MAP-BASED ELEVATION OF THE UPPER FOREST LIMITS IN TROMS, NORTHWESTERN NORWAY

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Abstract Elevations of birch (*Betula pubescens*) forest limits in northern Norway are measured by using 56 sheets of 1:50,000 scale topographical maps. The highest positions of forest land cover boundaries on uniform slopes with various aspects are selected as reference points of forest limits. The total number of the points is 1,052. The mean elevation of birch forest limits is 423 m a.s.l. This value shows a good agreement with the previous studies. The mean elevations of forest limits on slopes with four aspects are 394 m (north facing), 375 m (east facing), 452 m (south facing), and 439 m (west facing) respectively. The aspect of slopes with the lowest mean value of forest limits is not the north facing but the east facing in this region.

Key words: forest limit, timberline, ecotone, Scandinavia, Norway

1. Introduction

Some researchers summarized the long history of study on forest limits in geography, biology, and other relating disciplines (*e.g.*, Troll 1973; Oka 1991). We can recognize three kinds of forest limits corresponding to dryness, altitudinal coldness, and latitudinal coldness. The last two are known as the upper forest limit and the polar forest limit. The upper forest limits sometimes show very clear physiognomical boundaries and these limits are good examples of ecotones. In the fields, however, it is not so easy to decide the position of forest limits. This problem is also found when we consider the tree limits. Slatyer and Noble (1992) show that the timberline is the uppermost edge of continuous canopy forest and the treeline is the upper limit of the distribution of tree form. They also state that trees are defined as a height of more than about 2 m.

In this paper the author follows some recent papers presented by the Scandinavian researchers because he discusses the upper forest limits in the northwestern part of Norway. He adopts the terminology of Kullman (1990) for the forest limit and tree limit. When the author considers numerical definition of the forest limit in the actual fields, he follows Mook and Vorren (1996). They state "*the forest-lines are delimited according to the definition of Mork & Heiberg (1937): a distance less than 30 m between trees, at least 3 m tall.*" Some other researchers consider that trees are taller than 2 m and bring this value into the forest definition. However the value of 3 m is more reasonable because the forest limit

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seems to represent a more suitable growing condition than the tree limit.

Comprehensive explanation of forest limits had been described by many authors (*e.g.*, Crawford 1989; Kimmins 1997), so that the author does not mention enormous individual papers. Many studies on the forest limit and the tree limit can be summarized as following four discussing points:

- Estimation of the climatic position of the limits due to latitudes and elevation by using statistical methods and meteorological observation.
- Relationships between climate change and displacement of the limits in various time scales.
- Downward displacement of the limits due to grazing pressure by animals and human activities.
- Regional or local variety of the limits due to the small scale topography and climate, for example, aspects and inclinations of slopes.

The aim of this paper is to present a local variety of the distribution of forest limits due to the aspects of slopes around Troms by referencing 1:50,000 scale topographic maps as proxy data.

2. Method

Sirois (1992) states that the dominant two tree species in the northern Norway are Scots pine (*Pinus sylvestris*) and common birch (*Betula pubescens*). The immigration of common birch into this area occurred immediately after the deglaciation and Scots pine succeeded. The present limit of Scots pine forest lies in the common birch forest belt (Vorren *et al.* 1996a; Seppä 1998). Consequently the upper forest limits in this region are considered to be formed by common birch. The polar forest limit is not treated in this paper because it lies in far north along the coast of Barents Sea (Moen 1998; p.121).

Figure 1 shows the upper limit of birch forest with the elevation of about 400 m a.s.l. on the SW facing slope of Tromsdalen (69° 37′ N, 19° 05′ E) near the city of Tromsø. Figure 2 shows an example of birch woodland just above the upper forest limit on the SW facing slope of Skibotndalen (69° 22′ N, 20° 24′ E, ca. 600 m a.s.l.). Mook and Vorren (1996) show that the birch forest limit in this location is about 570 m a.s.l. These two figures may indicate the technical advantage of forest limits for delimiting by using small scale (*e.g.*, 1:40,000) aerial photographs or large scale (*e.g.*, 1:50,000) topographic maps.

The Norwegian topographic maps with a scale of 1:50,000 are published by Norwegian Mapping Authority (Statens kartverk). We can get any copy of these maps easily but there may be some difficulties for foreign researchers to get aerial photographs of some special areas. In this work, the author uses 56 sheets of 1:50,000 maps as proxy material for referencing the location of forest limits. Most copies were published as the 4th edition in the late 1980s and early 1990s. All these maps contain the description of 'forest' and 'group of trees' as legend items. The delimitation of the forest legend is checked between older editions and a new one for some same map areas. The author could not find any major changes along the upper limits but find good revision of low land areas. Accordingly the author neglected the difference of published years or editions among 56 sheets of maps.

Fig. 1 Birch forest limit on the SW facing slope of Tromsdalen (July, 1998). Elevation: ca. 400 m a.s.l., Location: 69° 37′ N, 19° 05′ E.

Fig. 2 Birch woodland above the forest limit on the SW facing slope in Skibotndalen (August, 1999). Elevation: ca. 600 m a.s.l., Location: 69° 22′ N, 20° 24′ E.

This work, of course, is not the first attempt to use 1:50,000 maps as a referencing material to forest limits. The author believes that many researchers used the upper boundary of 'forest' legend symbol as proxy lines of forest limits. For instance, Vorren *et al.* (1996b) show a reference map of study area with birch forest lines. The author checked the corresponding map (sheet No.1532 IV Kirkesdalen) and found a good agreement. An intensive study on the map-based tree lines in the whole area of Norway is presented by Strand (1998). His method of sampling is simple and systematic. He detects intersecting points between UTM grid lines and tree lines (may be the upper boundaries of forest symbols). He also summarizes the description criteria for the forest symbol on 1:50,000 maps: the forest symbol represents a forest patch with the minimum size of 50 by 100 m and the boundary is marked as a "tree line". In the present paper, the author considers that the upper boundary of forest symbol area represents a proxy line of forest limit but the accuracy or error is unknown.

Figure 3 shows the picture of west facing slope of Mt. Rundfjellet (750 m) and Mt. Blåfjellet (778 m) taken from the northeast coast of Tromsø Island (Tromsøya) across the 2 km wide strait (Tromsøysundet). The lower half of the slope (dark belt) is covered by the birch forest and the elevation of upper limit of the dark belt seems to increase gradually from the left to the right according to the slope aspect change from west to southwest. Figure 4 is the combination of the roughly traced topographic map and a small part of a sample aerial photograph (photogrammetric data are not available). The author considers that the upper limit of the dark belt on Fig. 3, the forest limit traced on a topographic map (Fig. 4 left), and the right side boundary of the dark belt on a sample aerial photograph (Fig. 4 right) agree well with each other.

Fig. 3 Forest limit on the west facing slope of Mt. Blåfjellet, 778 m (September, 1998). This is the same location of Fig. 4 but taken from the east coast of Tromsø Island (Tromsøya).

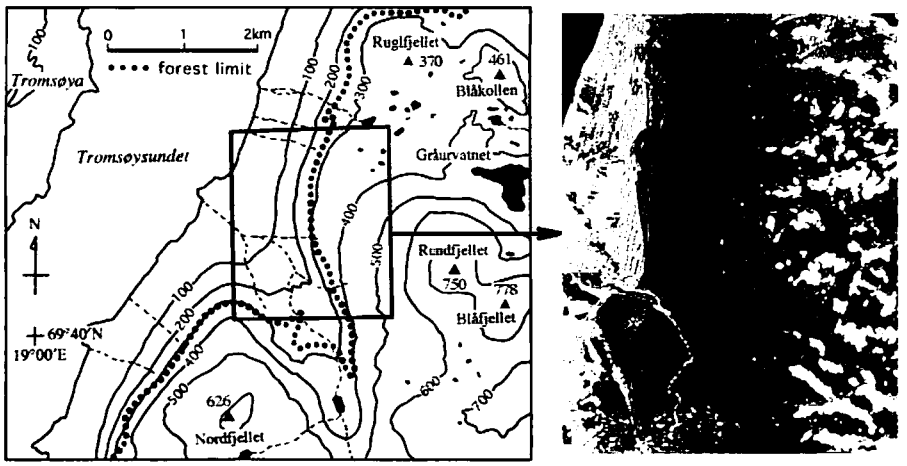

Fig. 4 An example of the forest limit indicated by maps and photos. Left (topographical map): the upper boundary of the forest symbol with some traces of contours. Right (aerial photograph): white patches of the right side are snow and the buildings of the left side are the housing complex.

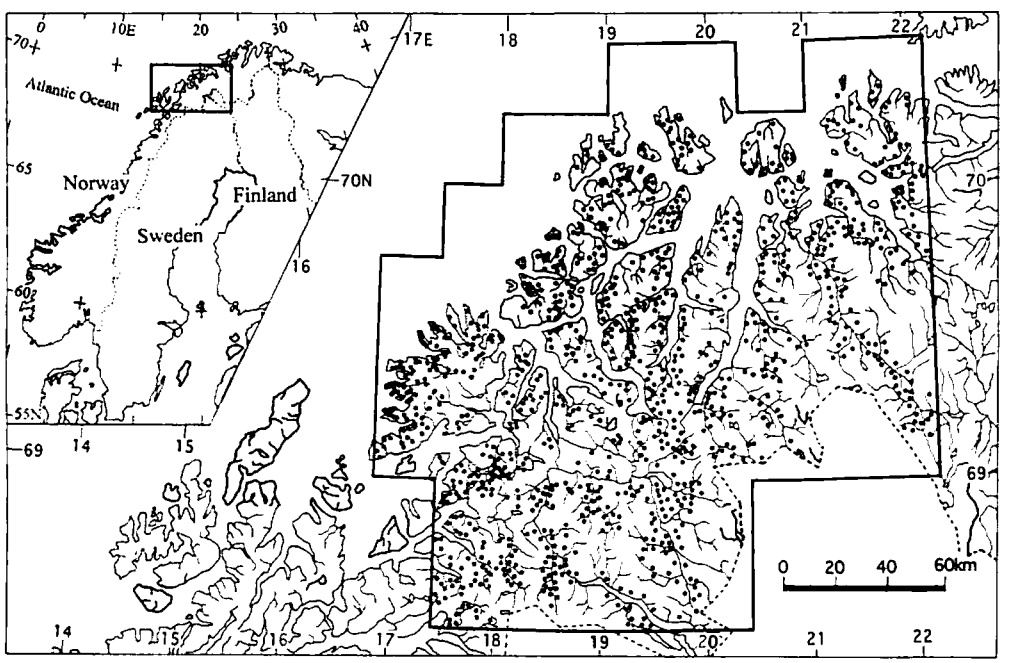

Fig. 5 Study area with reference points of the forest limits. Thick line in the main map indicates the area covered by 56 sheets of 1:50,000 topographic maps and the dots show the reference points.

Figure 5 shows the 1.052 reference points on 56 sheets of 1:50.000 maps (listed in the last of this chapter). The procedures of selecting the reference points, measuring the elevation of forest limits and the aspect of the slopes are as follows:

1. Selecting the highest point of a forest limit on a slope with long (at least 2 cm on a map) and straight or smooth contour pattern.
2. Measuring the aspect of the slope in 16 directions by fitting a tangent line to the contours.
3. Measuring the elevation of the point from the 20 m interval contours by the accuracy of 10 m.
4. When a reference point is found according to the procedure 1 on a slope with a given aspect of a valley, another point should be searched on the opposite slope of the same valley.

Map List (sheet numbers): 1333 I, II: 1334 II: 1432 I~IV; 1433 I~IV: 1435 II: 1532 I~IV: 1533 I~IV: 1534 I~IV: 1535 I~III: 1632 III, IV: 1633 I~IV; 1634 I~IV; 1635 II~IV: 1733 I~IV: 1734 I~IV: 1735 I~IV.

3. Results and Discussion

References of the forest limit elevations are summarized in Table 1. The mean elevation of the all reference points is 423 m a.s.l., and this value shows a good agreement with some previous works. Vorren *et al.* (1996a) stated that the elevation of birch forest limit in Troms is about 200 m a.s.l. along the northwestern coastal area, and 500-700 m a.s.l. in the inland area. Strand (1998) presents a statistically estimated map of "tree line". His map may show the birch forest limit in northern part of Norway because he used the forest area symbols on 1:50,000 maps as basic data. His map shows almost the same distribution as the climatic forest limit included in National Atlas of Vegetation (Moen 1998: p.113) but in Troms region his value is about 100 m lower than National Atlas.

The forest limits on the south facing and west facing slopes show the higher elevation (Table 1). On the other hand, the aspects around N and E show the lower elevation. It is interesting that the lowest value (364 m) appears in the direction of ENE. This fact has been reported by many researchers (Odland 1996). It is easy to understand the reason why the forest limit on the north facing slope is relatively low.

In case of the east facing slope, however, a perfect explanation will be hardly obtained. The first factor may be the much snow accumulation on the east facing lee side slope because the climate of this region is oceanic and the water vapor comes from west, the Atlantic Ocean. Another possible cause is thermal condition due to the diurnal motion of the sun. Consider a valley running north-south direction, the east facing slope can receive direct solar radiation only in the morning. The solar energy can be used to dry up morning dew on leaves so that the temperature of the canopy may not rise easily. Furthermore if it is foggy morning the sunshine will not be received by plants.

Consequently the difference between the highest and the lowest exceeds 100 m. This may imply nearly 100 km shift of forest limit in horizontal distribution. Table 2 shows the values of the aspects N, E, S, and W, each of which combining three directions. The

Table 1 Elevation of forest limits in 16 directions

Aspect of slopes (16 directions)	Mean value of forest limit (m)	Number of refernce points
NWN	393	60
N	393	71
NEN	395	56
NE	413	61
ENE	364	57
E	390	62
ESE	369	52
SE	416	56
SES	420	61
S	454	75
SWS	477	71
SW	478	85
WSW	457	81
W	431	96
WNW	426	52
NW	425	56
(total)	(423)	(1,052)

Table 2 Elevation of forest limits in 4 directions

Aspect of slopes (4 directions)	Mean value of forest limit (m)	Number of refernce points
N (NWN-NEN)	394	187
E (ENE-ESE)	375	171
S (SES-SWS)	452	207
W (WSW-WNW)	439	229
(total)	(418)	(794)

difference of about 75 m remains and the lowest value is not observed on the north facing slopes but on the east facing slopes. The histogram (Fig. 6) shows a simple image of statistical distribution. None of them are considered to be the normal distribution. but the shapes of distribution of aspects N and S seem to be different from those of W and E. The author has no idea about this but there is some possibility that the landform of valley. affecting the different distribution patterns, is controlled by the geologic structure. One of the most important points of views that are not treated in this paper is of course the problem of grazing. One example of such studies is presented by Hofgaard (1997). This paper was planned as a preliminary work for the geoecological and local climatological field study on the forest limit ecotone in the northern Norway.

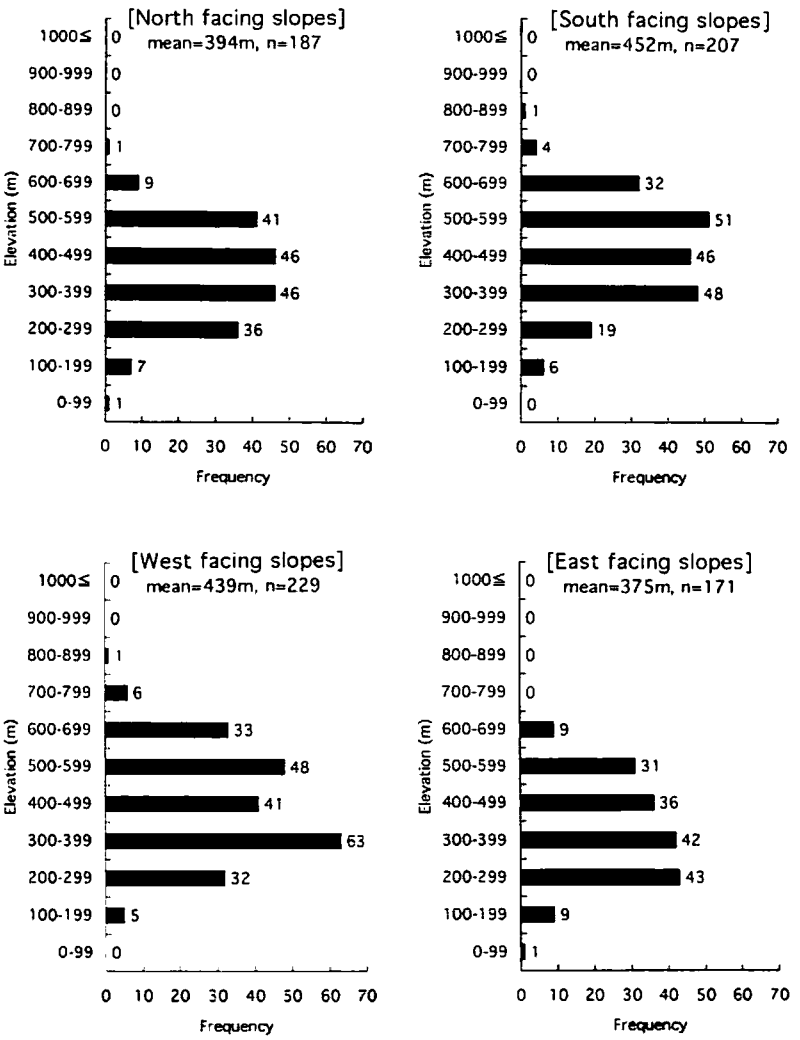

Fig. 6 Map-based elevation of the forest limits in Troms, Norway. Each aspect of slopes includes three directions, for example, the frequency for North is the sum of the three frequencies for NWN, N, and NEN. Four aspects, NE, SE, SW, and NW are excluded.

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