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On diseases and pathogens on forest trees in Norway 1966-1975

Part II

Abnormal formations. Physiogenic diseases. Diseases due to unknown or complex causes

Finn Roll-Hansen, Richard Horntvedt and Helga Roll-Hansen

Ås 1997

SKOGFORSK

Norsk institutt for skogforskning (NISK)

Norwegian Forest Research Institute
Direktør/*Director:* Knut Einar Fjulsrud

NISK, Høgskolevn. 12, 1432 Ås, *Norway.* Tlf./*Phone* +47 64 94 90 00

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ABSTRACT

ROLL-HANSEN, F., HORNTVEDT, R. AND ROLL-HANSEN, H. 1997. On diseases and pathogens on forest trees in Norway 1966-1975. Part II: Abnormal formations. Physiogenic diseases. Diseases due to unknown or complex causes. Medd. Skogforsk. 47(15):1-33.

The report summarizes and discusses reported and surveyed cases of diseases during the period. The physiogenic diseases are treated under the following main headings: Mechanical damage, winter frost and frost drought, frost in the growth period, summer drought, water logging, nutrient deficiency, poisoning by various chemicals, and industrial air pollutants. Various types of winter damage make up an important part of the cases. In spruce these were often associated with poor acclimation of foreign provenances planted on high sites. In pine, shoot dieback and red belts are common types of winter damage. Potassium deficiency was reported from abandoned cultivated fields and bogs. Industrial air pollutants caused much concern in the period, and notably fluoride emissions from aluminium works.

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ABNORMAL FORMATIONS (TERATISMS)

Multiple cones

1973. Oppland: Nord-Fron. *Pinus sylvestris*. Numerous small cones instead of dwarf shoots and needles along 10 cm of the leader. Multiple forming of cones is common in "Skjåk furu", a dwarf genotype of Scots pine from Skjåk in Oppland. This abnormality may thus be a purely genetic defect. But according to Tollef Ruden (pers.comm.) such abnormal development of cones has been caused in Japan in a Japanese pine species by destroying the uppermost part of the very young shoot in spring. Some kind of environmental stress may also have contributed in the present case.

Split leader

1966. Østfold: Aremark. *Picea abies*. Each year from 1963 (and probably earlier) the new leader in a young spruce had split longitudinally in its lower part; it had been possible to look through the shoot. The wound had healed in a few years (ROLL-HANSEN1967). According to H. Dalene the splitting was seen in early summer when the leader was about 20 cm long; the final leader length was 60-70 cm. The split leader was presumably genetically determined. But no splitting took place after 1966 and cones on the tree were not split.

Twisting of branches

1966. Østfold: Fredrikstad. *Abies veitchii.* Twisting of lower branches on some trees, so that the white underside of the needles was visible from above. *A. veitchii* is perhaps disposed to such an abnormal reaction. In 1994, we have again seen the same phenomenon on lower branches of *A. veitchii.*

Vegetative shoots from cones

1970. Møre og Romsdal. *Larix* sp. Vegetative shoots grew from the distal end of cones. This genetically determined teratism is relatively often found in *Larix*.

1966. Oppland: Øyer. *Picea abies.* On a single spruce there were several such cones. The teratism must be genetically determined.

MECHANICAL DAMAGE

Damage by drifting ice

1969. Sør-Trøndelag: Orkdal. *Picea abies.* Damage during many years along the river Husdalselva. A stand of 80-100 years old trees on a gravely riverbank normally flooded during spring, often with drifting ice. Most of the trees had bark wounds up to about 1 m above ground level, often about 1/3 of the stem circumference wide, on the side against the ice drift. There were young wounds, and older ones probably up to 20-30 years old. Some stem rot was found, but from many of the wounds serious rot had apparently not developed. Generally the most important wound stem rot in

Picea abies is caused by *Stereum sanguinolentum*. The number of spores of *S. sanguinolentum* is, however, very low at the time of drifting ice.

Wind damage

1973. Akershus: Ås. After a storm 12-14 June, *Picea abies* had much of killed, brown needles. On broadleaf trees the wind-worn leaves had necrotic parts, mostly near the leaf edges.

Hail damage

1973. Akershus: Ås. A heavy, local hail-shower 9 June damaged several broadleaf trees. The leaves were torn and perforated. A characteristic symptom, clearly seen on e.g. *Acer negundo*, was small, light, necrotic stripes where the hailstones had hit the leaf surface under acute angels (Fig. 1).

Fig. 1. Hail damage. Acer negundo. Small faint light-coloured necrotic stripes are characteristic for hail damage, where hail stones have hit a leaf surface under an acute angel (×1). Akershus: Ås 9 June 1973. (Phot.: Roll-Hansen)

WINTER FROST AND FROST DROUGHT

Top dieback in pine *(Pinus sylvestris)*

1969. Troms: Målselv.

1969. Finnmark: Alta and Karasjok.

The 1968 shoots, mostly the leaders, were partly or totally killed. Sometimes the 1967 shoots were damaged as well. The needles were straw-coloured. Most damage to fast-growing saplings of introduced provenances less than 5 m of height. The percentage of damaged trees varied from 1% to 50% in Målselv, up to 75-90% in Alta and Karasjok.

This particular type of dieback is found in *Pinus sylvestris,* mostly towards the alpine or northern forest limit. An extensive occurrence in 1963 was studied by VENN (1970). The damage is caused by winter frost, but very important is also insufficient acclimation of the shoots during the preceding cold summer.

Top dieback in spruce *(Picea abies)* plantations

1970. Buskerud: Ringerike.
1970. Telemark: Bø. 1.5 m high trees.
1970. Vest-Agder: Several communities. 2-4 m high trees.
1971. Akershus: Eidsvoll. 3 m high trees.
1972. Hedmark: Grue.
1973. Oppland. Seed orchards. Up to 6 m high trees.
1975. Telemark: Drangedal. 20-40 years old trees.

The stem leader was partly or totally killed during the winter, sometimes also the uppermost branch whorl and parts of the previous year's leader. The plantations were probably of foreign provenance, on high sites, and in very good growth. Poorly developed buds on the damaged shoots indicated incomplete maturation. In no cases parasites were found.

Two more cases may be mentioned separately:

1972. Vest-Agder: Audnedal. A plantation from 1967 on a bog at 250 m elevation. 1.5 m high trees. Fertilization: In 1967 rock phosphate + 30 g complete fertilizer around each plant; in 1969 again 30 g complete fertilizer around each plant. Late autumn 1971 the plants were green and vigorous. In April 1972 more or less of the leader was killed in 50% of the plants; in some of the plants there were also damaged branches. There had been a serious summer frost 19 July 1971. A frost ring had been formed in the middle of the 1971 annual ring. The ripening of the new shoots had been delayed by this frost; late wood had not been formed and the buds were poorly developed. The shoots had then been killed by frost and/or drought in the following growth rest period. The locality and also the luxurious growth after the fertilization had disposed the trees to frost damage.

1974. Oppland: Gran. An extensive damage, especially on 2-4 m high trees, was examined early in September. In some trees the upper part of the 1973 leader had been killed, in other trees the whole leader, sometimes also the upper part of the 1972 leader. But sometimes only the top bud of the 1973 leader had been killed. Fungal parasites were not found. A heavy frost ring had been formed in the outer part of the 1973 annual ring. The upper part of some leaders may have been killed by summer frost, perhaps in the turn August-September. But most of the damage is probably winter frost, or frost/drought damage. The summer frost may have delayed ripening of the tissue.

Bark damage and resin flow in spruce *(Picea abies)*

The following cases may be regarded as an extension of the previous section, but are treated under a separate heading due to the current concern about resin flow in spruce.

1967. Østfold: Idd. A special damage occurred at many localities in Østfold. Longitudinal cracks and necrotic flecks or stripes in the bark occurred on the 1966 stem internodes, on the 1965 stem internodes and on the 1966 branch internodes. The necrotic flecks were up to 10 cm long and 1.5 cm wide. There was no damage to the current (1967) shoots. Cambium and inner bark had been killed during the winter rest period 1966-67. Tangential and radial resin-filled cracks had been formed adjacent to the necroses. The necroses were totally or partially closed by callus growth in 1967. Abnormal high numbers of resin canals were formed in the 1967 annual ring, <1 mm from the cracks. No frost rings were found in the wood; however, frost rings are not formed after frost damage in the growth rest period. Isolation of fungi was tried from many of the necrotic parts. *Gremmeniella abietina* was found in a single isolate, and was probably secondary. It was concluded that the cracks and necrotic flecks and stripes in the bark had been formed by frost in the growth rest period 1966-1967.

1967. Vestfold: Andebu. Similar damage as above. 4-5 m high trees in very good growth at 150 m altitude. In damaged trees cambium and bark had been killed on one side or all round the stem. 15-16 trees, scattered in the stand, had tops killed 1-2 m downwards. Adjacent to the killed bark rows of abnormal resin canals had been formed early in the 1967 annual ring.

1969. Akershus: Nesodden. Damage to 2-10 m high trees was surveyed 5 August. In most of the damaged trees (20-25% of all the trees) the 1968 and parts of the 1967 shoots had been killed, mainly in the upper part of the crown, but sometimes further down. Sometimes, however, the leader was undamaged. Small necrotic flecks surrounded by fresh, living bark were found just below the totally killed parts of the shoots. No frost ring was found, but pathological resin canals occurred early in the 1969 annual ring. Parasites were not found. Conclusion: Frost damage during the growth rest period 1968-1969.

Such bark frost necroses seem sometimes to be of importance. Necrotic flecks in spruce bark and heavy resin flow were found simultaneously in great areas in Götaland and Svealand in Sweden in the early 1990's, especially in 1991. Bark cracks and great number of resin canals in the wood were reported. Frost after mild periods may have been the cause, such as the sudden April frost 1991 in Sweden and Denmark (BARKLUND et. al. 1995), and also in Norway (ROLL-HANSEN & ROLL-HANSEN 1993).

Shoot dieback in pine *(Pinus sylvestris)*

1967. Sør-Trøndelag: Oppdal. Severe damage from Drivstua northwards 30 km to Fagerhaug.

1967. Sør-Trøndelag: Trondheim. The upper parts of small coniferous trees (*Abies alba, Picea abies, Pinus mugo, Pinus sylvestris*), which had been above snow cover, were heavily scorched on the sun side.

1968. Rogaland, Hordaland, Sogn og Fjordane. H. Robak reported heavy scorching. Needles of all ages had been killed. The damage was often more or less one-sided, mostly on the north and east side of the crown. It had been worst in localities with much snow during the winter of 1967-68 and where the snow had stayed and partly frozen on the trees for a long time.

1969. Sør-Trøndelag: Midtre Gauldal. Sampled 17 June. Dieback of 1968 and 1967 shoots scattered in the crown. The needles were yellowish green to brownish yellow or straw yellow.

1970. Vest-Agder, Rogaland, Hordaland, Sogn og Fjordane, Møre og Romsdal. Widespread shoot dieback. The buds and the whole or distal part of the 1969 shoot were dead. Needles on killed shoots were light reddish brown. Sometimes there was dieback of older shoots and needles as well. Trees of all ages and sizes were affected. Most damage in the lower part of the crown of larger trees. The leader and uppermost shoots were seldom damaged. In general, the damage was not directional. Most damage at the SE side of the trees was observed, however, in the valleys of Romsdal and Sunndal in Møre og Romsdal; here, most damage was found just above the snow surface and a bit upwards. Planted as well as spontaneous Scots pine were damaged, but never Norway spruce, even where the species were growing side by side.

The damage occurred in all the counties mentioned, with no apparent gradients from coast to inland. There was a high frequency of damage in the lower parts of valleys and along roads, rivers and brooks. There was seldom damage high up (>500 m) in hillsides, but often damage at natural terraces.

1972. Sogn og Fjordane: Førde. Shoots and needles killed during the previous winter. The stem and branch leaders were usually not damaged. Sometimes only the distal part of the 1971 shoot was killed, but usually the whole shoot, and often also one or two older shoots. The killed needles were pale yellowish brown. *Juniperus communis*, *Calluna vulgaris* and *Vaccinium myrtillus* were also heavily damaged.

1972. Sør-Trøndelag: Oppdal. Møre og Romsdal: Sunndal. Widespread needle scorching and shoot dieback were observed in May from Lønset to Sunndalsøra, further along Sunndalsfjorden, and in the neighbour valley Virumdalen eastwards from Ålvundeid. The scorched needles were pale brown. In severely scorched shoots also the bark and buds were dead. The scorching apparently progressed from the distal half to the whole needle, from the distal part of the 1971 shoots to the whole 1971 and older shoots, from weaker side shoots to the branch leaders, and from the lower part of the tree crown and upwards. The leader and the uppermost branches were never damaged. There had been little snow last winter, and black frost with practically no precipitation after Christmas.

1974. Sør-Trøndelag: Oppdal, Orkdal, Rennebu, Snillfjord. Nordland: Fauske, Grane, Hamarøy, Løddingen, Rana, Saltdal, Sørfold, Tysfjord, Vefsn. Troms: Harstad, Kvæfjord. Brown needles on 1973 shoots; end buds usually killed.

Some needle scorching and killing of older shoots were found. Similar damage was reported from the valley Gudbrandsdalen and from Trondheim.

This type of damage is rather common, especially in areas adjacent to the mountains of southern Norway. The damage may often be classified as frost drought. It is then associated with prolonged periods of dry winds from the mountains hitting trees and shrubs on frozen ground. The killing of bark and buds may be a secondary effect of the killed needles. Juniper and heather, if not protected by snow, may be even more damaged than pine when the snow cover is sparse. Many years, the above snow parts of juniper and some garden evergreens are the only species damaged by frost drought. Curiously, Norway spruce is not damaged to any comparable extent.

Red belts

1975. Buskerud: Ringerike. Red belts were found in the southern part of Ådalen.

1975. Hedmark: Åmodt. *Pinus sylvestris.* NE slope of Molbergkampen near Osensjøen, at 500 m elevation. The belt was horizontal, about 1000 m long and up to 200 m wide. Brown needles, but undamaged buds. Very little damage to birch.

1975. Hedmark: Stor-Elvdal. *Pinus sylvestris.* Several more or less continuos red belts were seen in the pine forests along both sides of the river Glomma from Ophus and about 40 km northwards: Near Evenstad, a 2 km long belt on the SW side of the valley and a 4.5 km long belt on the NE side. Near Koppang, an 8 km long belt on the W side, and a 3.5 km long one on the E side. N of Koppang, a 4.5 km long belt along both sides of the side river Tresa. The largest belts extended from the valley bottom and 150 m upwards. Near Evenstad, where the direction of the valley is from NW to SE, the trees were most damaged at the NW side, indicating that damaging influence had spread downwards the Glomma valley. The buds were usually not damaged, but where needle scorching was severe the buds were killed as well. Only pine was damaged at Evenstad, not spruce or birch; even when they were growing together with scorched pine.

A red belt in Scots pine was also seen at Sollia in Atnedalen.

Red belts are associated with rapid temperature fluctuations in the border zone between a stable cold air basin and warm air sliding on top of it. In some cases the damage may be caused mainly by freezing, and pine and spruce may be equally much damaged. The buds of broadleaf trees may be damaged as well, resulting in torn and perforated leaves in the spring. In other cases the damage mechanism may be more like frost drought. As stated in the previous section, pine is for some reason much more vulnerable than spruce to frost drought.

Needle scorching in spruce *(Picea abies)*

1969. Hedmark: Ringsaker. Sampled 26 March. Needle scorching in small trees. Damage caused by sunshine and reflection from the snow, possibly combined with night frost.

1969. Buskerud: Ringerike. Sampled late in April. Scorched needles on 1968 shoots, mostly on the middle and basal parts of the shoots; the distal needles were green. A few scorched needles also on 1967 shoots. Probably a frost and sun scorch damage.

1970. Akershus: Nes. Sampled mid-April 1970. Late winter frost and sun scorch in trees up to 2 m of height in a plantation. Brown needles mostly on 1969 shoots. No damage to the lowest branches which had probably been covered by snow until 3-5 weeks ago.

1971. Nord-Trøndelag: Lierne. Young plantation of *Picea abies* at 350m elevation, examined in October. Many trees damaged. Heavy needle cast. A high percentage of the 1970 buds was killed during the growth rest period. In other buds microscopic shoots had developed within the bud scales, from others there had grown out visible, very short shoots. The damage had probably been made during winter, late winter or early spring.

1973. Nordland: Hemnes. *Picea abies* shoots up to 3 years old had been killed during the previous winter. Some places dead bark was found under still green needles. Frost rings were not found, but poorly developed annual rings the 3 last years. Killed buds had also been poorly developed. Pycnidia of *Gremmeniella abietina* were found on the bark of dead shoots. The primary cause was frost. *G. abietina* must be regarded as secondary.

1974. Vest-Agder: Åseral, elevation 350 m, examined July 1974. 3 m high trees of central European provenance planted on a drained bog. A frost ring in the outer part of the 1973 annual ring. Heavy damage by frost and/or drought the winter 1973-1974; not only shoots from 1973, but also 1972 and 1971 shoots were killed. Because of southern provenance and late summer frost, unripe shoots had been killed during the growth rest period on the bog disposed to climatic winter damage.

1974. Nord-Trøndelag: Steinkjer. Survey 5 June. Winter killing of spruce needles in an about 15 years old stand on high site. Dying of the 1973 and older needles, worst on the lowest 1 m above ground, lesser upwards to 2-3 m. The damage was often worst on the outer parts of the branches. A couple of small trees were so heavily damaged that they probably would die. Small, scattered trees outside the stand were not hurt at all. The depth of snow had been about 1 m during the winter since October.

1974. Nord-Trøndelag: Grong. Similar damage as in Steinkjer was observed early May.

1974. Nord-Trøndelag: Verdal, at Stiklestad. Similar, but heavier damage than in Steinkjer and in Grong was observed by J. Dietrichson early May 1974 in spruce provenance research plots.

Other cases of winter damage

1966. Hedmark: Stange. In March, the last year shoots (1965) in *Pinus contorta* had brown, dead bark and mostly reddish brown needles. The bark on the 1964 shoots was apparently not damaged, but some needles had discoloured parts, especially at needle tips.

1971. Hedmark: Åmot. Plantation of 0.5-1 m high *Pinus contorta* on a ditched and fertilized bog at 500 m elevation. 30-40% of the plants were damaged by winter frost. The upper part of leader and lateral shoots had been killed during the winters of 1969-1971. Secondary infections by *Gremmeniella abietina* were found in shoots damaged the winter 1969-1970 (ROLL-HANSEN & ROLL-HANSEN 1995). The provenance of the contorta pine was not known. *Pinus sylvestris* plants at the same locality were not damaged.

1973. Hedmark: Åsnes. 2/0 nursery plants of *Picea engelmannii*, the top bud often very poorly developed. Upper part of the shoots killed. Under still green needles the bark sometimes had a greyish green colour, indicating additional future development of the needle damage.

1975. Hedmark: Tynset. *Picea abies.* Sampled 16 May. A spruce hedge about 1.5 m high, heavily cut the autumn 1974; shoots from several years cut away. Heavy needle fall also of still green needles, apparently killed by frost drought. The heavy cutting in the fall seemed to have hindered full ripening and to have exposed the needles to frost drought.

FROST IN THE GROWTH PERIOD

Early spring frost

1973. Vest-Agder: Lyngdal. *Picea abies.* Spruce provenances from Trøndelag and northern Norway grafted on rootstocks about 5 years ago. The 1972 leader had been killed from the top downwards, but had mostly normal 1973 side-shoots from the basal sound part. Sometimes there had been a slight elongation of the shoots, still within the buds, before they had been killed. On some trees not only the leader, but also most of the uppermost side-shoots had been killed. A frost ring was found in the 1973 annual ring outwards from the 1972-1973 border. Sometimes a few normal tracheids had been formed before the abnormal wood formation. The northern provenances had probably started growth too early in the mild climate in Lyngdal and then been hurt by early spring frost.

1973. Nord-Trøndelag: Lierne, 480 m elevation. Planted *Picea abies* , 1-1.5 m high. The 1972 shoots and often upper part of 1971 shoots were killed. In the shoots from 1968 to 1971 a large frost ring was found in beginning of the 1973 annual ring. Sometimes the wood was abnormal outwards through all the 1973 annual ring. The damage had probably been caused by frost just when the cambium activity had started early spring 1973.

1973. Nord-Trøndelag: Namsskogan, and Røyrvik. *Picea abies*. Severe damage to several young plantations. The trees were about 1 m high. The provenances were probably often not the best ones in the relatively harsh climate. Injuries by frost,

wind and snow were found. In a spruce top investigated in October, the 1972 leader and upper part of the 1971 stem internode were killed. In living parts of the stem a frost ring had been formed at the start of the 1973 annual ring.

Late spring frost

1968. Vest-Agder: Farsund. *Abies alba.*

1974. Hordaland: Os. *Abies alba.* The current shoots had been killed by late spring frost. No parasites found.

1974. Nord-Trøndelag: Steinkjer, elevation 160 m. *Picea abies* planted 1964 on a bog. Examined late August. There were two frost rings in the 1974 annual ring, one in the innermost, the other in the outermost part. The plants had been hurt by late spring frost at the turn of May-June 1974 and by summer frost, probably at the end of July 1974.

1975. South-eastern Norway. Abies alba, A. procera, Fraxinus excelsior, Picea abies, Pinus sylvestris and Quercus sp. Temperatures below -5 C the last days of May caused severe frost damage to young plantations at many inland localities from Aust-Agder to southern parts of Hedmark. The new shoots and leaves had been killed. Late shooting provenances of A. procera were very little damaged. In spruce, there were also some needle scorching on older shoots, and a frost ring was found early in the 1975 annual ring. The leader and uppermost shoots were less damaged than the lower parts of the crown, probably due to later shooting. At localities or provenances where the buds had not bursted at the time of the frost, normal 1975 shoots were developed, also on branches with needle scorching and a distinct frost ring.

1975. Troms: Harstad and Kvæfjord. More or less necrotic leaves on early shooting tree and shrub species e.g.: *Lonicera coerulea, L. tatarica, Ribes nigrum, R. rubrum* and *Sorbus aucuparia.* Little or no damage to late shooting trees like *Fraxinus excelsior, Laburnum sp. and Quercus* sp.

Late spring frost is caused by low temperatures after growth start. A frost ring is therefore often formed in the innermost part of the new annual growth ring. The leader and upper branch whorl are often not damaged because of their late growth start. Late shooting species and provenances should be used at frosty localities.

Summer frost

1968. Sør-Trøndelag: Melhus. *Picea abies.* Brown needles on the 1968 shoots of small trees in a sample taken 10 October. The buds were usually not killed. There was a well developed frost ring late in the 1968 annual ring in upper parts of the stem.

1968. Sør-Trøndelag: Melhus. *Pinus sylvestris.* Examined 10 October. Scorching of upper part of the 1968 needles, needle base green. Faintly damaged needles were green, only with a chlorotic part at the middle of the needles. Frost ring in the late wood of the last annual ring.

1968. Nord-Trøndelag: Steinkjer. *Picea abies*, examined May 1969. Frost damage to trees planted 1964 on a bog. Shoot tips had been killed, probably in July 1968. Two distinct frost rings in the 1968 annual ring.

1969. Nord-Trøndelag: Namsos. *Picea sitchensis*, planted in spring 1969. Frost rings in the 1967, 1968 and 1969 annual rings. The 1968 buds had been poorly developed. Many buds and also young shoots had been killed. The provenances were not hardy enough.

1971. Hedmark: Grue. 350 m elevation. *Picea abies.* 12-15 years old fertilized plantation on a bog. Unripe leaders and side shoots damaged by summer frost 1971. A well developed frost ring halfway in the annual ring in the living part of the shoots.

1971. Hedmark: Os, Tolga, Tynset. 650-830 m elevation. *Picea abies*. Common damage to planted spruce 0.5-5 m high. A large frost ring in the outer part of both the 1970 and 1971 annual rings, probably after frost in August. In some trees the upper part of leader or only end buds had been killed. In other trees several shoots had developed from damaged, but not totally killed buds; these shoots were often very short, just reaching out from the bud scales. The shoots had been poorly ripened on these young, relatively fast-growing trees and therefor susceptible to summer frost.

1973. Hedmark: Grue. *Picea abies.* In a 10 years old plantation the upper end of the leader and other 1973 shoots had been killed by late summer frost. In the dead part of the shoots the growth of the 1973 annual ring had suddenly stopped, without the normal termination. In the living part of the shoots a large frost ring had been formed in the outer part of the 1973 annual ring.

Characteristic to summer frost damage is that often only the distal part of the leader and other new shoots are hurt, - that is the last ripening parts. Frost ring is found in the middle or outer part of the new annual growth ring. New shoots which later in the summer may grow out from partly hurt buds will be very short, often reaching just out from the bud scales. They are poorly ripened and very susceptible to later frost. Poorly adapted, late ripening provenances are especially exposed to summer or autumn frost.

FROST DAMAGE. MISCELLANEOUS

1966. Hedmark: Åmot. *Picea abies.* On many young trees in a stand at high site the leader and other shoots had been killed, probably during the winter rest period. But there had also been some summer frost damage; one or more frost rings were found in each of the annual rings of 1962, 1963, and 1965.

1969. Oppland: Vågå. *Picea abies.* Two stands planted about 15 years ago and one stand planted about 40 years ago. One of the two younger plantations was situated at about 400 m elevation on high site, with high herbs and grasses, not dry even this dry summer. In some trees only the top bud of the 1968 leader was killed, in others the leader was killed further downwards. There had been such killing of buds and leaders several years in succession. The other 15 years old plantation was at about 700 m elevation at a somewhat lower site. The damage was similar to that in

the other young stand, but fewer trees were damaged. The 40 years old plantation was severely damaged by deformed tops, similar to the damage earlier reported by ROLL-HANSEN (1960) in a plantation at Vågåmo in Vågå.

In a plantation of *Pinus sylvestris* of unknown provenance, about 40 years old, the trees were severely damaged by deformed tops. Local provenance in the same plantation had a good growth rate and no top damage.

The damage to plantations in Vågå is frost damage, described and discussed by ROLL-HANSEN (1960). Provenances of the above mentioned three spruce plantations are not known. Use of wrong provenance and a dry climate, not suitable to *Picea abies*, may be the main cause. Heaviest damage was found at high site during the years of fastest growth when poor ripening of the long shoots disposes to frost damage.

1969. Hedmark: Engerdal. *Pinus sylvestris.* Frost damage to a 90-100 years old naturally regenerated stand in a depression a few hundred meters from Trysilelva. Relatively high site. Canker-like wounds, surrounded by bark necroses, were common on the branches. Some branches were dying or dead because of ringing by the necroses. Shoots and branches in the lower parts of the crowns had been killed during several years. Many trees were in poor health with very reduced crowns, and many had died in the summer 1969. On nearly all the trees killing of shoots by *Tomicus piniperda* was found. Some breeding of the bark beetle was found in most of the weakened trees, sometimes killing the tree. The attacks of the bark beetle were now a bad threat to the stand.

1969. Sør-Trøndelag: Melhus. *Pinus sylvestris.* A 25 years old planted stand on a gravelly terrace exposed to frost near a river. Heavy frost damage to scattered spruces within the pine stand. Most damage in the lower parts near the river. Most pines had wounds, partly canker-like, on the branches, in some cases branches were girdled. Frost may have killed buds and shoots. The provenance may have not been the best one.

1970. Buskerud: Modum. *Picea abies.* A plantation from 1964-1965 at a frosty locality. Poorly ripened shoots, probably Central European provenance. Many buds and upper part of shoots had been killed by frost in the growth rest period. Frost rings in the early wood indicate that the trees might also have suffered by frost early in the growth period.

SUMMER DROUGHT

1975. Telemark: Bamble, near Rafnes. *Betula* sp., *Corylus avellana, Picea abies, Pinus sylvestris, Populus tremula, Sorbus aucuparia.* Survey 13 August and 6-7 October. In August, most distinct damage to birch; yellowing and browning of leaves. Less damage to rowan, still less on aspen. Green aspens might be found where all birches were brown. On pine the 1975 shoot had normal length, but the 1975 needles were often only 2/3 of normal length. Small pines on dry ridges were heavily damaged; most damaged were apparently the leaders, the distal part had stagnated and died, apparently before it was fully elongated.

Drought symptoms in *Picea abies* had not been observed in August, but these were very conspicuous in October. Characteristic was unnormal yellowing and dying of old needles, especially on weak side shoots and branchlets.

1975. Hedmark: Kongsvinger. *Picea abies.* Sampled 21 August. 2/2 plants had been planted in May 1975. Many plants had been killed by the very hard summer drought.

WATERLOGGING

1969. Aust-Agder: Froland. *Picea abies.* Sampled 10 May. 1,500 2/2 plants, provenance Germany: Hartz, planted in September 1968. 80% of the plants were dying in May. The roots were dead. The bark loosened at stem base. The situation was better along a ditch. The precipitation not far away had been 307 mm in September, 149 mm in October.

1971. Nordland: Vefsn. *Picea abies*. Some nursery plants had yellowish needles, somewhat hanging, short new shoots, and dead roots. Dense, wet soil had caused lack of oxygen.

NUTRIENT DEFICIENCY

Boron

According to BRÆKKE (1979) serious frost damage and "shoot dieback" frequently occur in peatland plantations at more than 20-60 km from the coast. The damage is often associated with low boron content in last year needles. Borax fertilization on boron-poor sites eliminated "shoot dieback" and reduced frost damage effects on survival and height growth in plantations of *Picea abies, Pinus contorta* spp. *latifolia* and *Pinus sylvestris*. Frost damage associated with boron deficiency has undoubtedly occurred on inland peat bogs in the period 1966-1975.

Magnesium

1967 and 1968. Telemark: Sauherad. *Picea abies*. Yellowish 2/2 plants in a nursery. Needles from yellowish plants contained 0.047-0.049% Mg, from green plants 0.079%-0.094% Mg.

1970. Aust-Agder: Evje og Hornes. *Picea abies.* Yellowish needles on trees planted on a field. The Mg content in the needles was 0.020%.

1970. Nordland: Saltdal. *Picea abies.* Symptoms of Mg deficiency in a forest nursery. Very low Mg content in the needles.

Phosphorous

1966. Vestfold: Stokke. *Picea abies*, 2/0 plants in a nursery. Diseased plants with blueish-reddish needles. Needles from diseased plants contained 0.119% P, healthy plants 0.168-0.175% P.

1966. Nord-Trøndelag: Verdal. *Picea abies*. Four years old plants in a nursery. Diseased plants had reddish needles, especially the 1966 needles. Diseased plants contained 0.127-0.131% P in the 1966 needles, 0.111-0.114% P in older needles. The values for healthy plants were 0.207% P in the youngest needles and 0.158-0.163% P in the older ones.

Potassium

1971. Vest-Agder: Vennesla. *Picea abies* planted on an old field on a bog. Typical potassium deficiency symptoms in October: the current needles had mainly a normal, green colour, the older needles were yellowish, the oldest a bit more green. Potassium deficiency is often found on cultivated bogs.

1973. Sogn og Fjordane: Sogndal. *Pinus sylvestris*. 17 years old trees planted on a drained bog. Yellowish needles, but the youngest needles were somewhat greener than the older ones. 0.29% K in the needles.

POISONING BY VARIOUS CHEMICALS

Sea salt spray

1969. Vest-Agder: Farsund. Abies alba, Picea abies, P. glauca, P. sitchensis, Pinus mugo, P. sylvestris and Pseudotsuga menziesii. Widely distributed salt spray damage occurred at Lista after storms 22 and 29 September 1969.

1971. Nordland: Hemnes and Vefsn. *Picea abies*. Damage, probably during the previous winter, was observed in April 1971. Most damage to last year's needles.

1973. Østfold to Rogaland. Damage to many species of trees and shrubs was observed in 1973 all the way along the coast from Østfold to Hafrsfjord in Rogaland. Heavy damage was seen as early as July 14, the day after strong western wind with no or little rain. Damage to the wind exposed side. Heavy scorching of birch leaves was registered in Sokndal as far as 3 km from the coast, on needles of Norway spruce and of Sitka spruce on the wind exposed side as far as 25 km from the coast in Gjesdal.

1973. Nordland: Værøy. Damage to *Pinus mugo*, sampled primo May 1973. Yellowish to brownish, dying or dead needles (all ages mixed) from a damaged branch contained 1.25% Cl and 0.455% Na. Needles from a healthy branch contained 0.371% Cl and 0.126% Na.

Road salting ($CaCl_2$)

1972. Hedmark: Elverum, Rendalen, and Åmot. *Picea abies* and *Pinus sylvestris*. Damage along gravelled roads treated with calcium chloride against dust. Damage by dust and water from the road. In spruce heavy needle loss and some trees killed. In pine some branches with only current needles in the fall, a symptom especially

observed in the middle and upper part of the crown. A few pines were dying from the top 1-3 m downwards. Killed pines and spruces were also found.

1973. Oppland: Nordre Land and other rural districts. *Picea abies.* Damage along gravelled roads treated with calcium chloride against dust. Some damage by dust from roads, but much more important at some locations was damage by run-off water from the road. Damage mainly in a belt 3-5 m from the road. Some trees were killed, many had more or less chlorotic or brown needles and needle loss. On chlorotic or still green spruce needles discoloured small flecks were sometimes found; they were brownish to blackish, sharply delimited, or more often diffuse. Buds were often killed, mainly on weak branches and shoots; buds at ends of the branches seemed to be more resistant. There seemed to be a tendency that the tops of the trees were more damaged than the rest. Cl concentrations in damaged needles were 0.34-0.50% of dry weight, against 0.014-0.094% in apparently sound needles.

Fertilizers

Calcium nitrate ($Ca(NO_3)_2$)

1970. Møre og Romsdal: Molde. *Picea abies.* Some needle scorching in a forest nursery after fertilization with granulated calcium nitrate on moist plants.

Urea ($CO(NH_2)_2$)

1967. Oppland: Lillehammer. *Picea abies.* A 75 years old stand, heavily fertilized with urea in June 1966. Heavy resin flow was registered on many of the trees in 1967. An abnormal high number of resin canals was found in the late wood in the 1966 annual ring, close to the border between the 1966 and the 1967 annual rings. Abnormal number of resin canals was not found in other annual rings. Another stand in Lillehammer, 100 years old, had been heavily fertilized with urea in 1966. Resin flow was registered in 1967. It is known that the wood in sick trees sometimes has abnormal high number of resin canals (FENGEL 1986).

Herbicides

Aminotriazole

1967. Hedmark: Grue. *Pinus sylvestris.* Examined 13 October 1967. Yellowish white needles on the young shoots of plants planted out in the field in May 1967. The systemic herbicide aminotriazole had been used in the forest nursery in August 1966. Pine is much less resistant to aminotriazole than spruce.

1974. Akershus: Bærum. *Pinus sylvestris.* Chlorosis of young shoots of small trees after spraying with aminotriazole.

MCPA (2-methyl-4-chlorophenoxyacetic acid)

1973. Akershus: Eidsvoll. *Picea abies*. Examined 1 July 1973. Twisted and curled new shoots in 4-year-old plants in a nursery after spraying with MCPA.

Sodium chlorate, $NaClO_3$

1966. Hedmark: Elverum. *Picea abies*. Damaged and killed trees along a ditch from a field treated with sodium chlorate.

TCA (Trichloroacetic acid, sodium salt)

1969. Oslo. *Picea abies*. Damage to the young 1969 shoots on a spruce after TCA-spraying in the summer 1968. The same locality as mentioned below for *Pinus sylvestris* in 1969 in Oslo.

1969. Oslo. *Pinus sylvestris*. Some damage and needle fall in 1968 and further damage to the new 1969 shoots of big pines. It had been sprayed with TCA against *Deschampsia flexuosa* in the summer 1968. TCA had apparently stayed some places in the rocky ground. Heavy watering was recommended to wash out the TCA. The trees recovered.

1974. Hedmark: Stor-Elvdal. *Pinus sylvestris*. Yellowing and browning of the young 1974 needles after TCA-spraying 15 May 1973.

Other chemicals

Ammonia, NH_3

1967. Nordland: Vefsn. *Picea abies*. A Christmas tree had been standing in the cowhouse from the day before Christmas Eve to Christmas Eve. After the tree had been taken in from the cowhouse the needles got a more or less brownish-black colour. The bark had been killed in the 1967 and 1966 shoots, and partly also in the 1965 shoots. The needles were brownish-black where the bark had been killed. Experiments showed that high concentration in the air of NH_3 produces the same symptoms in spruce. The NH_3 concentration in the cowhouse had been high enough to cause the damage.

Soda lye, silage effluent, and sulfamic acid

1975. Hedmark: Elverum. *Picea abies*. The soil had been polluted from a ditch from a straw leaching unit. Spruce trees about 15 years old were damaged within a small, lower-lying area. In the centre of this area the trees were 3-4 m high. Outside the area the spruces were up to 10 m. in good growth, without symptoms of damage. At the border towards the clearly affected area there was a tendency to abnormal bushing and to winding growth of the leader and of the upper branches. At heavier damage the annual shoots had more or less lost their needles, especially at the tops of the trees, and the remaining needles were greyish brown. At the most heavily affected part of the area most of the trees were dead. Within the area of damaged spruces the growth of grass was more luxurious than outside, and with some thistles.

At the centre of the area there was much of *Xanthoria* on the bark, indicating more nutrients and higher pH than usual. Soil analyses showed high contents of NaOH from the straw leaching, which had caused high pH and high Na contents. But there was also enrichment of Ca, Mg, K and Mn, which in the silage effluent may have leached from the straw. In the needles, however, the content of e.g. K, Mg, Mn and Zn was generally reduced. The high content of Na ions may have caused displacement of other ions, and the high pH of the soil may have resulted in less dissolvable compounds of some of the metals.

INDUSTRIAL AIR POLLUTANTS

Borax ($Na_2B_4O_7$*10 H_2O)

1974. Østfold: Askim. Glass-wool works. *Pinus mugo* and *P. sylvestris.* Needle scorching at several localities within 500 m from the works. Close to the works, up to 40% of the distal part of the needles was killed. Less damage on current needles (1974) than on older ones. Within each locality and age of shoots the needles were scorched to about the same degree. The scorching was different from fluoride damage; there was no sharp boundary between the scorched and the green part of the needle. There was scarcely any fluoride emission of importance. But the emission of borax was high. The works calculated that the dust emission was 75,000 kg pr. year, and about half of it might be borax. There was good correlation between scorching and content of boron in the needles. Scorching was found from 75-100 mg B/kg needle dry weight. Boron-containing dust from the glass-wool works seemed to have been the most likely cause of the damage.

Fluorides

1973. Aust-Agder: Moland. Aluminium works at Eydehavn. For the years 1970-1971 the calculated fluoride emission had been 20-22 kg F/h according to data given by the works. Clearly visible damage in 1973 to *Pinus sylvestris* at 0.6 km from the works, less damage at 1.45 km, no visible damage at 6.5 km (STAVRUM & WALBERG 1974).

1971, 1973. Vest-Agder: Farsund. Aluminium works at Lista.

Survey 13 October 1971: On *Betula pendula* and *B. pubescens* no damage was found. On *Picea glauca* very little or no damage was found at places where *Pinus sylvestris* was heavily damaged. On *Pinus sylvestris* heavy fluoride damage was found until 400 m SSE of the works. The needles were usually scorched 5-30 mm inwards from the tips. Scorching was practically only found on the current needles. The damage rapidly decreased and disappeared farther from the works. Two samples of pine needles, each a mix of 1971 and 1970 needles, collected 200 m SSE of the works, contained 130 and 216 mg F/kg.

Survey 7 May 1973: The area of scorching was nearly the same as at 13 October 1971, but somewhat heavier scorching some places. A new hall, hall number 2, had

been in full production from 4 April 1973. The total production at the two halls was now 52,000 ton aluminium per year, and the fluoride emission about 6 kg F/h.

Survey 18-19 July 1973: Needle scorching was found on *Picea abies*, *P. sitchensis*, *Pinus contorta*, *P. sylvestis* and *P. uncinata*. Current needles were far more damaged than older ones. *Pinus contorta* seemed to be less damaged than the other listed tree species. The aluminium production was doubled March-April 1973, and there was also start-up difficulties with the hall number 2.

1973. Rogaland: Karmøy. Aluminium works at Håvik.
Fluoride emission in 1972 was 32-33 kg F/h, 45% as gas, 55% as dust. In 1973, damage to *Pinus sylvestris* was observed at 1 km and 1.7 km from the works, more damage on the 1973 needles than on the 1972 needles (STAVRUM & WALBERG 1974).

1973. Hordaland: Kvinnherad. Aluminium works at Husnes.
Fluoride emission in 1973 was about 31 kg F/h, mostly particulate. In 1973 there was very severe scorching to *Pinus sylvestris* at 0.3 km from the works, at 1 km relatively slight scorching (STAVRUM & WALBERG 1974).

1973. Hordaland: Odda. Aluminium works at Tyssedal.
Fluoride emission 14-16 kg F/h. Survey 18-19 July 1973: Typical fluoride scorching of previous years' needles on *Pinus sylvestris* was found as far as 9 km north of Tyssedal, on the west side of Sørfjorden.

A survey in May 1973 of epiphytic macrolichens on *Pinus sylvestris* indicated that *Pseudevernia furfuracea* was sensitive to fluorides (HORNTVEDT 1975). Damage to transplanted *Pseudevernia furfuracea* was found at several plots within 6 km from Tyssedal, but no damage to current pine needles was found.

1967, 1968, 1970, 1970-72. Sogn og Fjordane: Årdal. Aluminium works at Øvre Årdal. *Pinus sylvestris.* The old pine forest of Vettismorki has been a subject of several studies, due to its value from a nature conservancy point of view.

Damage to old pine trees was observed 27 July 1967 in Vettismorki, starting near the river Fleskdøla, 12-13 km NE of the works. Some were dying, with needle scorching typical for fluoride. The F content in 1967, 1966, and older needles was 12, 47, and 91 mg/kg, respectively.

Damage to *Pinus sylvestris* in different parts of Vettismorki was assessed in 1968 by BRAANAAS (1970). The proportion of trees with severe scorching of the needles varied from 4% to 21%; the proportion of dying trees varied from 0% to 25%.

Survey 28 March - 2 April 1970: Old pine trees were investigated on 17 sample plots (HORNTVEDT 1971). At the most damaged plots 40-50% of the trees were dead or dying; no plots had only healthy trees. Needle scorching was more severe on the 1969 needles than on the 1968 needles, but the F content was higher in 1968 needles. Apparently, pine needles are far more sensitive to fluorides during their first vegetation period than later. Slight scorching was found at F concentrations in

current needles as low as 10 mg/kg. At Resnes, 13 km in the opposite direction from the works, there was severe scorching of 1968 and 1969 needles.

A detailed and extensive survey of the vascular plant flora and fluoride damage in Årdal in 1970-72 was made by ROMØREN (1973). The species were ranged into tree groups of fluoride sensitivity on the basis of how far from the works they showed leaf scorching. The most sensitive group contained *Pinus sylvestris*, *Convallaria majalis*, *Maianthemum bifolium*, *Hypericum maculatum* and *H. perforatum*.

1966, 1968, 1973, 1974. Møre og Romsdal: Sunndal. Aluminium works at Sunndalsøra.

Survey 29 November 1966: Needle scorching on *Pinus sylvestris* was found along Sunndalen at Musgjerd, 24 km E of the works, and at Gjøra and Grensa, 33 and 37 km E of the works.

June 1968: Revision of permanent sample plots in young stands of *Pinus sylvestris* at different distances eastwards from the works along Sunndalen. Needle scorching and F concentrations in 1967 needles were as follows:

Mæle, 3.5 km ESE, severe scorching, 68.5 mg/kg.

Løykja, 7 km ESE, severe scorching, 41.8 mg/kg.

Grødal, 8.5 km ESE, severe scorching, 37.0 mg/kg.

Hoås, 10 km ESE, severe scorching, 24.8 and 58.5 mg/kg.

Ørsund, 22 km ESE, moderate scorching, 35.5 mg/kg.

Musgjerd, 24 km ESE, slight scorching of 1967 needles, moderate scorching of 1966 and 1965 needles, 8.9 mg/kg.

Gjøra, 33 km ESE, no scorching of 1967 needles, slight scorching of 1966 and 1965 needles, 8.0 mg/kg.

Grensa, 37 km ESE, no scorching of 1967 and 1966 needles, very slight scorching of 1965 needles, 7.8 mg/kg.

Survey 18 August 1974, *Pinus sylvestris*: Unusually severe damage at Gjøra, 33 km from the works. Up to 15 mm long tip-burn on the current needles; the F content was 53 mg/kg.

An experiment to compare the resistance of conifer species was established in 1959. The degree of damage was assessed in 1966, 1967 and 1973 (HORNTVEDT & ROBAK 1975). The species were ranged as follows by decreasing resistance, based on needle scorching and premature shedding: *Larix decidua, Tsuga heterophylla, Picea abies, Abies procera, Picea engelmannii, Abies nordmanniana, Abies concolor, Pseudotsuga menziesii, Abies alba, Picea omorika* and *Pinus sylvestris*. Individual variation was especially high in the *Picea* species, offering possibilities for selection and breeding.

1971. Nordland: Vefsn. Aluminium works at Mosjøen.

Survey 17-18 April 1971, *Picea abies*: At Skogsåsen, 4.5 km SSE from the works, there was severe damage, especially on the northern side of exposed trees. Most of the 1969 needles had fallen off, those left were brown. There were also brown needles on older shoots. At the south-eastern edge of a stand, however, no

damage was seen. Skogsåsen is exposed to winds from NNW, i.e. to emissions from the works, but also to winds from Vefsnfjord. During the same survey widespread climatic or salt spray damage was found along the fjord. An interaction between fluoride and sea salt spray could not be excluded, neither at Skogsåsen nor at another locality, Nyrud gård, not far from the works. But it must be concluded that emission has been an important damaging factor. It is known from 1965 that Skogsåsen is especially exposed to fluoride damage from Mosjøen aluminium works (ROLL-HANSEN 1967).

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In the last part of the period 1966-1975 there was a general trend of reduction of damage of forest trees caused by fluoride emission from the Norwegian aluminium smelters. Fluoride content in the emissions had been reduced by changed technology at the older smelters, and by use of effective new technology at new smelters. It is also very important that the new smelters are placed where emission is rapidly spread by wind, not at narrow fjords and in narrow valleys like those in Årdal or Sunndal.

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1972. Telemark: Lunde. Brick works at Bratsberg.

Survey 13 July 1972: At 350 m from the brick works *Picea abies* trees had severe scorching; almost all the new needles were totally brown, but neighbouring trees could be nearly undamaged. In this case *Pinus sylvestris* was less damaged than *Picea abies*. But on some of the pines there was considerable scorching on current needles and also some on the 1971 needles. The scorching was typical for fluoride damage. *Salix caprea* had some scorching at the leaf-edge, *Betula* sp., *Trifolium pratense* and *T. medium* no scorching.

700 m from the works: Distinct scorching of current needles of some spruce trees, other trees apparently without damage. On some of the spruces the uppermost and the basal part of the crown were undamaged or little damaged; the middle part, however, relatively much damaged. Some leaf-edge scorching on *Sorbus aucuparia*.

800 m from the works: Less damage, but fairly severe scorching of current needles on some small spruces.

The F content was not very high, but high enough to cause scorching. In 2 years old spruce needles was found up to 61 mg/kg. The F content in the needles decreased with increasing distance from the brick works.

1971. Nordland: Meløy. Fertilizer works at Glomfjord.

Survey 13-14 September 1971: Close to this complete fertilizer works the ground vegetation was nearly eradicated. Among still living plants the salt tolerant *Puccinellia retroflexa* dominated. Several *Pinus sylvestris* trees were killed. Living pines at the edge of the most damaged area had severe apical scorching of both 1970 and 1971 needles. Their F contents were 156 and 125 mg/kg, respectively. In addition to gaseous and particulate fluorides from the works, the area was also

heavily polluted by rock phosphate (apatite) dust from discharging of ships at the quay just below.

At 1-1.5 km from the works the current needles were undamaged, the 1970 needles had apical scorching, reminding of fluoride damage. The F content in 1970 and l971 needles was 18.5 and 9.5 mg/kg, respectively.

1972. Østfold: Moss. Glass works.

Survey 12 July 1972: At 100m from the glass works scorching was observed on *Acer platanoides, Betula pendula, Fraxinus excelsior, Salix caprea, Tilia* sp. and *Ulmus* sp. On *Pinus mugo* all current needles were scorched inwards 50-100% from the tip, but there were no symptoms on older needles.

Fluoride emission from the glass works had been unusually high - about 6 kg F/h - during the spring and early summer 1972. The use of fluorides in the glass production was stopped at the onset of the damage. A survey later the same summer showed that the new leaves developed afterwards had no damage symptoms. The fluoride content was much higher in the broadleaf trees than in *Pinus mugo*, but the damage was less.

1972. Oppland: Jevnaker. Glass works.

This glass works is situated at the foot of a small slope. On the slope, at a distance of 100-200 m from the works, up to 90% of the old *Picea abies* and also some *Pinus sylvestris* trees were dead or dying in 1972. Typical and partly severe F scorching was found in young as well as in old trees. There was an exceptionally high number of resin canals in the 1971 growth ring in the 1971 shoots both in pine and spruce, located at a distance outwards of about 2/3 of the ring width. The average emission of hydrogen fluoride (HF) from the works was reported to be 0.2 kg F/h, but it may have been periodically higher. In the flat terrain southwards from the top of the slope the damage rapidly vanished, and only slight scorching to some pines was found at 700 m from the works.

Sulphur dioxide

1966, 1967. Hedmark: Vang. Asphalt mill.

Very slight damage to *Picea abies* and *Pinus sylvestris* close to the mill. The asphalt production was 30,000 ton during May-September, the five months of production. It was calculated that the mill was in function totally 500 hours during this period of production, that the SO_2 emission was 4 kg/h, that is 2,000 kg totally.

1973. Akershus: Eidsvoll. Pulp mill.

Damage to plants and small trees of *Picea abies* was observed early June 1973. Regeneration appeared to be difficult near the pulp mill.

1966. Nordland: Rana. Iron works.

In August 1966 the forest had a brownish colour within great areas around the iron works. A sample of *Picea abies* had brown needles and a sample of *Betula*

pubescens had leaves with symptoms which very well might have been caused by SO_2.

1970, 1971, 1972. Vest-Agder: Kristiansand. Nickel works.

Survey 13 June 1970: Considerable scorching of pine needles was found up to 2 km E and W of the nickel works. At the arboretum Myren, 1 km S of the works, the tree species had reacted very differently on the emission from the works. *Pinus cembra* and *Pseudotsuga menziesii* were dying. *Abies alba, Fagus sylvatica, Fraxinus ornus, Pinus sylvestris* and *Sequoiadendron giganteum* were severely damaged. *Picea omorika, Picea orientalis* and *Ulmus glabra* showed medium damage. *Acer pseudoplatanus, Aesculus hippocastaneum, Fraxinus excelsior, Tilia cordata, Chamaecyparis lawsoniana* and *Ulmus carpinifolia* were little, or not damaged.

Survey 21 June 1971: *Chamaecyparis lawsoniana* 'Triomf van Boskoop' and another *Ch. lawsoniana* were the only coniferous trees not hurt at all. *Ch. lawsoniana* seems to be a valuable park tree in SO_2-polluted areas.

Survey 15 May 1972: The situation at Myren was worse than on 21 June 1971, possibly because of heavy emission the last year and special weather conditions. According to data given by the works, the mean SO_2-emission in the year 1971 was 71 kg/h, the mean emission in September 1971 was 130 kg/h. There were also emissions of Cl_2 and HCl, but these were probably of less importance.

1966. Telemark: Tinn. Fertilizer factory.

Survey 15 August 1966: In the area near Såheim the damage to *Picea abies* was worse in 1966 than registered one year earlier (ROLL-HANSEN 1967). Many spruces had died the last year, and the damage was now visible far higher up the slope on the southern side of the valley, and also visible on the northern side. It was also visible farther downwards the valley than before. Sulphur dioxide must be the main cause of this damage to spruce. During the period January-August 1976 the total mean oil combustion at Såheim and Vemork had been 1,222 ton per month. The narrow valley is probably the cause of the severe damage by the amounts of sulphur dioxide emitted.

1974. Vestfold: Tønsberg. Oil refinery.

Survey 29 May 1974 around the Esso oil refinery at Slagentangen. Damage to *Betula* sp. and *Picea abies* in the direction north to east from the chimneys. No distinct damage to *Pinus sylvestris*. Wind from south to south-west is dominating during the summer. Some *Betula* sp., both large trees and smaller ones, were killed close to the refinery. Farther away, up to 5 km, some *Betula* sp. had conspicuously thin crowns. Reddish-brown discoloration of spruce needles. Some trees were totally brown, others quite green, independently of age or size of the trees, of suppression or dominance, of open or closed stand, of dry or moist soil. The difference appeared to be genetically conditioned. The damage was probably caused by high concentrations of SO_2 during a short time.

1969. Buskerud: Øvre Eiker. Sulphite pulp mill at Skotselv.

Severe damage to *Picea abies* up to 1.4 km from the pulp mill at Skotselv. Less damage to *Pinus sylvestris*, but some trees were killed up to 300 m from the mill. Because of an accident at the mill there had been very high emission of SO_2 during 14 days in the summer.

1969. Vestfold: Larvik. Semi-chemical pulp mill.

Damage to various conifers, Betula verrucosa and other broadleaf trees occurred after an accident in the acid producing unit of the semi-chemical pulp mill, resulting in very high emission of SO2 during a few hours in August 1969. On Pinus sylvestris the 1969 needles were almost totally scorched; on older needles there was no visible damage.

1968-1974. Telemark: Porsgrunn. Fertilizer factories, etc. at Herøya.

Survey 30 October 1968: Needle scorching was found on Pinus sylvestris at several localities in the vicinity of the industrial complex at Herøya. The symptoms were not indicative of fluoride damage. The main cause of the damage was probably SO2.

Survey 24 September 1969: At one locality 1-1.5 km from the works spruce trees were dying. At another locality the broadleaf trees were little damaged, the pine trees, however, were dead or dying. The bark beetle Blastophagus piniperda had propagated on dying pines; heavy attacks on the pine shoots aggravated the primary emission damage. At 2-2.5 km from the works there were still many dead or dying pines and heavy attack by B. piniperda. At 2.5-3 km from the works scorching was found on the 1968 needles, but no symptoms of damage to the current year needles, and no dead or dying trees . At 5 km from the works the pine needles had a healthy, green colour.

HORNTVEDT (1972) described and surveyed the injuries to *Picea abies* and *Pinus sylvestris* in the vicinity of Herøya, and made the following evaluation of the different air pollutants in the area with regard to their importance for the observed forest damage: SO_2>HF>NO_2>Cl_2>NH_3>HCl. The SO_2-emission in 1967-1969 was higher than ever before; and especially from the end of September 1968 to the beginning of April 1969 there had been episodically very high emissions in periods of up to 24 hours. The area was surveyed again in 1972 and 1974. No or insignificant damage to the needles formed after 1970 was found. The apparent reason was that the main source of SO_2-emission had been brought under better control.

DISEASES DUE TO UNKNOWN OR COMPLEX CAUSES

Pine galls

1973. Vest-Agder: Vennesla. *Pinus sylvestris*. Within an area of about 200 m in diameter many of the pine trees had numerous galls on stems and branches. The galls were often rounded, of varying size, from quite small, up to 10-15 cm in diameter.

Spruce decline

1975. Aust-Agder: Birkenes. *Picea abies*.

Survey early spring 1975 (HORNTVEDT 1976): The district forest officer had reported the disease in February 1974, but according to one forest owner the symptoms were visible the preceding winter as well. The disease was apparently spreading from the upper to the lower part of the crown, and from the oldest towards the youngest needles on each branch. A less common symptom was that the last 4-5 annual shoots on some branches in the top of the trees were completely defoliated, whereas the rest of these and other branches had a normal green colour. Most commonly the branches were partly defoliated and the remaining needles were yellow. On some branches the needles were more yellowish on the side facing up than on the side facing down. The symptoms were only found on older trees. The diseased trees occurred scattered within otherwise healthy stands. There was no obvious correlation between the occurrence of the disease and various stand or site characteristics, e.g. density, exposure, or soil fertility and moisture as reflected by the vegetation type. All the stands were growing on well-drained moraine soil with a podsol profile. No rot was found in diseased trees inspected, and *Armillaria* was not found at the base of the trees. Fruitbodies of needle or bark fungi which might have caused the disease were not found on the diseased branches. Chemical analyses of the needles showed that there was significantly less nitrogen, calcium, magnesium and manganese in needles from diseased trees than in those from healthy trees. The concentration of potassium, phosphorous and sodium was not significantly different in the two groups. - Within the last 15 years (1960-1975) the diseased trees had a poorer diameter growth than the healthy trees. The early summer of 1959 had been exceptionally dry. Annual growth rings from Birkenes showed that the healthy trees suffered little this summer, whereas the diseased trees seemed not to have been able to recover from the stress they experienced this year. A full explanation of the syndrome could not be given.

Cracks in spruce needles

1967. Sør-Trøndelag: Røros. *Picea abies*. Sampled 14 July. An about 20 years old, slowly growing 2-3 m high spruce plantation. Distance between plants 3 m. All 1967 needles were undamaged, green. But there were many brown older needles (1962-1966) up to 1.5 m above ground, scattered among the green needles. On the brown, dead needles, but also on some totally green ones, longitudinal, clear stripes were seen with a hand lens. Here, longitudinal cracks had been formed under the intact epidermis inwards into the parenchyma. The cracks were filled with a clear liquid of relatively low viscosity. The damage was apparently confined to needles which had been covered by snow. The cause must be physical, but we do not know the mechanism.

Abnormal needle fall

1972. Hedmark: Elverum, Kongsvinger, Sør-Odal, Våler. *Picea abies.* Surveys in September and October 1972. Heavier autumn needle fall than usual, especially northwards in Elverum. More than usual of brown-coloured needles in the fall. Also report on dying of more than usual of suppressed, small twigs. The precipitation deficit in the years 1969-1972, causing low ground water, may have stressed the spruce.

1972. Hedmark: Åmot. *Picea abies.* Sample taken 7 December. Some branches had only, or practically only, 1971 and 1972 needles. But the needle fall was very irregular. In some cases nearly all 1970, 1969, and 1968 needles were gone, whereas some from 1967, 1966, and 1965 still were kept. In another case there were fairly many green 1963, 1962, and 1961 needles, whereas nearly all 1971-1964 needles were gone, only a few needles from 1971, 1967, and 1964 were left.

1972. Akershus: Asker. *Pinus mugo.* Sampled 18 October 1972. Unusually heavy autumn needle fall.

1972. South-eastern Norway. *Pinus sylvestris.*

Somewhat heavier autumn needle fall than usual was reported from great parts of south-eastern Norway, perhaps especially northwards from Elverum. The needles seemed to have got a more conspicuous brownish-yellow colour than usually, perhaps because of special climatic conditions the summer 1972, especially from 18 August onwards. The precipitation deficit in the years 1969-1972 is probably the main cause of the unusually heavy autumn needle fall.

1973. Hedmark: Åmot. *Picea abies.* Sampled 13 March 1973. Relatively few old needles left, probably related to the relatively heavy needle fall the autumn 1972.

SUMMARY

Abnormal formations

Numerous small cones (multiple cones) instead of dwarf shoots and needles were found on the leader of a Scots pine tree.

Split leader was observed in a young Norway spruce tree. For several years the leader had split longitudinally in its lower part; it had been possible to look through the shoot.

Twisting of lower branches was observed in *Abies veitchii* trees, so that the white underside of the needles was visible from above.

Vegetative shoots growing from the distal end of cones were found in larch and spruce.

Mechanical damage

Bark wounds caused by drifting ice were observed in a stand of old spruce trees on a riverbank normally flooded during spring. From many of the wounds serious rot had apparently not developed. The reason is probably that the number of spores of *S.*

sanguinolentum, the most important wound rot fungus, is very low at the time of drifting ice.

Leaf damage from strong wind and from a heavy hail shower (Fig. 1) are described.

Winter frost and frost drought

A type of top dieback in pine, known as "straw-coloured tops" occurred in Troms and Finnmark in 1969. This particular dieback is found in young Scots pine, mostly towards the alpine or northern forest limit. It is caused by winter frost, but also very important is insufficient acclimation during the preceding summer.

Top dieback in spruce plantations occurred at several places in south-eastern Norway. The stem leader was partly or totally killed during the winter, sometimes also the uppermost branch whorl and parts of the previous year's leader. The damaged plantations were mostly of foreign provenances on high sites. Poorly developed buds on the damaged shoots indicated incomplete maturation. In some cases fertilization and summer frost could have contributed to this. In no cases parasites were found.

A special damage that occurred at localities in Østfold, Vestfold and Akershus in 1967-69 was bark necroses with resin flow in the top of younger spruce. Longitudinal cracks and necrotic flecks or stripes in the bark occurred on the 1-year-old leader, and also on the 2-year-old stem internode and branch internodes.

Shoot dieback in pine is a rather common type of damage, especially in areas adjacent to the mountains in southern Norway. The damage may often be classified as frost drought. It is then associated with prolonged periods of dry winds from the mountains hitting trees and shrubs on frozen ground. The killing of bark and buds may be a secondary effect of the killed needles. Juniper and heather, if not protected by snow, may be even more damaged than pine when the snow cover is sparse. Many years, the above snow parts of juniper and some garden evergreens are the only species damaged by frost drought. Curiously, Norway spruce is not damaged to any comparable extent. Widespread damage occurred in 1968 in western Norway from Rogaland to Sogn og Fjordane, in 1970 from Vest-Agder to Møre og Romsdal, in 1972 in Møre og Romsdal and Sør-Trøndelag, and in 1974 in Sør-Trøndelag, Nordland and Troms.

Red belts in pine forests were observed at several places in 1975, especially in Hedmark. In one red belt at Evenstad, Hedmark, pine, spruce an birch all occurred side by side, but only pine was damaged. Red belts are associated with rapid temperature fluctuations in the border zone between a stable cold air basin and warm air sliding on top of it. In some cases the damage may be caused mainly by freezing, and pine and spruce may be equally much damaged. The buds of broadleaf trees may be damaged as well, resulting in torn and perforated leaves in the spring. In other cases the damage mechanism may be more like frost drought, and pine is for some reason more sensitive than spruce.

Needle scorching in spruce can be caused by large temperature fluctuations on clear days in late winter. The trees become dehardened by high temperatures at daytime, and damaged by low temperatures during night. As the damage occurs

before growth start, no frost ring is found in the annual growth ring. This damage was reported in 1969, 1970, 1971, 1973 and 1974 from different parts of the country. The damage is usually confined to above snow parts of the trees.

A special type of needle scorching in spruce occurred in Nord-Trøndelag in 1974, when damage was worst on the lower branches which had been covered by snow.

Winter damage in lodgepole pine was reported in 1966 from Stange, and in 1971 from Åmodt, Hedmark, were Scots pine was undamaged.

Frost in the growth period

Damage by early spring frost was observed in 1973 in Lyngdal, Vest-Agder, on spruce provenances from Trøndelag and northern Norway grafted on rootstocks about 5 years ago. These had started growth earlier than the local provenance, and therefor damaged by frost. Sometimes there had been a slight elongation of the shoots, still within the buds, before they had been killed. A frost ring was found at the start of the 1973 annual ring.

Late spring frost is caused by low temperatures after growth start. The new shoots are damaged, and a frost ring is often formed in the innermost part of the new annual growth ring. The leader and upper branch whorl are often not damaged because of their later growth start. Widespread damage occurred in 1975 in south-eastern Norway from Aust-Agder to southern parts of Hedmark.

Summer frost mostly damages the outer part of the leader and other new shoots, i.e. the last maturing parts. A frost ring is often found in the middle or outer part of the annual growth ring. Summer frost damage was reported in 1968 from several places in Nord- and Sør-Trøndelag, and in 1971 and 1973 from Hedmark.

Some other cases of frost damage that could not be classified into one of the above categories are discussed under the heading: Frost damage. Miscellaneous.

Summer drought

Severe summer drought occurred in 1975 in south-eastern Norway. Damage to several tree species in Bamble, Telemark, was recorded in August and October. Yellowing and defoliation in birch were widespread in August. Aspen was obviously the most drought tolerant deciduous species. In Scots pine the 1975-shoot length was mostly normal, but needles were shorter. In spruce the drought resulted in unnormal yellowing and loss of older needles, especially in weaker branchlets.

Waterlogging occurred in a nursery and in a first-year plantation.

Nutrient deficiency

Boron deficiency can be a problem in continental areas, especially on drained bogs, by predisposing conifers to shoot dieback initiated by frost.

Phosphorus deficiency was reported from nurseries only.

Potassium deficiency occurred in a spruce plantation on a field, and in a pine plantation on a bog.

Magnesium deficiency in spruce was reported from two nurseries and one plantation on a field.

Poisoning by various chemicals

Damage by airborne sea salt occurred in 1969 at Lista, Vest-Agder, in 1971 and 1973 in Nordland, and in 1973 along the southern coast from Østfold to Rogaland. In this last case damage occurred as far as 25 km inland.

Road salting ($CaCl_2$) caused damage to pine and spruce along gravelled roads in Hedmark and Oppland. The damage is caused partly by direct effects on the needles, partly by effects on the soil.

In 1967, heavy resin flow was registered on many trees in two mature spruce stands, both heavily fertilized with urea in 1966. Abnormal high number of resin canals was found late in the 1966 annual growth ring.

Unintentional damage caused by the herbicides aminotriazol, MPCA, sodium chlorate and TCA were reported.

Damage from soda lye, silage effluent, and sulfamic acid was observed in Elverum, Hedmark. The soil had been polluted from a ditch from a straw leaching unit. Spruce trees about 15 years old were damaged and partly killed within a lower-lying area. Soil eutrophication and needle nutrient imbalance were indicated, in addition to possible poisoning effect of the leachates.

Industrial air pollutants

Emission of borax from a glass-wool works damaged Scots pine and Mountain pine within a distance of 500 m. Although boron is an essential nutrient, too high uptake may result in damage.

Fluorides emitted from aluminium smelting works are the most important plant damaging air pollutants in Norway. Varying extent of forest damage was recorded at all works, depending on emitted quantities and local topography. Damage to conifers was observed 1-2 km from the works at Eydehavn, Lista, Karmøy and Husnes, 9 km at Tyssedal, 13 km at Årdal, 35 km at Sunndal, and 4.5 km at Mosjøen.

In Scots pine slight damage was sometimes observed at F concentrations in current needles as low as 10 mg/kg. At 40-50 mg/kg and above the damage was usually severe.

A field experiment was made in Sunndal to test fluoride tolerance of different conifers. European larch showed no damage symptoms at all. Also Western hemlock was promising. The other species tested: Several firs, two spruce species, Douglas fir and Scots pine were all significantly damaged.

At Mosjøen there were some cases of unexpected severe damage, considering emission quantity, topography and distance from the works. It could not be excluded that air-borne sea salt contributed to the damage in some cases.

Fluoride damage also occurred at a brick-works, two glass-works and a fertilizer works.

Emission of sulphur dioxide from the nickel works at Kristiansand damaged several coniferous species in an arboretum about 1 km away. Other cases of SO_2

damage were recorded at pulp mills, an iron works, an oil refinery and two fertilizer works.

In total, the damage caused by SO_2 was less extensive than that caused by fluorides. This situation is probably specific for Norway. It was indicated in several cases that SO_2 damage is caused by acute high concentrations. This is in contrast to fluoride damage which often results from slow accumulation at rather low air concentrations.

Diseases due to unknown or complex causes

Within a small area in Vest-Agder many of the pine trees had numerous galls on stems and branches.

Cracks under epidermis in spruce needles were observed at Røros.

Abnormal needle fall was reported in 1972 in spruce from Hedmark and in pine over most of southern Norway. A main cause may have been precipitation deficit during the years 1969-1972.

A case of spruce decline was reported in 1975 from Birkenes, Aust-Agder. The symptoms included yellowish discoloration and abnormal loss of older needles, and also shoot dieback, mostly in the upper part of the crown. The symptoms had developed during the last two years. Chemical analyses of the needles showed that there was less nitrogen, calcium, magnesium and manganese in needles from diseased trees than in healthy trees. During the last 15 years the diseased trees had less diameter growth than the healthy trees. Apparently, the exceptionally dry summer of 1959 had been critical for the declining trees.

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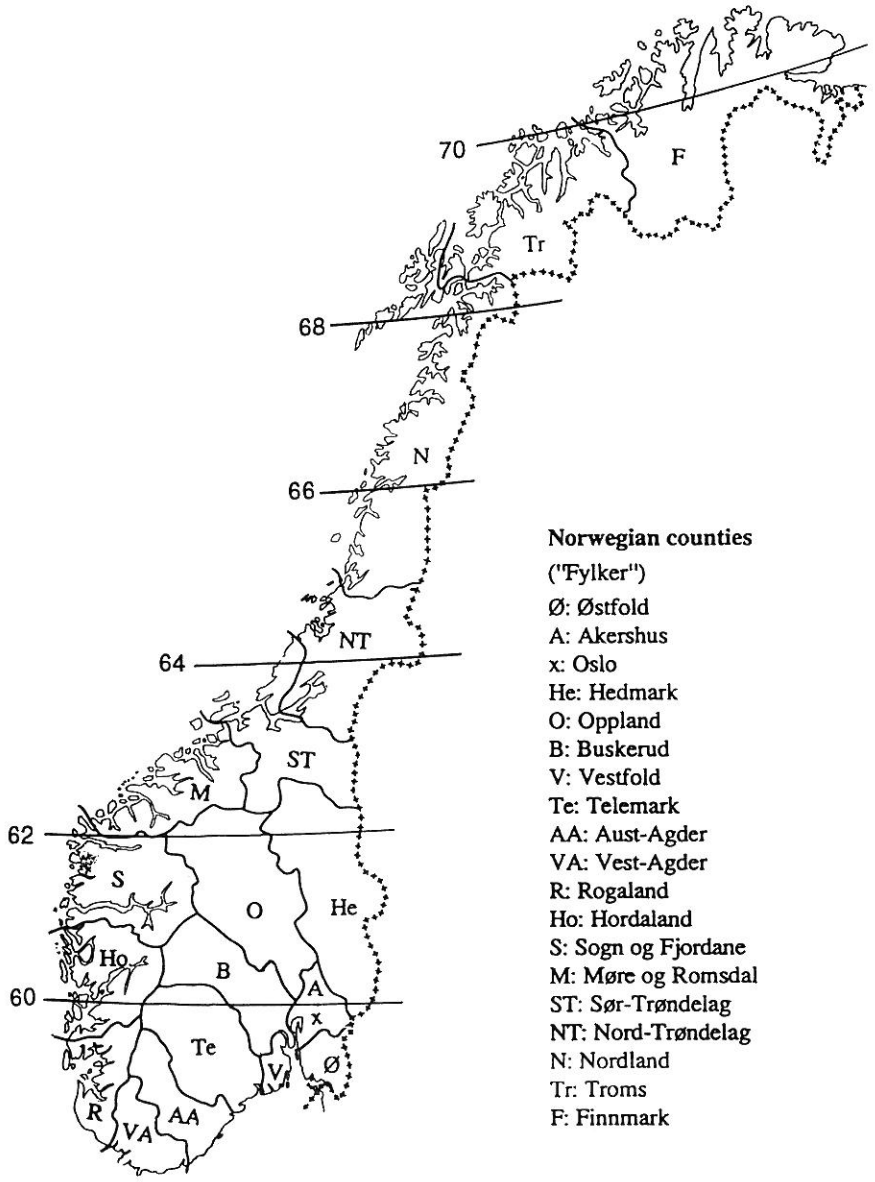

Norwegian counties
("Fylker")
Ø: Østfold
A: Akershus
x: Oslo
He: Hedmark
O: Oppland
B: Buskerud
V: Vestfold
Te: Telemark
AA: Aust-Agder
VA: Vest-Agder
R: Rogaland
Ho: Hordaland
S: Sogn og Fjordane
M: Møre og Romsdal
ST: Sør-Trøndelag
NT: Nord-Trøndelag
N: Nordland
Tr: Troms
F: Finnmark

County map of Norway

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