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Natural enemies of the green spruce aphid in spruce plantations in maritime North-West Europe

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SUMMARY

The population development of *Elatobium abietinum* in Iceland has been observed to be different from that of the other North Sea countries where the population peak occurs in late spring/early summer. In Iceland peak populations occur in the autumn resulting in a more serious growth loss than the loss incurred by infestations in spring and early summer. Experimental evidence indicates that absence of certain natural enemies may be the reason for this change in development. Therefore, during a three-year period surveys have been undertaken in districts of Denmark, Great Britain, Iceland and Norway to provide further information on natural enemies of *Elatobium abietinum* in its original area of distribution. Special emphasis was given to areas in Norway with a climate similar to that of Iceland. These areas might later serve as a source for possible introduction of natural enemies to Iceland. Sitka spruce and other *Picea* spp. were sampled, so were trees with or without *Elatobium* infestation. The finds are presented in separate tables for predators, parasitoids and pathogenic fungi. No feeding experiments were undertaken. Therefore, to evaluate the predator status of the sampled species, literature references are referred to. The surveys indicate that in Iceland several important natural enemies are absent, which may therefore account for the differing population development. Possible introduction of important natural enemies can be done from any of the other countries, preferably from northerly coastal areas of Norway with a climate similar to that of Iceland, and with a richer fauna of natural enemies.

Key words: *Elatobium abietinum*, natural enemies, *Picea*, North-West Europe.

YFIRLIT

Náttúrlegir óvinir sitkalúsar, Elatobium abietinum *Walker, í greniræktun á svæðum í norðvestur Evrópu þar sem úthafsloftslag ríkir*

Stofnþróun sitkalúsar á Íslandi hefur reynst vera frábrugðin stofnþróun hennar í öðrum löndum í norðvestur Evrópu þar sem stofninn nær hámarki síðla vors eða í sumarbyrjun. Á Íslandi nær stofninn hins vegar hámarki að haustinu, en af því leiðir mun meira vaxtartap trjáa en þegar stofninn nær hámarki að vorinu. Niðurstöður athugana benda til þess að skortur á ákveðnum náttúrlegum óvinum geti verið orsökin fyrir þessum mun á stofnþróun. Því hefur verið gerð þriggja ára könnun í Danmörku, Stóra-Bretlandi, Íslandi og Noregi til að afla frekari upplýsinga um náttúrlega óvini lúsarinnar á upprunalegu útbreiðslusvæði hennar. Sérstök áhersla var lögð á þau svæði í Noregi þar sem loftslag er svipað og á Íslandi. Frá þeim svæðum mætti hugsanlega síðar flytja náttúrlega óvini til Íslands. Tekin voru sýni af sitkagreni og öðrum grenitegundum og eins voru sýni tekin af trjám með og án sitkalúsar til samanburðar. Niðurstöður þessarar könnunar eru birtar í sérstökum töflum fyrir hvern hóp náttúrlegra óvina, þ.e.a.s. rándýr, sníkjudýr og sjúkdómsvaldandi sveppi. Ekki var gerð rannsókn á fæðuvali og því stuðst við fyrri rannsóknir til að ákvarða hvort þau rándýr sem fundust séu í raun afræningjar á sitkalús. Könnunin bendir til þess að á Íslandi vanti mikilvæga náttúrlega óvini sitkalúsar og það sé ástæðan til þess mismunar í stofnþróun sem áður var getið. Hugsanlegur innflutningur náttúrlegra óvina er mögulegur frá hverju þeirra landa sem könnuð voru, en heppilegust væru þó þau strandsvæði Noregs þar sem loftslag er svipað og á Íslandi en fjölbreyttari náttúrlegir óvinir.

INTRODUCTION

In the coastal areas of North-West Europe, Sitka spruce, *Picea sitchensis* (Bong.) Carr., is an important species in the forest plantations because of its rapid growth and its resistance to salty sea water spray. However, the introduced Sitka spruce suffers from infestations by the green spruce aphid, *Elatobium abietinum* Walker. Infestations cause Sitka spruce to readily shed its needles, with growth loss to follow (Carter, 1977; Day and McClean, 1991; Seaby and Mowat, 1993; Thomas and Miller, 1994; Orlund and Austarå, 1996).

Contrary to regions with a continental climate where *E. abietinum* exists holocyclicly, the development is anholocyclic in oceanic regions with a mild winter climate; in some years even as paracyclic populations (Carter and Austarå, 1994; Harding and Carter, 1997). In these oceanic regions the populations can continue to breed throughout the winter, the resulting population reaching a peak in late spring/early summer (Carter and Cole, 1977; Day, 1984; Carter and Nichols, 1988; Crute and Day, 1990). After bud burst the population breaks down and stays at a low level throughout the growing season. This has been claimed to be due to changes in the nutritional values of the phloem sap (Parry, 1974). A different development of anholocyclic populations has been observed in Iceland where *E. abietinum* has recently been introduced and where the population peak occurs during the autumn/early winter (Ottósson, 1985). It is known that very few of the predators considered to be important on *E. abietinum* are found in Iceland (Ólafsson, 1991; Agnarsson, 1996). Only 4 species within the most important groups of predators (i.e. Coccinellids, Hemirobiids and Syrphids) are present in Iceland, i.e. *Syrphus ribesii*, *S. torvus*, *Parasyrphus tarsatus* and *Coccinella 11-punctata*, and only one of them, *S. ribesii*, is common. As far as other predators are concerned *Notiophilus biguttatus* is common and 7 Empididae species are present in the country. Several arachnids are present, some of which are common (Agnarsson, 1996). How important these species are is not known, but von Scheller (1963) has stated that arachnids have played an important role in controlling *Elatobium* outbreaks. Considering parasitoids, two *Praon* species are present as well as *Aphelinus abdominalis*, which is also known as a hyperparasitoid. The hyperparasitoids *Asaphes suspensus* and *A. vulgaris* are also present. The status of pathogens is unknown.

Crute and Day (1990) have suggested that the development of summer/autumn/winter populations cannot be explained exclusively by changes in nutritional values of phloem sap and that it is modified by natural enemies. In a modelling experiment they found a similar population development to that in Iceland when certain predators were excluded from the model.

The Nordic Group of Forest Entomologists discussed the possibilities that lack of certain natural enemies might be one important factor for the divergent aphid development in Iceland, and suggested that the population dynamics of *E. abietinum* in the Atlantic coastal region of Europe be investigated. As an approach to the study it was agreed that Denmark, Great Britain, Iceland and Norway should undertake comparative surveys of natural enemies of the aphid. The survey in Denmark and Iceland was concentrated on pathogenes, but all groups of natural enemies were surveyed in Norway and Great Britain. The aim of the study was to gain further information on natural enemies of *E. abietinum* in its original area of distribution, with special emphasis on areas in Norway which may later serve as a source for possible introduction of natural enemies to Iceland. This paper presents the results of these surveys.

In Denmark surveys were carried out by the Royal Veterinary and Agricultural University (RVAU), in Great Britain by the Forestry Commission (FC), in Iceland by Iceland Forest Research Station (IFRS) and in Norway by the Norwegian Forest Research Institute (NISK).

MATERIALS AND METHODS

Predators and parasitoids

Sampling. In Norway (in 1993 to 1995) sample trees were selected at random both inside compartments and along edges. In small groups of 10–12 trees, all trees were sampled. Also samples were taken randomly, up to approximately 2 m height of the canopy, by beating branches over trays and by visual observations of foliage. Collected material was stored in 70% ethanol. Notes were taken on the *Elatobium* situation, stand structure and environmental conditions. In the last year, notes were made on standardized recording cards.

In Britain (in 1995), prethicket, pole-stage and mature crops were sampled separately. At two Scottish sites post mature crops were also sampled. The technique used was by thermal fogging with a 'knock down' insecticide. The canopy invertebrates were readily immobilised by 'Pybuthrin' and fell into nylon collecting funnels temporarily suspended beneath the canopy. This is a well tested technique (Stork, 1987) and has been used in several faunistic studies particularly in the tropics; in Britain there is a requirement that operators should be trained and certificated.

In order to get a good thermal convective lift of the insecticidal fog, the operation is best carried out at the coolest and calmest part of the day, which is normally at dawn. June was selected as the sampling period to take advantage of the greatest range of invertebrate activity which coincides with the *E. abietinum* population peak in Britain (Carter and Cole, 1977). Twenty five funnels, each 1 m^2 were suspended under the canopy being sampled. The application of the 'Pybuthrin' fog only took a few seconds, and under good climatic conditions stayed in the canopy for some 10 minutes before dispersing upwards. Insects commenced dropping almost at once, and the sample funnels were kept in place for 2 hours; the entire catch from each funnel was collected in 70% industrial methylated spirit (ethanol mixture). Notes on the site conditions were made on standardized recording cards.

In Iceland, populations of *Elatobium* were sampled for parasitoids and insect pathogenic fungi in 1994–1996. Sampling for predators was not carried out, due to low summer populations of the aphid during this period. The samples were examined for parasitized aphids before being sent to RVAU for examination for insect pathogenic fungi.

Sampling localities. In Norway surveys were undertaken during three years in young plantations and small groups of *P. sitchensis* and

P. lutzii in the coastal areas of West and North Norway. In 1993 samples were taken from several plantations in 7 localities in Møre and Romsdal county between 62°N and 63°N in late June. In 1994, 24 localities in Nord Trøndelag and southern part of Nordland counties between 64°N and 65°N were surveyed in early June, a repeated survey being undertaken in the same localities in early August. In 1995, the survey was done in 38 localities in northern part of Nordland county between 68°N and 69°N in mid-June. Thus the surveyed areas extended from latitudes well south of to well north of Iceland.

Elatobium populations were generally low. In 1993 the aphid was present in most of the sampled plantations, in 1994 infestations were found only in a few plantations and in 1995 only one plantation and a few small groups or rows of trees were found to be infested with the aphid. All identified species presented in Tables 1 and 2 were collected both from *Elatobium* infested and uninfested trees.

In Britain, 1995 was a moderate outbreak year for *E. abietinum*. Fourteen locations were sampled for natural enemies in both *P. abies* and *P. sitchensis* stands ranging from 51°N on the English-Welsh borders, 53°N in Eastern England, 56°N in West Scotland to 57°N in the Scottish Uplands.

Insect pathogenic fungi

Sampling and incubation. Sampling of aphids for diagnosis for infection by insect pathogenic fungi was carried out by each participating country. The diagnosis was done by RVAU.

The sampling from *E. abietinum* populations was performed in two ways:

1) Aphids were sampled by cutting shoots of Sitka spruce with live *E. abietinum* and taken to the laboratory. Dead aphids were examined immediately, living aphids were transferred to petri dishes or plastic boxes with moist filter paper and incubated for one week at room temperature. Dead aphids were removed every day and examined for possible fungal diseases. This procedure was followed for all material sampled by RVAU. In a few cases with dense *E. abietinum* infestations, living material sampled by other participants was also sent to RVAU and incubated as described.
2) Aphids were sampled from cut shoots and either transferred to 70% ethanol or dried. The material was then forwarded to RVAU for examination and diagnosis. This procedure was followed for material sampled by FC, IFRS and NISK.

Sampling localities. In Denmark samples were taken from localities on Zealand (between 55°N and 56°N) in April–June 1993. In one locality (Rosenfeldt) sampling was repeated four times with about one week interval in order to obtain data on the development of fungal infection over time. Furthermore, the distribution of the fungus-killed aphids on the needles was investigated.

An autumn attack of *E. abietinum* occurred in 1993 in Thy, Northwest Jutland (57°N). For Denmark this was an unusual event, and this was sampled in November (Harding, 1994; Harding and Carter, 1997). At four localities 15 trees with especially severe attacks were sampled. In December the sampling in Thy was repeated and two localities in Western Jutland (56°N) were included. A more detailed quantification of the level of fungal infection was attempted by incubating single needles with 1–2 *E. abietinum* in 25 ml plastic cups with 5 ml 2% water agar (4 needles per cup). A total of 2243 aphid were incubated during the sampling in November, 1466 during the second sampling in December. Sampling of shoots was repeated in North-West Jutland in October 1994 and November 1995.

In Great Britain, *E. abietinum* putatively infected by insect pathogenic fungi were collected by FC from densely colonised trees in Sussex and Surrey (approx. 51°N) in May, June and November 1993. In June 1995 sampling was undertaken by RVAU in three localities in Wales (Hafren, Montgomery and Ludlow, Shropshire, between 52°N and 53°N). More than 2500 *E. abietinum* were incubated as described above.

In Norway, sampling of aphids for examination and diagnosis was carried out by NISK simultaneously with sampling for predators and parasitoids.

In Iceland, sampling of aphids was carried out at 5 localities in West Iceland in June 1994 by RVAU. In October–December 1994 aphid were sampled at 20 localities by IFRS in Western and Southern and Eastern Iceland. The shoot samples were sent to RVAU and 4988 *E. abietinum* were examined and diagnosed. All sampling sites were located between 63°N and 65°N.

Diagnosis. Freshly killed aphids were placed for 24 hours in a humid chamber on glass slides to allow spore discharge of primary spores of fungi from Entomophtorales on to the slides. The glass slides with projected spores were then stained with 0.001% lactophenol-cotton blue or 1% aceto orceine (nuclei staining). Further cadavers were dissected and stained with lactophenol to determine the presence of resting spores of fungi from Entomophtorales. Dried killed aphids and aphids in ethanol were stained with lactphenol-cotton blue or aceto-orceine to determine the presence of spores on the cuticle and legs.

RESULTS

Predators and parasitoids

The recorded predators are listed in Table 1, the parasitoids in Table 2 and the pathogenes in Table 3.

In Norway the *Elatobium* populations were obviously declining after the heavy outbreak period 1987–1990. As already mentioned, they were at low levels in all three years, and lower in 1994 and 1995 than in 1993; in several localities the aphid was not found. In 1995 greatest numbers of aphids were found on trees in small groups, while in the larger stands *Elatobium* was recorded only in one stand. The species recorded from Norway were collected from Sitka spruce and *Picea lutzii* but not necessarily found with the aphid.

In Norway, the three coccinellid species were found in various localities in 1993 on *Elatobium* infested trees. In 1994 and 1995 no specimens were found in the more northern localities. *R. lignosa* and *R. limbata* were found on aphid infested trees in 1993 only (Møre and Romsdal). *A. subfuscus* was found in 1993 and 1995, both years on trees infested by *E. abietinum*. Hemerobiids were found all three years in Norway, both on infested and uninfested trees. *A. nemorum* was found both in Møre and Romsdal and Nordland on infested and uninfested trees. Species within Aphidiidae were recorded all three years, while Aphelinidae and the hyperparasitoides *Asaphes* spp. and *Coruna clavata* (Sullivan, 1988) were found only in 1994.

Pathogenic fungi

Six species of insect pathogenic fungi, all from Zygomycotina:Entomophthorales, were isolated from *E. abietinum* (Table 3). Only one of these, *Entomophthora planchoniana*, was earlier documented on this aphid species. *Neozygites fresenii* was the only species found in all countries; in Norway and Iceland it was the only pathogen isolated.

The abundance of fungal pathogens differed significantly over time and between localities. In Denmark only a few trees colonised by *E. abietinum* were found in spring 1993; population levels were very low and several surveys were unsuccesful. In Zealand *E. planchoniana* was isolated from two localities, but was not found in the other localities surveyed. During the autumn attack in Thy 1993, four of the species listed in Table 3 were present: *E. planchoniana, Erynia neoaphidis, N. fresenii* and *Zoophthora phalloides*. In 1994 no aphids were found in these localities and in 1995 moderate numbers of *E. abietinum* revealed no fungus attack. The

Table 1. Potential invertebrate predators of *Elatobium abietinum* in maritime North-West Europe recorded during this study.
1. tafla. Hugsanleg rándýr (hryggleysingjar) á sitkalús sem fundust á rannsóknartímanum á úthafsloftslagssvæðum í norðvestur Evrópu.

Species *Tegund*	Distribution recorded[a)] *Skráð útbreiðsla[a)]*	References and recent data sources[b)] *Heimildir og gagnaskrár[b)]*
Coleoptera—*Bjöllur*		
Coccinellidae		
Anatis ocellata	DK, GB	3, 23, 29, 30, 31, FC
Adalia 2-punctata	GB, N	4, 31, NISK, FC
A. 10-punctata	GB, N	19, 31, NISK, FC
Aphidecta obliterata	DK, GB, N	3, 4, 19, 23, 29, 30, 31, NISK, FC
Calvia quatuordecimpunctata	GB	FC
Coccinella 7-punctata	DK, GB	3, 23, 30, 31, FC
C. hieroglyphica	GB	4, 19, 31
Exochomus quadripustulatus	GB	FC
Propylea 14-punctata	GB	4, 19, 31, FC
Scymnus abietis	GB	31, FC
Cantharidae		
Cantharis decipiens	GB	15, FC
C. nigricans	GB	FC
C. pallida	GB	FC
C. rufa	GB	FC
Malthodes fuscus	GB	FC
M. marginatus	GB	FC
Podabrus alpinus	GB	FC
Rhagonycha femoralis	GB	FC
R. lignosa	GB, N	5, FC, NISK
R. limbata	N	NISK
R. testacea	GB	FC
Elateridae		
Agriotes pallidulus	GB	FC
Athous haemorrhoidales	GB	FC
A. subfuscus	N	30, NISK
Denticollis linearis	GB	FC
Dolopius marginatus	GB	FC
Liotrichus affinis	N	NISK
Selatosomus incanus	GB	FC

Continued on next page—*Framhald á næstu síðu*

infection level was in overall pattern low: of 2243 aphids sampled and incubated from Thy, only 33 proved to be infected.

In Sussex and Surrey, UK, only *E. planchoniana* was documented, and only in spring samples. The only specimen found with resting spores of *E. planchoniana* was from UK. This species was not found in samples from Wales, but two *Conidiobolus* species, *C. obscurus* and *C. coronatus*, were recorded only from the Welsh localities. The infection level in Wales never exceeded 2%.

In Norway, only *N. fresenii* was found yet only in one locality.

Species	Distribution recorded	References and recent data sources
Diptera—*Tvívængjur*		
Syrphidae		
Melanostoma scalare	GB	FC
Episyrphus balteatus	GB	FC
Syrphus ribesii	GB, Ic	FC, RVAU
S. torvus	N	NISK
Parasyrphus sp.	N	NISK
Empididae	N	36, NISK
Neuroptera—*Netvængjur*		
Hemerobiidae		
Hemerobius atrifrons	N	NISK
H. perelegans	N	NISK
H. pini	N	NISK
H. simulans	N	NISK
H. stigma	N	4, NISK
Wesmaelius nervosus	N	NISK
Hemiptera—*Skortítur*		
Anthocoridae		
Anthocoris nemorum	N	18, NISK
ARACHNIDA—ÁTTFÆTLUR		
Araneida—*Köngulær*		
Araneidae		
Meta segmentata	N, GB	NISK, FC
Meta mengei	N, GB	NISK
Linyphiidae		
Drapestica socialis	GB	FC
Bolyphantes index	N	NISK
Lepthyphantes tenuis	N	NISK
L. obscurus	N	NISK
Theridiidae		
Theridion sisyphium	GB	FC
Thomisidae		
Xysticus sp.	N	NISK
Lycosidae	N	NISK
Opiliones—*Langfætlur*	GB	FC

a) DK=Denmark—*Danmörk*, GB=Great Britain—*Stóra Bretland*, Ic=Iceland—*Ísland*, N=Norway—*Noregur*, W=Wales—*Wales*, NI=Northern Ireland— *Norður Írland*.
b) Collection data from—*Úr gagnasafni*: FC=Forestry Commission, NISK=Norwegian Forest Research Institute, RVAU=Royal Veterinary and Agricultural University, IFRS=Iceland Forest Research Station—*Rannsóknastöðvar Skógræktar ríkisins*.

The same pathogen occurred in samples from Iceland. In Iceland spring population levels were very low, and no infection was observed during the survey in spring 1994; during the autumn peak, infection levels varied between 0 and 19.8% (primary spores or

Table 2. Mummies, and parasitoids emerging from *Elatobium abietinum* in maritime North-West Europe during this study.
2. tafla. Sníklar í sitkalús og sníklar sem klöktust úr sitkalúsum á rannsóknartímanum á úthafsloftslagssvæðum í norðvestur Evrópu.

Species *Tegund*	Type[c] *Gerð*[c]	Distribution recorded[a] *Skráð útbreiðsla*[a]	References and recent data sources[b] *Heimildir og gagnaskrár*[b]
Hymenoptera—*Æðvængjur*			
Aphidiidae			
Lysaphidus schimitscheki	P	GB, N	22, 31, FC, NISK
Praon sp.	P	GB, N	31, FC, NISK
Aphelinidae			
Aphelinus abdominalis	P&H	N	NISK
Pteromalidae			
Asaphes suspensus	H	GB, N	35, NISK
A. vulgaris	H	GB	30, 31, FC
Asaphes sp.	H	N	35, NISK
Coruna clavata	H	N	35, NISK
Mummies—*Blaðlýs með sníklum*		N, Ic	NISK, IFRS

a) See Table 1—*Sjá 1. töflu.*
b) See Table 1—*Sjá 1. töflu.*
c) P=Parasitoid—*Sníkill.*
H=Hyperparasitoid—*Ofursníkill (sníkill sem sníkir á öðrum sníkli).*

Table 3. Insect pathogenic fungi isolated from *Elatobium abietinum* in maritime North-West Europe during this study.
3. tafla. Sjúkdómsvaldandi sveppir sem fundust í sitkalúsum á rannsóknartímanum á úthafsloftslagssvæðum í norðvestur Evrópu.

Pathogen *Sjúkdómsvaldur*	Distribution recorded[a] *Skráð útbreiðsla*[a]	References and recent data sources[b] *Heimildir og gagnaskrár*[b]
ZYGOMYCOTINA—*OKSVEPPIR*		
Entomophthorales—*Flugumygluættbálkur*		
Ancylistaceae		
Conidiobolus obscurus	W	RVAU
C. coronatus	W	RVAU
Entomophthoraceae		
Entomophthora planchoniana	DK, NI	11, 12, RVAU
Erynia (=Pandora) neoaphidis	DK	RVAU
Neozygites fresenii	DK, Ic, N, GB	RVAU, IFRS, NISK
Zoophthora phalloides	DK	RVAU

a) See Table 1—*Sjá 1. töflu.*
b) See Table 1—*Sjá 1. töflu.*

resting spores) in samples collected in October and November, whereas only 2 of 3577 aphids sampled in December were infected.

The additional study of the distribution of fungus-killed aphids on the needles exhibited a characteristic pattern: The majority of the killed aphids was found on the shoot axis (38%) or on the inner third of the needles (43%). Only 19% were placed on the middle or outer part of the needles.

DISCUSSION

Predators and parasitoids

The survey was not planned in a way that makes it possible to exclude casual finds of predators from systematic presence or absence on trees infested or not infested with *E. abietinum*. Since no feeding experiments have been undertaken we have to rely on literature records to evaluate the predator status of the sampled species.

Coccinellids are known to be important predators also of *E. abietinum* (Börner and Heinze, 1957; von Scheller, 1958; Ohnesorge, 1959; Bejer-Petersen, 1962; Parry, 1992). In Norway *Aphidecta obliterata* has never been found north of Møre and Romsdal county, and the northernmost known records of *Adalia bipunctata* and *A. decempunctata* are from the eastern parts of Nord Trøndelag county (Vik, 1991). This is probably the most obvious reason why these species were not found in 1994 and 1995. All three *Coccinella* spp. however, are known also from the northernmost parts of Norway. The reason why we did not find them or other coccinellids might be the low *Elatobium* populations, coccinellids soon leave host plants when prey density becomes low.

Within the Cantharidae there are species known to be aphid predators (von Scheller, 1958; Frazer, 1988), and *Rhagonycha lignosa* has been recorded from *E. abietinum* in Great Britain (Carter, 1973). *R. lignosa* is not known further north than Møre and Romsdal county. *R. limbata,* however, has been recorded even from Finnmark county (Vik, 1991). So, if *R. limbata* feeds on *Elatobium*, the reason why we did not find it during the last two year's surveys also may be that *Elatobium* populations were low.

Among the Carabids, von Scheller (1958) mentions *Notiophilus biguttatus* as one of the predators of *E. abietinum*.

Of the Elaterids the genus *Athous* is known to contain predators of *E. abietinum,* and *A. subfuscus* has been found feeding on *E. abietinum* (von Scheller, 1958).

Among Syrphidae and Hemerobiidae there are important predators also on *E. abietinum* (Börner und Heinze, 1957; Hussey, 1952; von Scheller, 1958, 1963; Ohnesorge, 1959; Crute and Day, 1990). In Norway larvae of *Hemerobius atrifrons* were observed voraciously feeding on *E. abietinum* on trees in the field.

Also within the diptera family Empididae there are predators on aphids living on forest trees (Sunderland, 1988). The unidentified adult species recorded in 1994 were collected on trees with large numbers of *E. abietinum*, but without finding any diptera larvae.

Among the Anthocoridae, *Anthocoris nemorum* is considered an important predator of aphids (Hodgson and Aveling, 1988). Although no records have been found connecting *A. nemorum* to *Elatobium*, it is reasonable to assume that it is predaceous also on *E. abietinum* since it was found on trees infested by this aphid both in 1993 and 1995.

Most of the hymenopterous parasitoids were collected as mummies, the adults emerging in the laboratory. Some of these turned out to be hyperparasites, but the parasitoid *Lysaphidus schimitscheki* was identified (Mackauer and Starý, 1967). Others were found to belong to the parasitoid genus *Praon.* In Iceland however, no adults emerged from mummies in the laboratory.

Species within the spider families listed in Table 1 have been recorded as predators of aphids in forests (Sunderland, 1988). Von Scheller (1963) states that in an outbreak area of *E. abietinum* large numbers of arachnids were present and contributed considerably to the reduction of aphid numbers.

Only a few of the species listed in Table 1 have been found in Iceland: among the important predators three syrphid species and one coccinellid are known (Ólafsson, 1991). No hemerobiids have been recorded. Several arachnids are present, some of them common (Agnarsson, 1996). How important these ones are is not known, but as already mentioned, von Scheller (1963) has stated that arachnids have played an important role in controlling *Elatobium* outbreaks.

Considering a possible introduction of natural enemies to Iceland, Norway may serve as a suitable source: the climate in the northerly coastal areas is probably much the same as in Iceland, and the surveys have shown that several more of the important predators are present in Norway than in Iceland. As to parasitoids, mummified aphids were found also in Iceland, but here adults failed to emerge and therefore no species were identified.

Pathogenic fungi

Six species of insect pathogenic fungi were encountered from *E. abietinum* during this study. Of these, only *E. planchoniana* was fully recognized before as a pathogen (Day, 1984, 1986). According to Day's studies this fungus occasionally appears to cause a significant mortality within populations of *E. abietinum*, and even quite early during the season (late March) Day found it to be the primary mortality factor resulting in more than 12% mortality among the aphids collected. Earlier, however, von Scheller (1958) observed an unidentified fungus on *E. abietinum*, and he suggested that this fungus had a significant influence on the population development of the aphid. Further, Ohnesorge (1959) observed an "*Entomophthora*" species on *E. abietinum* and proposed it to be the cause of an unexplained disease among the aphids. Both observations could be attributed to one of the insect pathogenic fungi described fully in our study.

The species *E. planchoniana, C. obscurus, N. fresenii* and *E. neoaphidis* represent the four species of insect pathogenic fungi which have often been documented as the most common pathogens on aphids in annual cropping systems (Papierok and Havukkala, 1986; Feng *et al.*, 1991; Keller, 1987, 1991; Balazy, 1993; Steenberg and Eilenberg, 1995). The composition of species is therefore similar to several other aphid-pathogen systems. *Z. phalloides* is also known from aphids, but is more rare (Keller, 1991). In Denmark, this species has been isolated from cereal aphids (*Rhophalosiphum padi*), but only from one specimen on the winter host, *Prunus padi* (Eilenberg *et al.*, unpublished) This species may be specifically adapted to a forest ecosystem. *C. coronatus* is a generalist among Entomophthorales isolated from a range of insect species (Balazy, 1993).

The apparent uneven distribution of the fungal pathogens in *E. abietinum* populations may reflect local variations in time and space rather than general regional trends. Each aphid pathogen may differ significantly in abundance between year and locality, and dramatic changes between years have been experienced in cereal systems (Eilenberg *et al.*, unpublished), *E. neoaphidis* being common and prevailing one year and almost absent another year when *E. planchoniana* was present. More detailed studies are needed to clarify how population dynamics between host and pathogen develop in different countries. The conditions in the different systems studied were very different and, in some cases, very favourable for the fungal pathogens. It should, however, be noted that the overall prevalence of insect pathogenic fungi in *E. abietinum* in our study was rather low. Conditions needed to support the fungal pathogens to develop epizootics and thus reduce the populations of *E. abietinum* are so far unknown. An important factor may however be that the population levels of *E. abietinum* in general were low or locally moderate, and no outbreaks occurred.

The preliminary observations of the distribution of diseased aphids, the results of which do not fully agree with the only previous record (Day, 1984), point out the need for more detailed studies of the host-pathogen interaction. Also the possible interaction between *E. abietinum*, its fungal pathogens and other tree-dwelling aphid species deserves further studies to clarify if transmission of disease between *E. abietinum* and other species takes place and if such transmissions are important for the development of epizootics.

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