

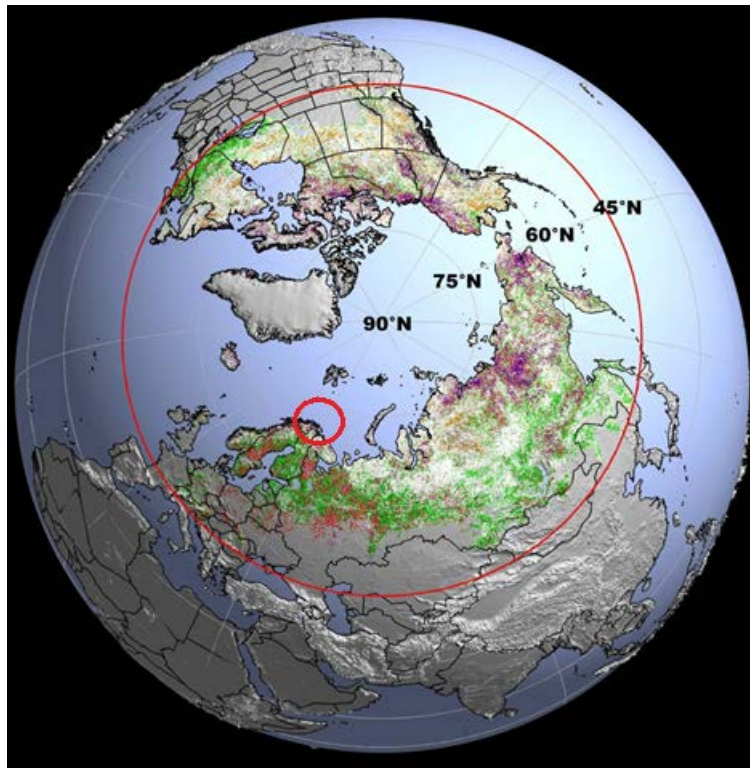


# Forest and tundra biomass change in the forest-tundra ecotone of northernmost Norway during the last century (1914-2012)

Hans Tømmervik



# Increase of plant growth per decade- 1982-2011



Trend in Arctic and Boreal Region Plant Growth with Respect to 1982 (% per Decade)



Greening/productivity  
increased in 32-39% of the  
Arctic

Browning: < 4%

Stable: 57-64%

Source: Xu, L., Myneni, R.B., Chapin III, F.S., Callaghan, T.V., Pinzon, J.E., Tucker, C.J., Zhu, Z., Bi, J., Ciais, P., Tømmervik, H., Euskirchen, E.S., Forbes, B.S., Piao, S.L., Anderson, B.T., Ganguly, S., Nemani, R.R., Goetz, S.J., Beck, P.S.A., Bunn, A.G., Cao, C., Stroeve, J.C. 2013. Temperature and Vegetation Seasonality Diminishment over Northern Lands. *Nature Climate Change*, 3: 581-586.

# «Shrubification»: From heath to shrubs and forests



[Abisko](#), Sweden (Photo: [Prof. Terry Callaghan - EU-Interact](#))

# Sources



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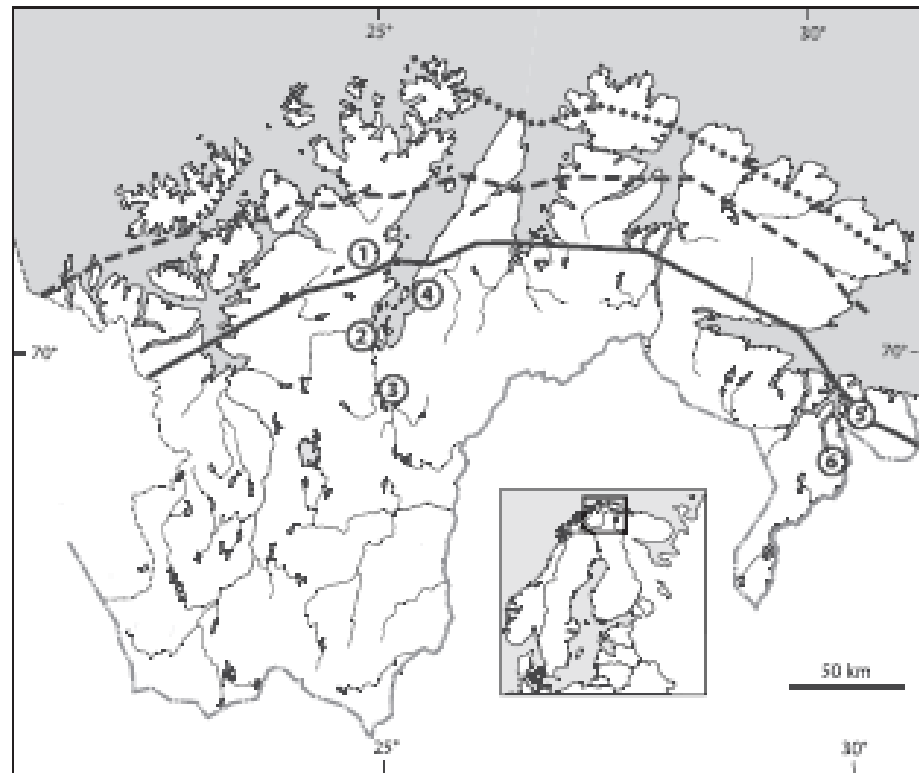
**ORIGINAL  
ARTICLE**



## Latitudinal forest advance in northernmost Norway since the early 20th century

Annika Hofgaard<sup>1\*</sup>, Hans Tømmervik<sup>2</sup>, Gareth Rees<sup>3</sup> and Frank Hanssen<sup>1</sup>

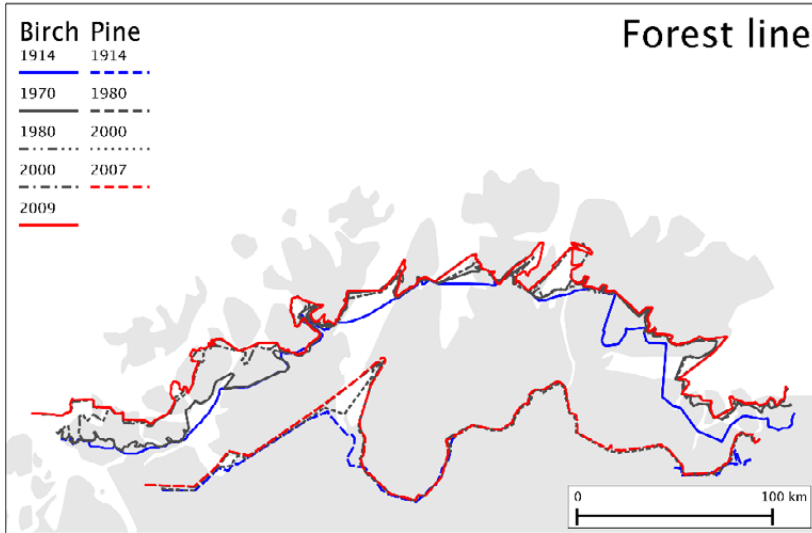
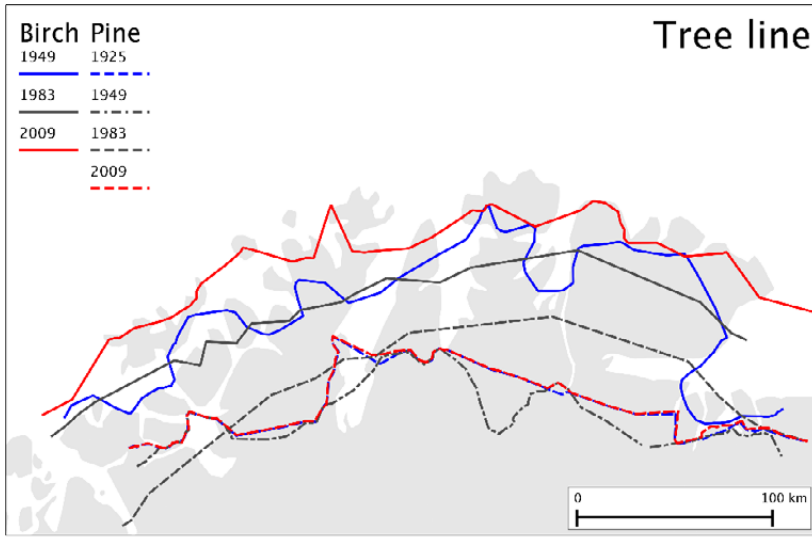
On going analysis for a manuscript in preparation



**Figure 1** The study region of Finnmark county in northern Norway with commonly cited and used latitudinal delimitations for birch forest (---) and pine forest (—) according to Hustich (1983; no. 4 in Table 1), and southern limit of arctic tundra (...) according to the Circumpolar Arctic Vegetation Map (CAVM Team, 2003; no. 15 in Table 1). Encircled numbers indicate test sites used for land cover type classification (1, Smørfjordeidet; 2, Stabbursnes; 3, Porsangmoen; 4, Børselv; 5, Jarfjord; 6, Pasvik). The inset map show location of the study region in north-western Europe.

# The forest/treeline study

- Four specific objectives were addressed:
- (1) to analyse region-wide changes in latitudinal forest line and tree line locations since the early 20th century;
- (2) to calculate rates of change of these positions, and to assess uncertainties arising from different data sources;
- (3) to analyse how these differ between two dominating tree species, *Betula pubescens* and *Pinus sylvestris*;
- (4) to place the results in the context of DGVMs.

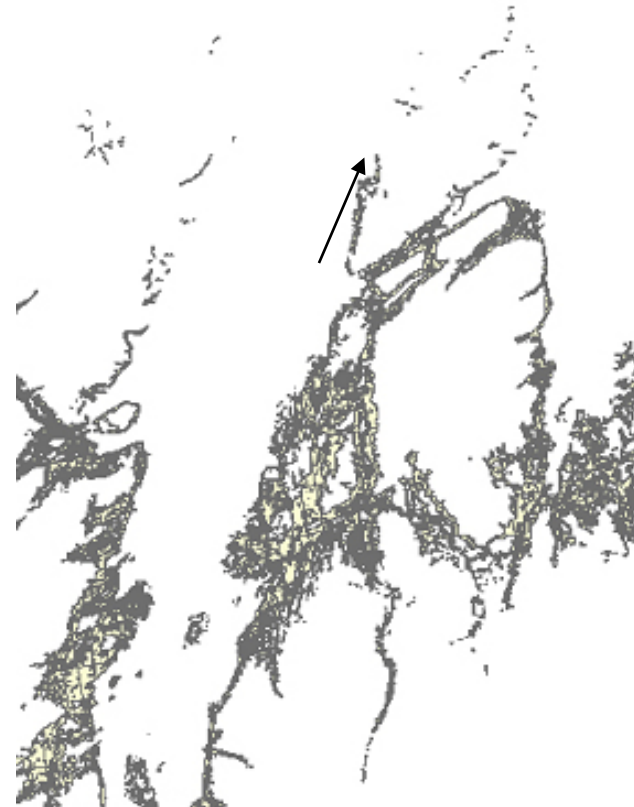




Data basis and northward expansion for birch and pine forest lines and tree lines in Finnmark county, northern Norway, in the period 1914–2009 for the band method (cf. Appendix S2). ID numbers for data sources refer to those in Table 1; the main source is given in bold. Calculated northvalues are given in relation to first recordings per line type and species (given in bold), respectively. Negative values indicate ward expansion southward retreatment.

Line type	Data source ID	Number of longitudinal bands	Number of pixels (25 m × 25 m)		Latitudinal range (m)		Northward expansion			
			Region total	Band average and range	Average and range	SD	Total distance 1914-2009 (km)		Distance per year (m)	
							Mean	SD	Mean	Range
Birch										
Forest line 1914	1	738	28452	39 (20-364)	1550 (0-29200)	5008.1	0	0	0	0
Forest line 1975	5, 7	738	37507	51 (20-403)	3611 (0-39600)	8039.7	6.5	7.65	107	-61–657
Forest line 1980	5, 7, 9	738	35802	49 (20-346)	3100 (0-40175)	7903.2	10.7	9.27	162	-29–635
Forest line 2000	6, 10, 13, 14	738	40397	55 (20-291)	4915 (0-40275)	9721.7	14.0	9.36	163	-28–462
Forest line 2009	6, 8, 11, 12	738	44530	60 (20-546)	5460 (0-40600)	10033.4	14.8	9.46	156	-22–409
Tree line 1949	3	629	23981	38 (20-420)	1353 (0-30675)	4825.5	0	0	0	0
Tree line 1983	4	629	17497	28 (20-104)	195 (0-2100)	219.4	-5.1	11.66	-151	-874–566
Tree line 2009	6, 8, 12, (15)	629	21317	34 (20-257)	346 (0-5525)	433.7	20.4	12.37	340	-10–705
Pine										
Forest line 1914	1	372	14219	38 (20-273)	764 (0-15900)	2278.4	0	0	0	0
Forest line 1980	5, 7, 9	372	16988	46 (20-483)	4105 (0-64400)	13749.3	6.4	10.90	97	-46–698
Forest line 2000	6, 10, 13, 14	372	17296	46 (20-377)	3647 (0-62900)	12398.8	4.3	9.50	51	-34–524
Forest line 2009	6, 8, 11, 12	372	17143	46 (20-426)	4472 (0-66575)	14652.2	6.8	11.25	71	-29–499
Tree line 1925	2	645	20938	32 (20-621)	439 (0-19675)	1723.6	0	0	0	0
Tree line 1949	3	645	22292	35 (20-264)	380 (0-9850)	647.5	-6.1	8.37	-254	-1319–213
Tree line 1983	4	645	19131	30 (21-50)	242 (25-750)	168.2	14.1	18.08	243	-546–753
Tree line 2009	6, 8, 12	645	2094	32 (20-335)	503 (0-19225)	2003.1	0.8	1.29	10	-46–157

# Porsangerfjord 1914 and 1979

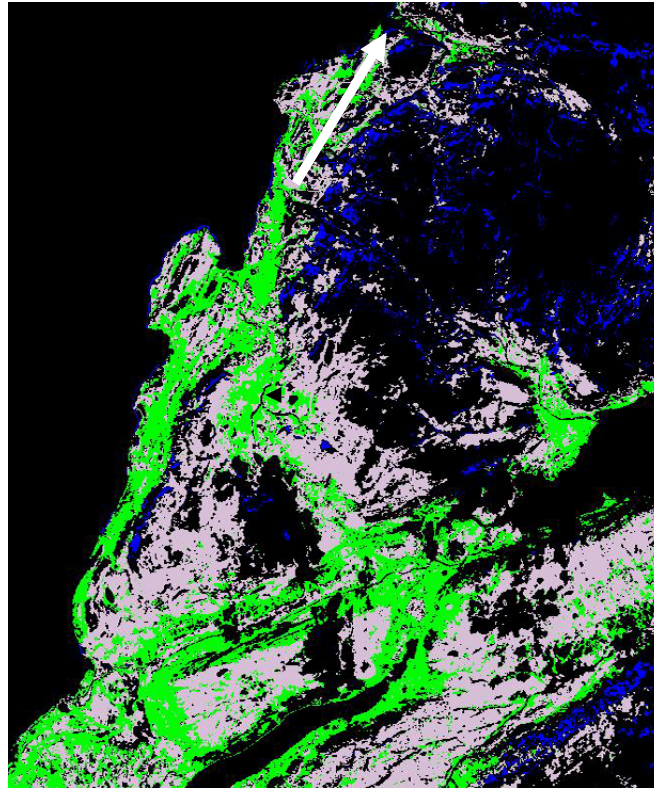
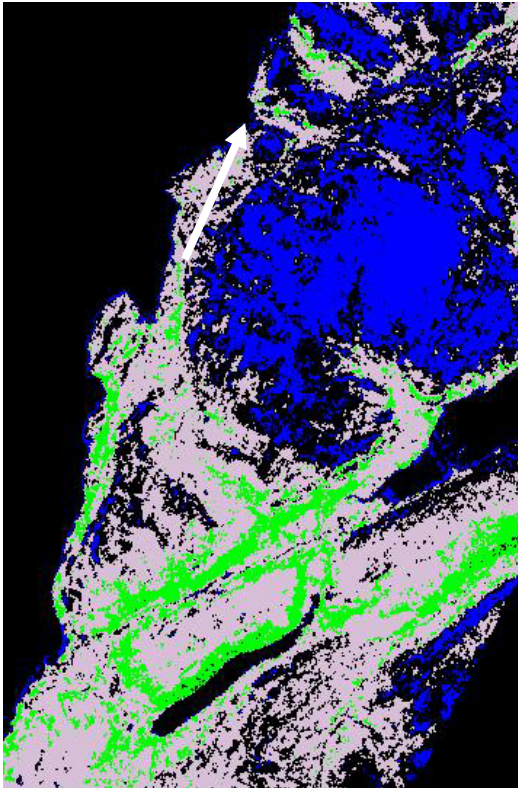


Change in northern forestline: 1914-1979/91: more than 30 kilometers northwards. 1914-2007: more than 33 kilometers northwards.

# Change in forest line: 1980-2007

1980

2007



Change in forestline  
1980-2007:  
4.1 km  
northwards



Forestline: Comparison of MSS 1980 and Forest cover map 1979/1991 = 700 meters discrepancy

Forest map 1979/91

# Conclusions of the tree and forest line study 1914-2009

- **Birch tree line advanced 20.4 km (340 meter per year)**
- **Birch forest line advanced 14.8 km (156 meter per year)**
  
- **Pine tree line advanced only 0.8 km (10 meter per year)**
- **Pine forest line advanced 6.8 km (71 meter per year)**



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**ORIGINAL  
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**Latitudinal forest advance in  
northernmost Norway since the early  
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Annika Hofgaard<sup>1\*</sup>, Hans Tømmervik<sup>2</sup>, Gareth Rees<sup>3</sup> and Frank Hansen<sup>1</sup>

# Part II: the land cover and biomass changes

- As many of the studies of the vegetation change and biomass change in the northerly lands have been assessed in a coarse manner using remote sensing often covering the whole circumpolar or circumboreal area our objectives in this study are:
  - to assess the vegetation change (tundra vs forested land)
  - and the biomass change the last century

# Definition of forests

- The forest line represents the northern limit of the closed boreal forest, and we use the commonly used canopy cover of 30% as the threshold for forest/non-forest (cf. CAVM, 2003).
- Our nominal criteria were that tree heights should exceed 2 m and that forest canopy cover should exceed 30% (CAVM Team, 2003),
- and that the distance between trees should not exceed 30 m for forested parts, in order to follow the same principles commonly used in the early 20th century (Mork & Heiberg, 1937).
- North of the forest line the distance between single trees or small groups of trees increases towards the tree line, at which tree-sized (>2m) tree species individuals cease. Beyond this location the tree species exist as non-tree sized krummholz, saplings and seedlings.

# Definition of forests



## Statistical data and map data used in the analysis.

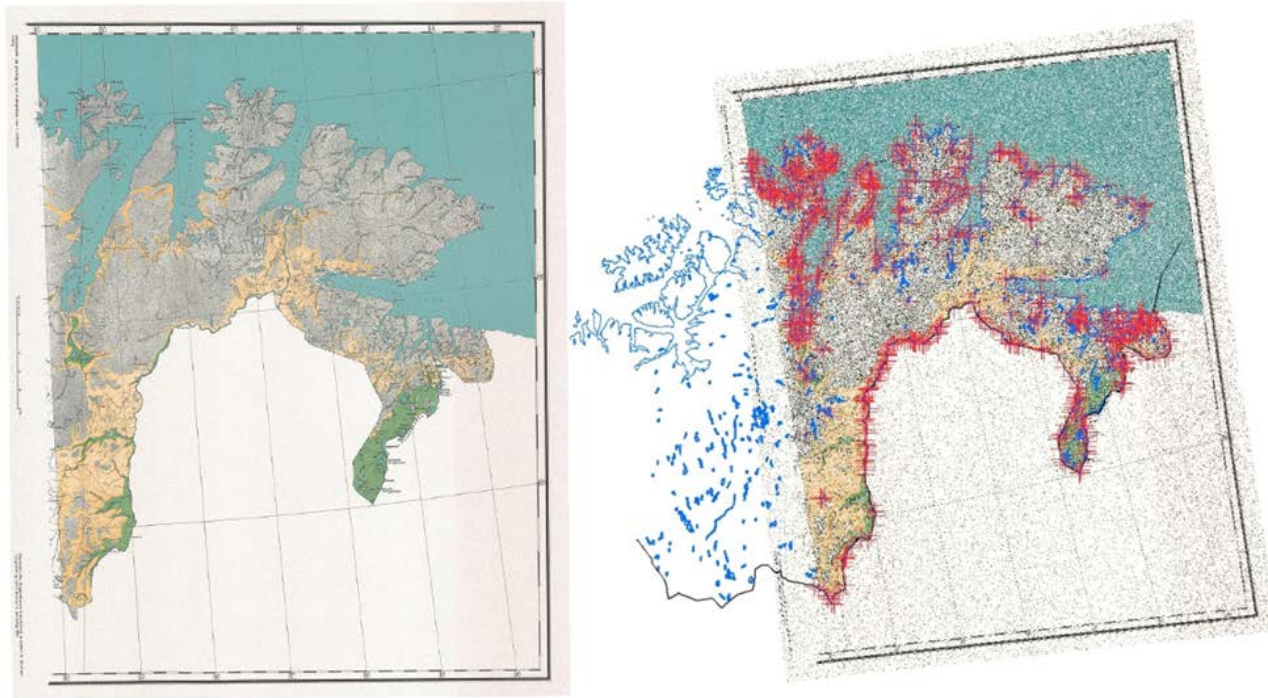
Statistical and map data	ID	Scale	Period - Year	Reference/Source
<b>Statistical data</b>				
Census of Forestry 1927	1		1917-1920	Norges Offisielle Statistikk VIII. 34
Census of Forestry 1933 (above the limit of coniferous forests)	2		1930-33	Landskogstakseringen
Agricultural census 1947	3		1927-1947	Norges Offisielle Statistikk X. 161
Census of Forestry 1957	4		1945-1957	Norges Offisielle Statistikk XII. 6
Census of Forestry 1967	5		1957-1967	Norges Offisielle Statistikk XII. 248
Census of Forestry 1967	6		1957-1967	Norges Offisielle Statistikk XII. 255
Census of Forestry 2005-2011	7		2005-2011	Fylkesmannen i Finnmark
				Statistics of Norway
<b>Historical maps</b>				
Forest map for northern Norway 1914	8	1:500.000	1910-14	The General Director for Forestry in Norway (1914)
Pine forest map for Finnmark and Troms counties, 1925	9	1:1.430.000	1925	Juul (1925)
Forest map for northern Norway, 1949	10	1:2.000.000	1949	Ruden (1949)
<b>Present map data</b>				
Land cover map	11	1:50.000	1990	Statkart (1990)
Circumpolar Arctic Vegetation Map (CAVM)	12	1:7.500.000	2000-2003	CAVM Team (2003)
Vegetation map Norway 2007, based on satellite imagery from 1998–2007	13	1:50.000	1998-2007	Johansen (2009)
Land cover map	14	1:50.000	2011	Statkart (2011)



# Map transformation

- A digital version of the old forest map from 1914 was prepared in ARCGIS 9.3.1(ESRI, Redlands, CA).
- The map was adjusted relative to recognizable static map features such as national borders, the coastline and non-regulated lakes greater than 1 km<sup>2</sup> in the 2009 version of the national topographic vector dataset N50
- Based on these static map features the map was digitized, georeferenced, and transformed to the Universal Transverse Mercator (UTM) projection (zone 33; WGS datum). Analysis based on 881 control points showed a residual error of 20 m, which is acceptable for present purposes (Pezzi et al., 2011).

# Transformation of the old forest map from 1914 to present UTM projection



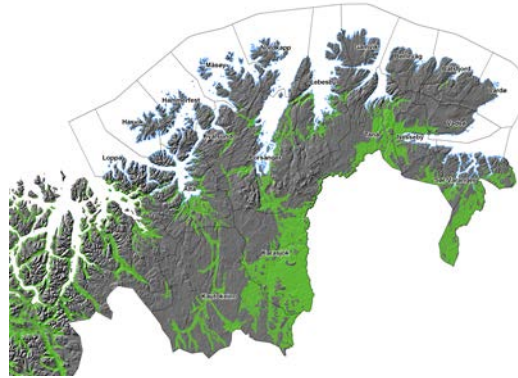
Forest cover map for the eastern part of Finnmark County from 1914 (General Director for Forestry in Norway, 1914). Pine forests are shown in green and birch forests in yellow. Grey represents non-forested areas. In the right hand panel the map from 1914 is transformed and superimposed on a modern digital topographical map.

# Further work

- The basic sources for the old map were topographic maps produced in the period 1870–1910 together with information from local forest authorities.
- We used the present topographic map in order to remove/filter out areas with lakes, ponds, bogs, barren mountain outcrops, steep cliffs etc. not existing in the 1914 map.

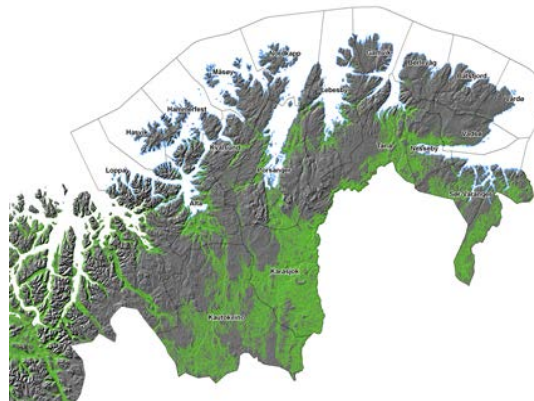
# Forest cover in Finnmark county

1914

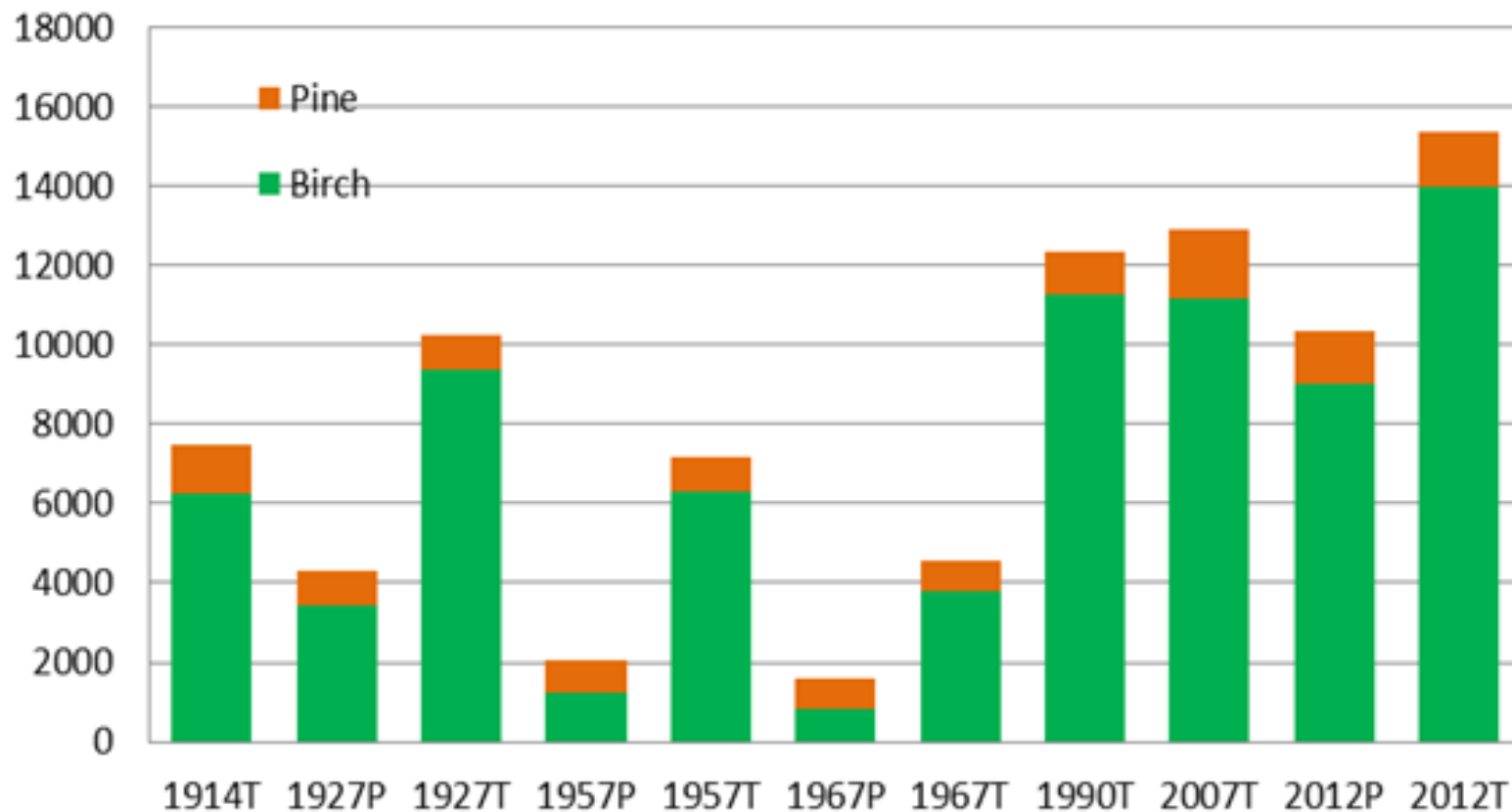


Birch forest change 1914-2012.

2012



## Finnmark: Forest cover 1914-2012



# Other land cover types in Finnmark

## 2005-2012 Landscape survey

- Tundra/mountain heaths/bogs : 30530 km<sup>2</sup>
- Lakes : 2300 km<sup>2</sup>
- Farmland/pastureland : 360 km<sup>2</sup>