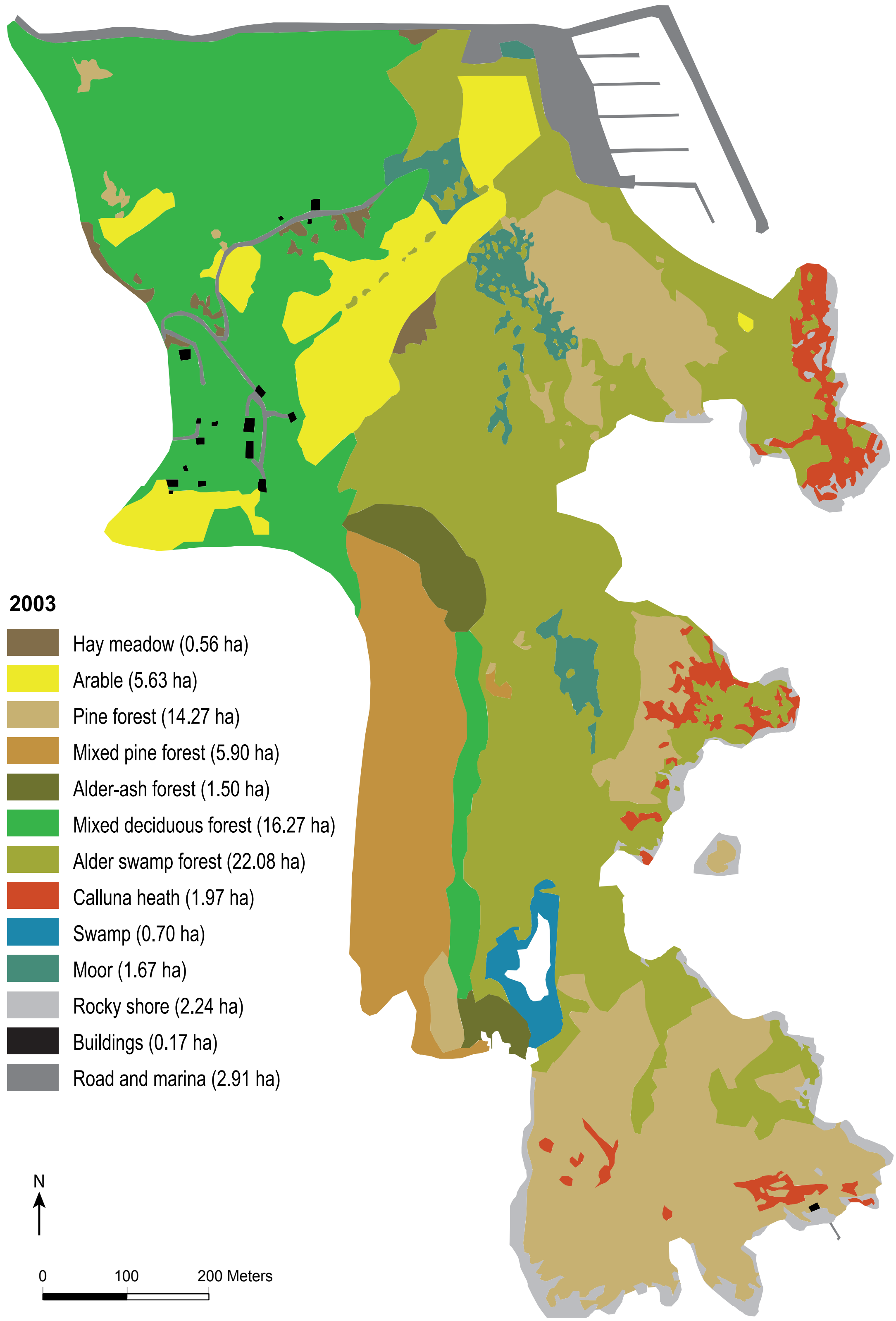

Fig. 3: The spatial distribution of vegetation in 2003

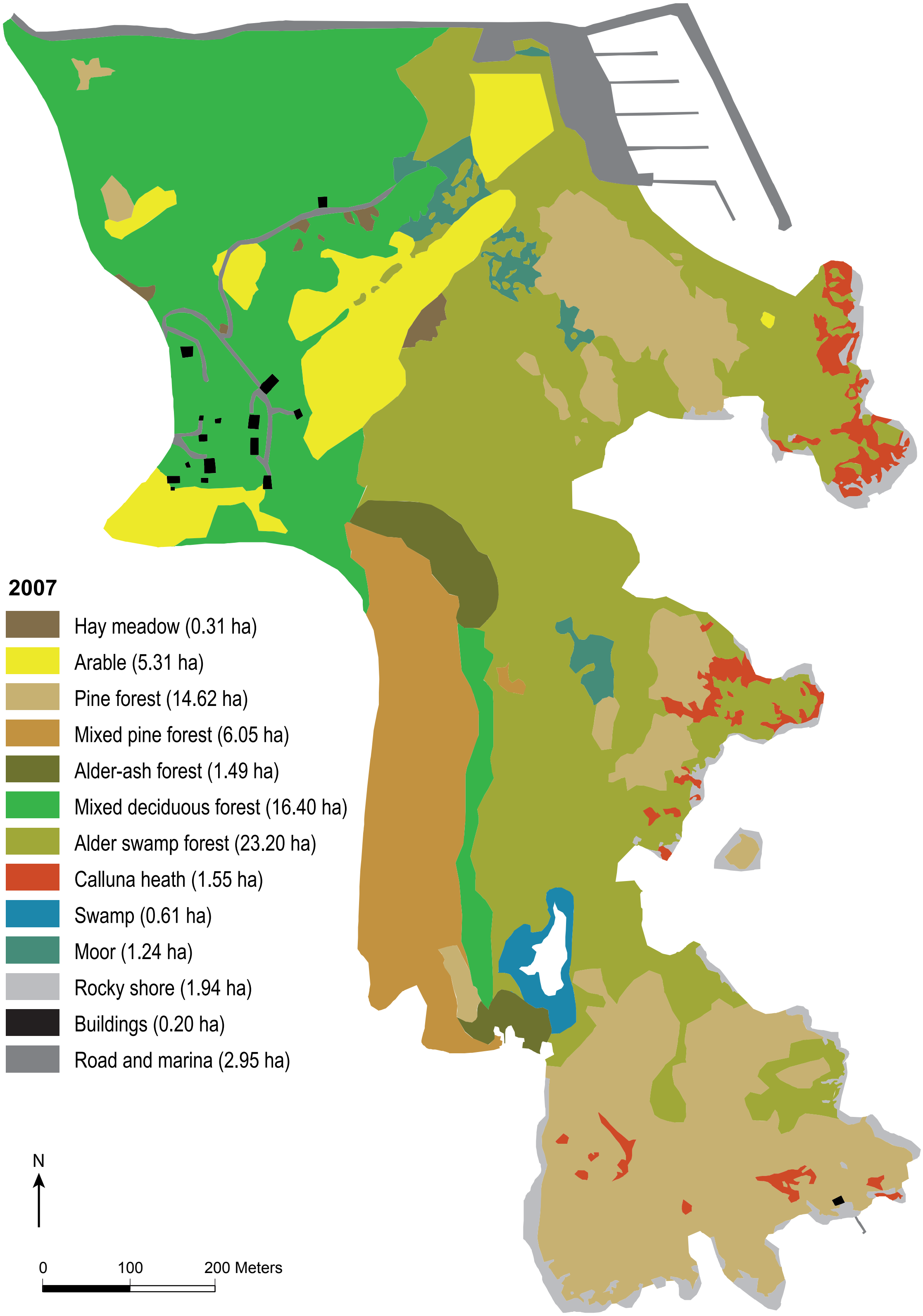

Fig. 4: The spatial distribution of vegetation in 2007

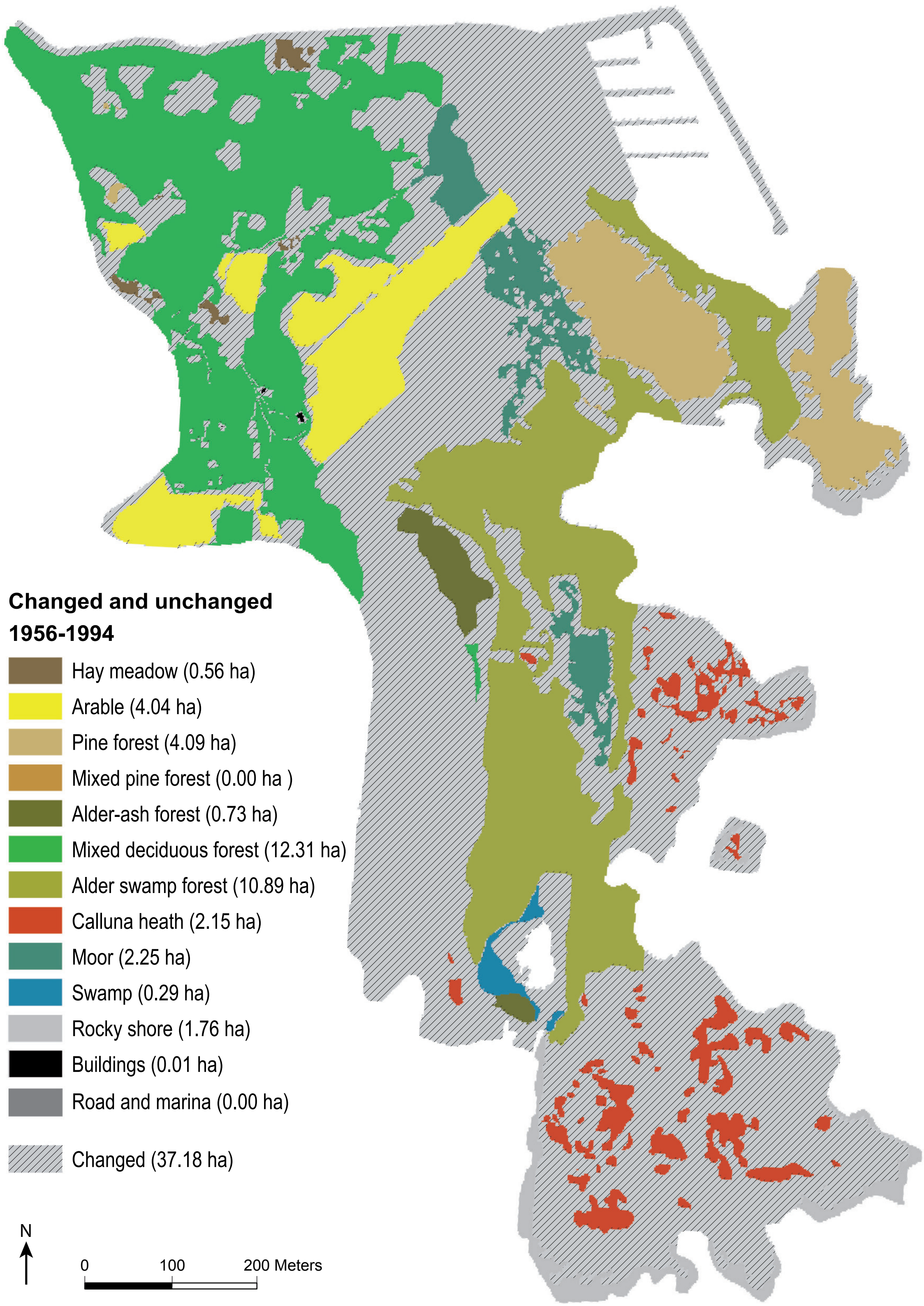

Fig. 5: Areas with changed land cover during 1956–94 Categories with individual signatures did not change

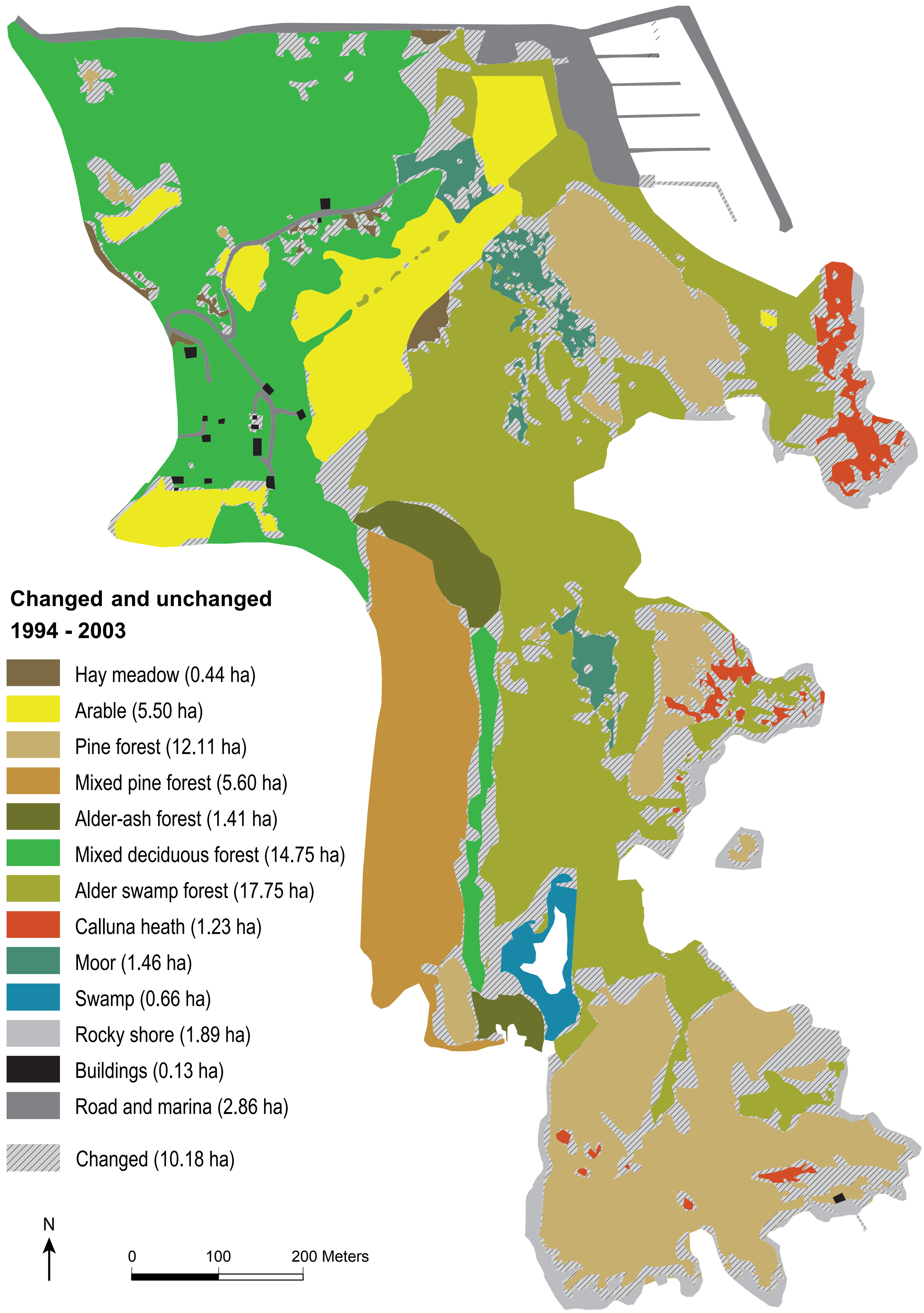

Fig. 6: Areas with changed land cover during 1994–2003. The degree of change is far lower than the 1956–1994 transitions (Fig. 5), but alterations in the distribution and type of vegetation were still in process

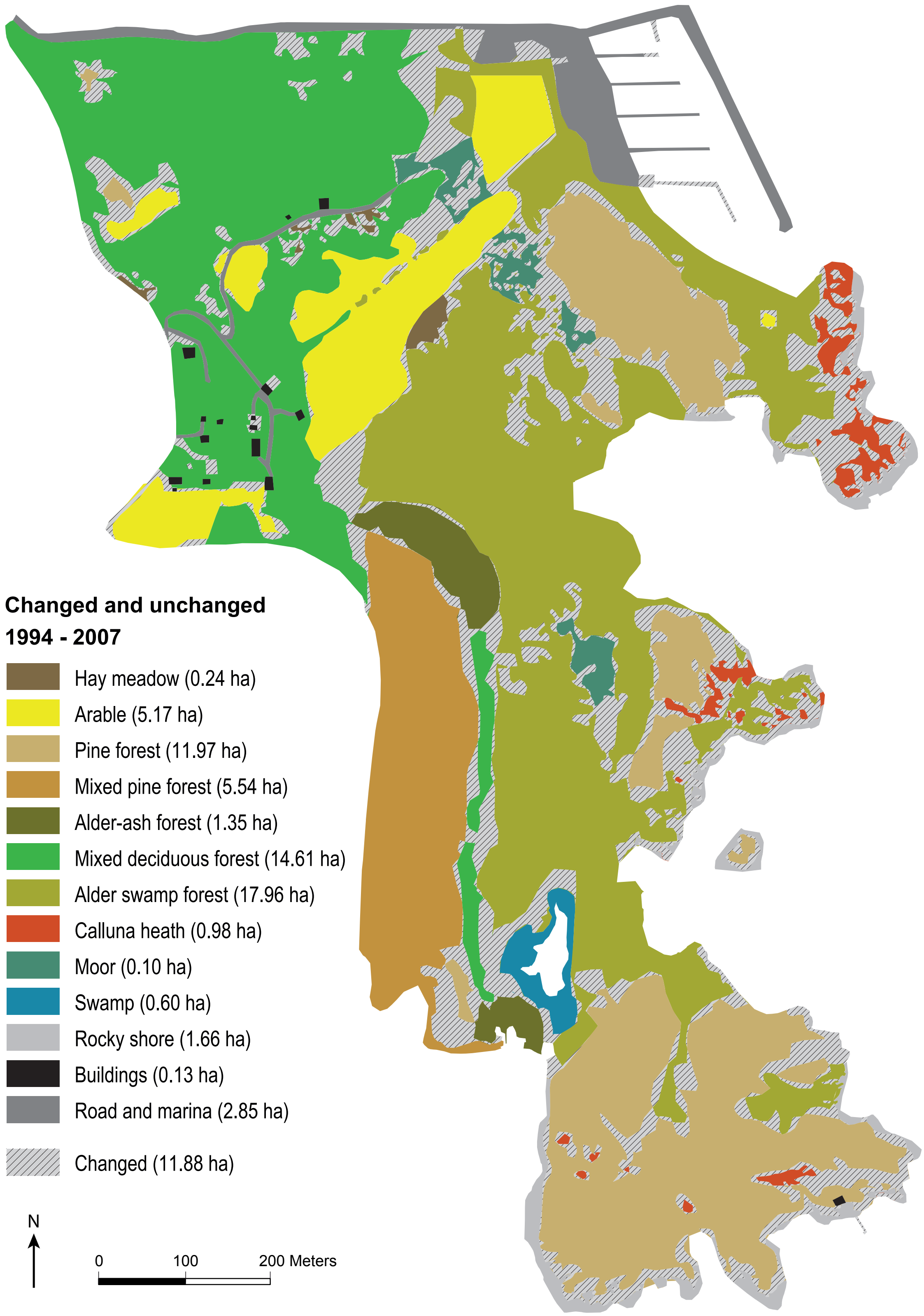

Fig. 7: Areas with changed land cover during 2003–2007

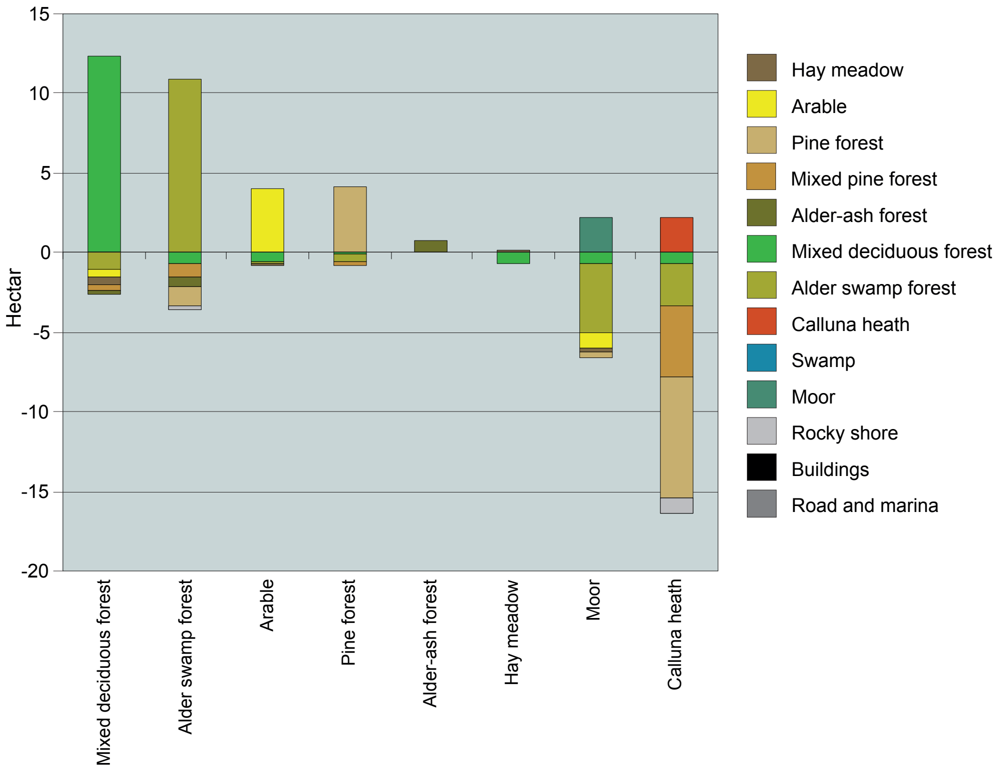

Fig. 8: Stability and change in vegetation during 1956–1994, the period with the most extensive changes. Bars above the baseline represent areas with no change; bars below represent areas with change. The sections of each bar show how much land of each type was lost to various other types of vegetation

2008). The actual alpine treeline at Stord is ca. 400 m a.s.l. The highest point in the study area is 52 m a.s.l., while major parts are 0–30 m a.s.l. Soil profiles dug in the lower, central part proved that the area was partly covered by forest, probably alder swamp forest, during late Holocene. A peat layer was found above the black forest soil layer, indicating the forest was later replaced by moor and wet grassland (Lundberg 2005b). The transition between forest soil and peat layer has not been dated, but historical sources may give some indication.

In the Middle Ages, most farms at Stord had timber for sale, much of which was exported to Scotland, The Netherlands, and other parts of Europe. During the 16th century a toll station was established at Eldøy, ca. 4 km south of the study area. Deforestation increased during the 16th and 17th centuries, when water-powered, more efficient saws came into use. Freight quays were constructed throughout the region and at Stord 8–10 foreign ships were loaded with timber annually. In 1751, 18 ships loaded timber from the island (Lundberg 2005b). The historical records from the toll station give detailed information about the type and quantities of timber exported. Undoubtedly extensive parts of Stord were deforested in the period 1550–1750, on a regional scale. Land taxation papers from 1665 inform that no forest was left in the area being studied. The forest must have been cut down some time before then, probably during the previous century.

Land taxation papers and descriptions of land reallotments from the 17th century to early 20th century provide further evidence. For example, the outfields belonging to the farm at Hystad had no forest, only pasture, in common with most farms in the region at that time. As just mentioned, the study area had no forest at all in 1665. Livestock grazing had been intensive since the 16th century (with 178–296 annual grazing units) and increased significantly in the mid-19th century with peaks in 1820 (512 annual grazing units) and 1855 (465 annual grazing units). Grazing pressure decreased in the beginning of the 20th century (272 annual grazing units in 1939). There was no forest in the study area in 1723 either, when the grazing pressure was far below the situation during the 19th century. The high grazing pressure during the 19th century explains why forest did not have a chance to develop. Some forests may have developed

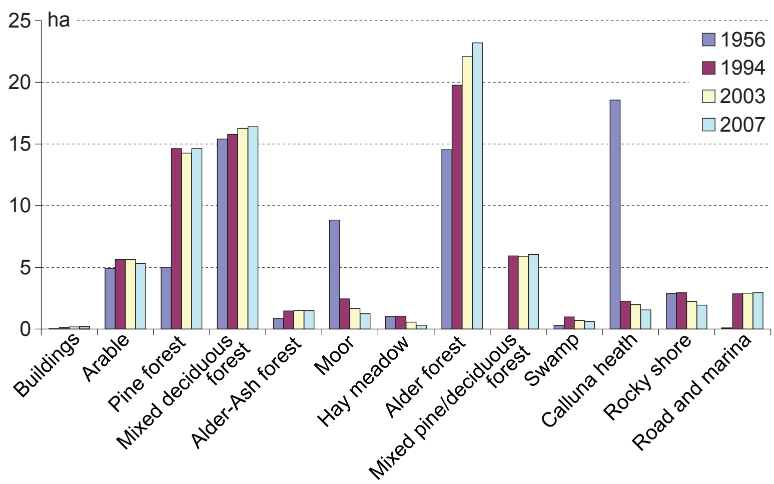

Fig. 9: Size of vegetation types/land cover in 1956, 1994, 2003, and 2007

by the end of the 19th century, probably on steep slopes often avoided by cattle, when grazing pressure started to decrease. The rate of forestation increased in the 1930s, when the grazing ceased completely on one of the eight holdings. The rate of increase continued as grazing gradually came to an end on the remaining holdings until the 1960s.

The historical-geographical analysis and the GIS analysis showed that all forest stands in the study area are first generation forests. This was also confirmed by local informants, the oldest born in 1917, telling that no mature forest were around when they were young. The young age of the trees can also be seen from the diameter of the trunks. The stem of alder trees typically are 20–30 cm in diameter and dendrochronological samples showed that most of the oldest alder trees found developed from seeds in the 1960s. The oldest found developed in 1946. The same young age was found with ash and pine, typically developed from seeds in the 1950s and 1960s, at the time when grazing came to an end where they grow and in a period when summer temperatures were decreasing.

Gehrig-Fasel et al. (2007) detected forest expansion in the Swiss Alps and found that recent increases in temperature explained far less than the abandonment of land-use. Tasser et al. (2007) studied changes in land-use and reforestation in the Eastern Central Alps and observed reforestation in the majority of abandoned areas. They concluded that seed dispersal and agricultural use were the most important variables influencing reforestation. The nearer an area was situated to old trees, the higher the reforestation rate. The less intensively land had been used previously and the longer the area had been abandoned, the higher the tree density.

The spatial analysis proved that vegetation change is more than a one-way process. One type of vegetation can lose and gain terrain from another type of vegetation and vice versa. For example, in the study area mixed deciduous forest both lost and won terrain from alder swamp forest. This is to be expected in an area with rather young forests because the different types of vegetation need time to colonise available space and to reach optimal adaptation to their ecological niches. Bryn (2008) has provided strong evidence that changes in land-use, and livestock grazing in particular, have been a major driving force behind recent alterations in vegetation mosaics in eastern Norway.

Alder has an ecological optimum on wet soils, and in Central Europe the species is often found in riparian ecosystems (e.g., *Auen-Wälder*), flooded areas along rivers and lakes, and similar habitats. It is a lowland species; in the Alps it is found up to 1800 m, and in Norway up to 550 m. Alders can live to 100–120 years, or longer in exceptional cases. In the study area, only a few alders are older than 60 years, as shown by tree ring analysis. Interactions with the filamentous bacteria *Frankia* makes alder a key species in the ecosystem, able to supply plant available nitrogen to other parts of the system.

The central valley in the middle of the study area is situated at low elevation, 0–1 m above sea level. As mentioned, the valley was a shallow sound in the early Holocene, and the present-day peninsulas to the east were small islands. Isostatic land uplift caused the former seabed to become land and the brackish lagoon found in the area today is a remnant of the former sound. Isostatic land uplift has now come to an end and no further change in elevation is expected.

The low elevation is the reason why soils are rather wet. Seawater regularly flows into the lagoon at high tide through a southern canal, and at extreme high tides seawater also flows in from north-east, through the floor of the alder swamp forest. This north-eastern flow of seawater has an impact on extensive areas of terrestrial land covered by forest. Alder is resistant to seawater more than most other tree species and together with a permanent high groundwater table this is a major reason why alder is likely to dominate at low elevations in the foreseeable future.

In summary, it can be concluded that primeval forests in the study area were completely cleared, and used and/or sold as timber or wood for other purposes, by no later than the 16th century, and probably before then. Thereafter, livestock grazing prevented reforestation, until the pastures gradually were abandoned between the 1930s and 1960s. The detected processes of vegetation change and recent forestation have been a response to changes in land-use. Recent vegetation change is an adaptation to PNV in the area.

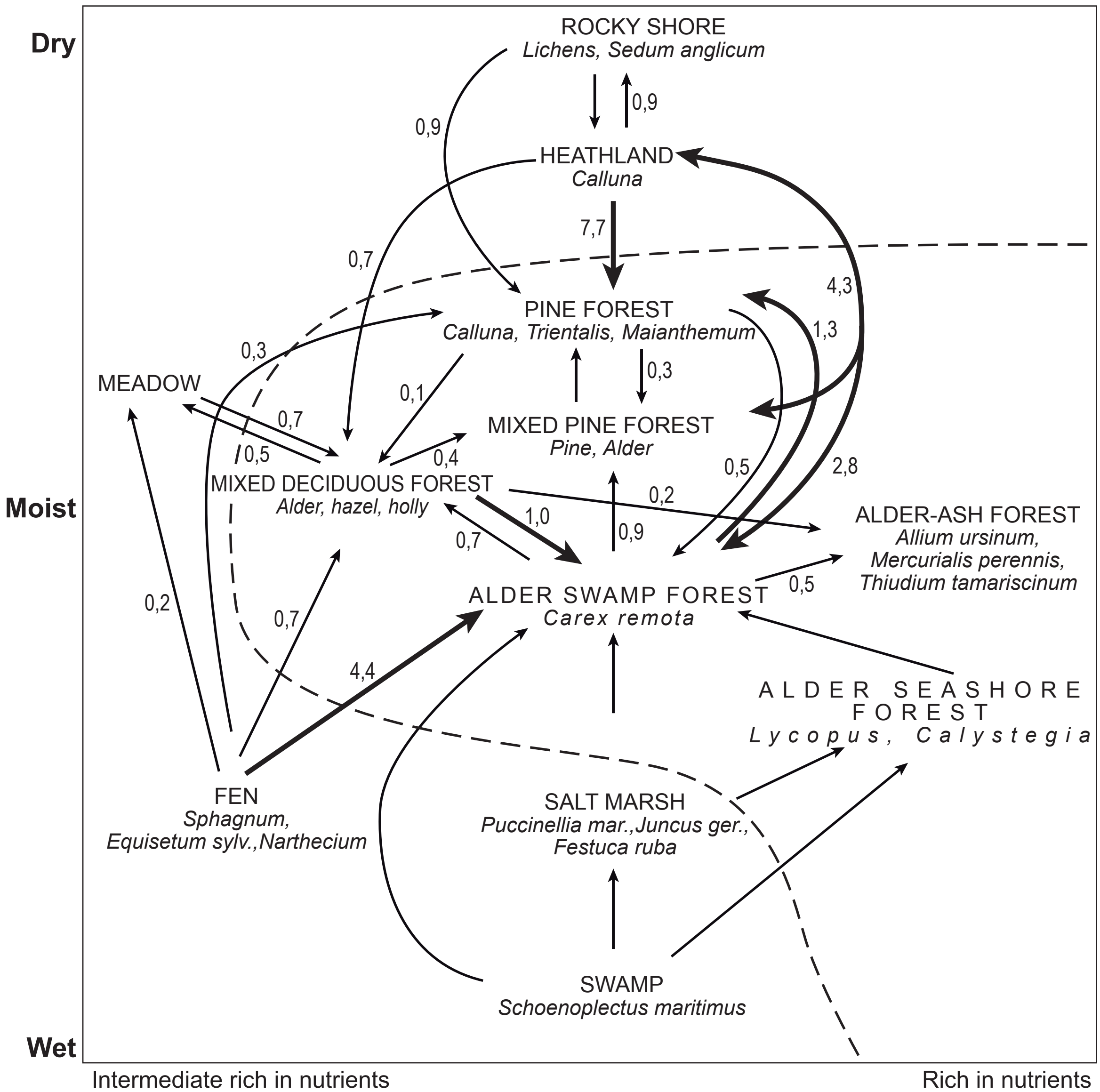

Fig. 10: Succession diagram showing transformations among vegetation types during 1956–1994, the period with most radical change. Arrows indicate the direction of change. Thick arrows represent major transformations (> 1 ha). Numbers are in ha. The stippled line marks the border between forest and open land

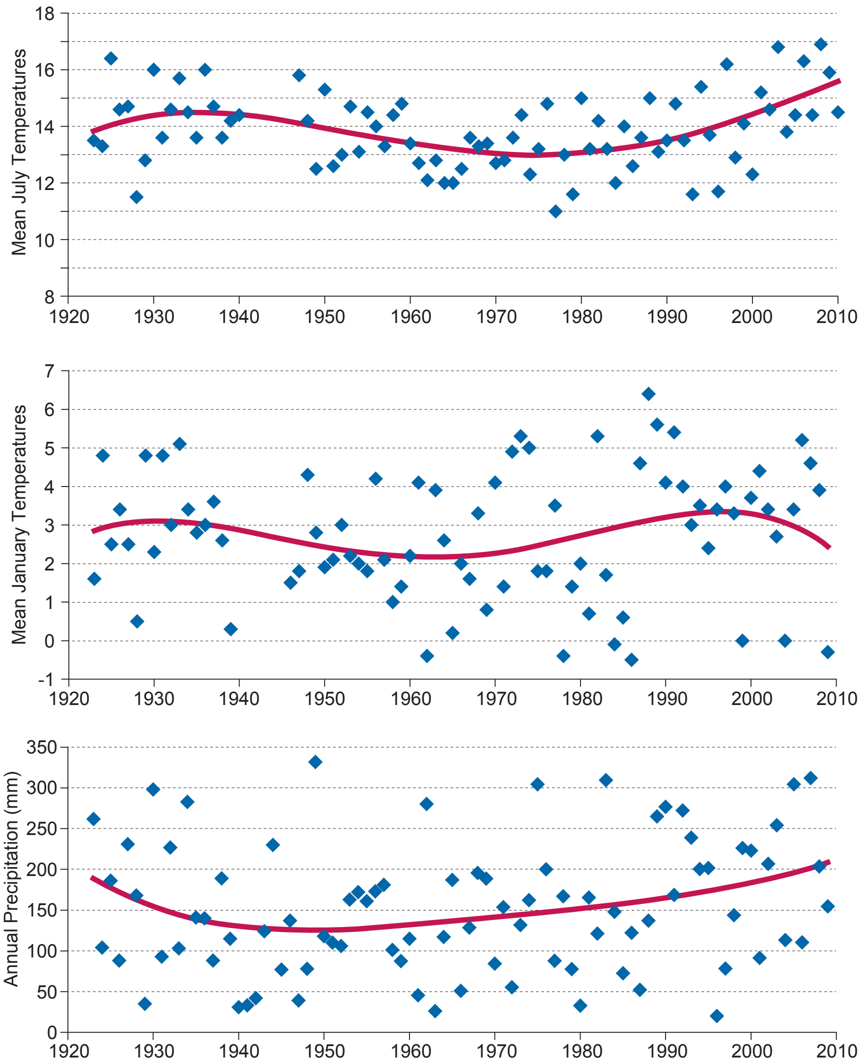

Fig. 11: Climate data from neighbouring meteorological stations. Trend lines were produced with polynomial smoothing of 4th order. A) Variation in mean July temperature 1923–2010. B) Variation in mean January temperature 1924–2010. C) Variation in precipitation during 1923–2009

5 The relation between climate variations and vegetation dynamics

Climate has a major impact on vegetation in terms of species composition and development. The distribution of vascular plants is primarily impacted by the heat-sum or the mean temperature of the warmest month (Dahl 1998). Mean July temperatures in the study area have changed significantly during the last 90 years. No linear trend can be seen for the period as a whole, but periodic trends are clearly visible. When this is compared to the vegetation development during those periods some interesting trends are revealed. The spatial analysis of vegetation change showed significant forestation during 1956–1994. During the first part of this period the trend line of mean July temperatures decreased ca. 0.6 °C and then increased again ca. 0.8 °C until 1994. In the shorter period, 1994 to 2003, the trend in mean July temperatures increased ca. 1.0 °C and then 0.8 °C until 2007. The figures reveal that the rate of forestation was high during 1956–1994 (53.4% increase) and has been significantly lower since then, with 4% and 3.6% increase during 1994–2003 and 2003–2007 respectively. This is interesting taking into consideration that space for further forest expansion was available (e.g., moor surrounded by alder swamp forest). The major increase in forestation came during 1956–1994, a period without a one-way, unambiguous trend in mean July temperatures.

This is an indication that a force other than climate change was responsible for the extensive forestation, most likely the cessation of livestock grazing. The most significant increase in mean July temperatures has occurred since 1994, in a period when the rate of forestation slowed down. Again, this points to another explanatory factor than climate.

The amount of annual precipitation varied between 1923 and 2010, but even the most 'dry' years during the 1940s had sufficient precipitation to support forests. Precipitation is probably not a limiting growth factor in this temperate, humid climate.

If climate change had been a major force in the extensive lowland forestation revealed in the study, a process of simultaneous forestation should be seen across the study area. This is not what was detected. On the contrary, forestation developed asynchronously and was detected first in those land holdings where grazing first came to an end, in the 1930s, at times when no forestation took place in neighbouring land holdings where grazing still was going on. In the latter areas forestation started decades later, when grazing came to an end there in the 1960s.

Bryn (2008) found that recent change in forest range change in SE Norway was due to regrowth after abandoned utilisation. He tested the possible impact of changes in land-use versus climate change and found that 97% of forest expansion during 1959–2001 took place far below the upper potential climatic and edaphic forest limit. He found no indication that forest expansion in 1959–2001 was driven by increasing temperatures, as summer temperatures fell during that period.

In 1956, 1994, 2003, and 2007 there were gaps between actual and potential forest range. The detected vegetation change during that period already had the required climatic potential for forest growth, but land-use had depressed the potential development of forest since the Middle Ages. Climate change is not needed as an explanation for the transition from pasture to forest. These findings are supported by recent studies carried elsewhere in Norway (Fjellstad and Dramstad 1999; Olsson et al. 2000; Moen et al. 2006; Bryn 2008; Lundberg 2008).

6 Conclusion

During the last 80 years, Norwegian forests have expanded significantly. Today, forests are more widespread than ever before in historical times. Global warming is often mentioned as a possible explanation for the recent regrowth seen in a number of different habitats, such as old meadows, former pastures, heathlands, moors and mires, and alpine areas.

In the study area, soil profiles revealed the existence of primeval forests in the early Holocene. Historical sources inform about extensive exports of timber from the 16th century, and during the period 1550–1750 most of the regional forests were clearcut. The area comprised heathland and wet pasture, which had been used for cattle grazing since at least 1665, with no forests in the vicinity. The study area belongs to one farm, Hystad, which has eight holdings. It was common land until 1881, when the outfield was split into eight individual plots, one for each farmer. The cadastral map, which was drawn in connection with the land re-allotment in 1881, shows that no forest was present then. Stone fences were constructed along the borders between the plots, to allow separate and individual grazing regimes in each of them. The stone fences still exist and were used in the study as a basis for reconstructing former land-use and forest development in the separate plots.

In 1956, forests covered 49.5% of the area, but *Calluna* heath was the largest single type of vegetation, covering 26% of the area. In 1994, alder swamp forest was the largest type of vegetation, covering 26%. In total, 76% of the area was covered by forest, an increase of 53.4% compared to 1956. *Calluna* heath had decreased to < 3% of the area, corresponding to a decrease of 88% compared to 38 years before. Forestation continued until 2007, but at a far lower rate (4% until 2003 and thereafter 3.8% until 2007).

Mean July temperatures had a long-term decrease after the peak in the mid-1930s until the mid-1970s, followed by an increase until 1994 and thereafter. The increase until 1994 slightly superseded the decrease after the 1930s, as a trend of ca. 0.2 °C. Further increases in mean July temperatures took place until 2003 and an even larger increase occurred until 2010. From 1994 to 2010, the increase trend was ca. 1.8 °C, compared to its 2010 mean (trend) of 15.6 °C, i.e., ca. 1.6 °C higher than the trend for the peak of the warm 1930s.

Comparing climate trends with forest expansion, it is apparent that forest expansion was most extensive during 1956–1994, when there was no distinct, one-way trend in mean July temperatures. The well-defined increase in mean July temperatures since 1994 has been accompanied by a far lower forestation rate than in the previous period. This is an indication that another factor other than climate change was responsible for the extensive forestation process detected.

Where and when forestation started may give some indication as to the reasons for the transformation that took place. Forestation did not start simultaneously throughout the area, as might be expected if climate change was a triggering force. Initially, forestation started on a plot where livestock grazing first came to an end in the 1930s. The youngest forest stands are found in the plots where grazing lastly came to an end, during the 1960s. The present age structure of the forest stands corresponds very closely to the land-use history of the individual plots. The age structure of the forest stands corresponds very well to the number of years since grazing in each of the plots came to an end. This is strong evidence that land-use change is a major driving force in the distinct forest expansion detected.

Acknowledgement

The author gratefully appreciates the assistance of the late Tore Borvik who rectified aerial photos from 2003 and 2007 and also helped with the GIS analysis.

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Author

Prof. Dr. Anders Lundberg
Department of Geography
University of Bergen
Fosswinckelsgate 6
5020 Bergen
Norway
anders.lundberg@geog.uib.no