NAFC Publ. No. 1

Cone and Seed Diseases of North American Conifers

CFAN Publ. No. 1 COFAN Publ. No. 1

This report was published by the North American Forestry Commission (NAFC). The Commission, which is organized under the Food and Agriculture Organization of the United Nations, consists of the national forestry agencies from Canada, Mexico, and the United States. Specialists from these three countries meet in study groups to exchange technical information on such topics as insects and diseases, tree improvement, silviculture, atmospheric deposition, fire management, engineering, and light frame construction. Chairpersons and meeting locations of the study groups rotate among the three countries. This publication is available from any one of the following offices:

International Forestry Branch
Canadian Forestry Service
Government of Canada
Ottawa, Ontario K1A 1G5
CANADA

International Forestry Staff
Forest Service
Department of Agriculture
P.O. Box 96090
Washington, DC 20013-6090
USA

Director General de Normatividad Forestal
Progreso No. 5
Secretaria de Agricultura y Recursos Hidraulicos (SARH)
Mexico 21, D.F.
MEXICO

Ce rapport est publié par la North American Forestry Commission (NAFC). La Commission, qui relève de l'Organisation des Nations unies pour l'alimentation et l'agriculture, se compose des organismes nationaux de science forestière du Canada du Mexique et des États-Unis. Les spécialistes de ces trois pays se réunissent en groupes d'étude aux fins d'échange d'information technique portant sur des questions tel que: insectes et maladies, amélioration des essences, sylviculture, dêpôt atmosphérique, gestion des incendies, technogenie et construction légère à ossature de bois. Les présidents et les lieux de rencontre de ces groupes d'étude sont choisis à tour de rôle dans ces trois pays. On peut obtenir cet ouvrage d'un des bureaux ce-dessous:

Direction des Affaires internationales
Service canadien des forêts
Gouvernement du Canada
Ottawa, Ontario K1A 1G5
CANADA

International Forestry Staff
Forest Service
Department of Agriculture
P.O. Box 96090
Washington, DC 20013-6090
USA

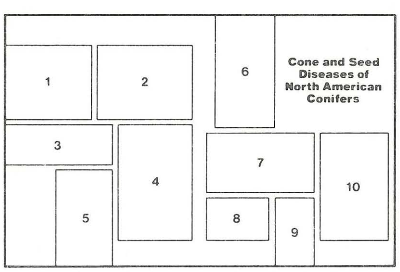
Director General de Normatividad Forestal
Progreso No. 5
Secretaria de Agricultura y Recursos Hidraulicos (SARH)
Mexico 21, D.F.
MEXICO

Este informe fué publicado por la Comision Forestal de América del Norte (COFAN). Esta Comision fué creada por la Organización para la Agricultura y la Alimentación (FAO) de las Naciones Unidas (ONU), y consiste de las agencias forestales nacionales de Canadá, Mexico y los Estados Unidos. Especialistas de estos tres paises se juntan en grupos de estudio para intercambiar información técnica sobre temas tales como insectos y enfermedades, mejoramiento genético, silvicultura, polución, manejo del fuego, ingeniería y contrucciones con marcos livianos. Los dirigentes de grupo y la ubicación de las reuniones se rotan entre los tres paises. Esta publicación se puede obtener de cualquiera de las siguientes direcciones:

International Forestry Branch
Canadian Forestry Service
Government of Canada
Ottawa, Ontario K1A 1G5
CANADA

International Forestry Staff
Forest Service
Department of Agriculture
P.O. Box 96090
Washington, DC 20013-6090
USA

Director General de Normatividad Forestal
Progreso No. 5
Secretaria de Agricultura y Recursos Hidraulicos (SARH)
Mexico 21, D.F.
MEXICO



COVER PHOTOS

1. *Pucciniastrum americanum* on white spruce cones (Maritimes Forest Research Centre, CFS).
2. Southwestern pine cone rust on the underside of *Quercus* sp. leaves (R. Salinas Quinard, Sec. Agr. Re. Hid.).
3. White spruce cone attacked by Inland spruce cone rust and coneworms (J.R. Sutherland, CFS).
4. Southwestern pine cone rust on *Pinus* sp. stem (B.H. Ebel, USFS).
5. Necrosis of loblolly pine cones caused by pitch canker (L.D. Dwinell, USFS).
6. Inland spruce cone rust on a white spruce cone (J.R. Sutherland, CFS).
7. *Chrysomyxa pirolata* on the underside of a *Pyrola asarifolia* leaf (J.R. Sutherland, CFS).
8. *Pucciniastrum americanum* on white spruce cones (Maritimes Forest Research Centre, CFS).
9. Southern cone rust on first-year cone of slash pine (T. Miller, USFS).
10. *Sirococcus* blight on a terminal shoot of lodgepole pine (J.R. Sutherland, CFS).

Cone and Seed Diseases of North American Conifers

Edited by

Jack R. Sutherland, Thomas Miller,
and Rodolfo Salinas Quinard

North American Forestry Commission
Publication Number 1

March, 1987

Victoria, British Columbia, Canada

ISSN 0835-3212
ISBN 0-662-15282-4
Cat. No. Fo29-18/1E

CONTENTS

PREFACE

In 1981, the 17th meeting of the Study Group on Forest Insects and Diseases, North American Forestry Commission, FAO, held in Acapulco, Mexico, approved the preparation of a publication on cone and seed diseases of North American conifers. The publication was prepared by plant pathologists familiar with cone and seed diseases in Canada, Mexico and the United States of America. The author(s) for each major section of this publication are acknowledged in footnotes in the text. Sections not credited as to source were prepared jointly by the first two editors. Contributors of pictures are given by name and affiliation in the legends to the figures.

ACKNOWLEDGEMENTS

We thank all the authors and other contributors to this publication. Special thanks are due M.L.N. Nams for compiling information on disease and host distributions and in preparing early drafts of certain sections of the publication. S.J. Hopkinson and T.A.D. Woods prepared several of the microphotographs and the scanning electron micrographs. Mark S. Griffin assisted with mounting photographs and correcting literature citations and figure legends. Daphyne Lowe and T.A.D. Woods did an outstanding job of proof reading. John C. Wiens did the layout and artwork and made innumerable suggestions for improvement. We acknowledge the support provided by the Canadian Forestry Service, Secretaria de Agricultura y Recursos Hidraulicos, Mexico, and the USDA Forest Service.

INTRODUCTION

Although North American foresters and forest pathologists have always been aware of certain cone and seed diseases, particularly cone rusts, it is only with the recent advent of seed orchards, tree improvement programs, and intensively managed forest nurseries that the importance of already-known and newly discovered diseases has been recognized. A major technological change that has spurred interest in cone and seed diseases has been the change from collecting cones from wild stands to the production of cone crops in seed orchards. There, the high value of the crop has increased the importance of diseases. Once management of trees for seed production became commonplace, foresters needed to protect their valuable crop from all losses, including diseases. Since it was in the southern United States that North America's first seed orchards were established, it was there that the importance of diseases such as southern pine cone rust was first recognized. As orchards have been established elsewhere on the continent, other diseases such as Inland spruce cone rust have been shown to be major impediments to cone production. Undoubtedly other diseases will become evident as the number of seed orchard species and their geographic distribution expands.

Just as seed orchards have made us realize the significance of diseases, the increasing demand for nursery stock and the development of new cultural systems such as container nurseries have demonstrated the importance of seed pathogens and seed-borne diseases. For example, precision sowing in bareroot nurseries has shown the extent of losses from seed fungi, while in containers, seed-borne pathogens such as *Sirococcus* blight have been recognized for the first time. The ever-increasing international trade in tree seeds is another development that has increased the interest in seed-borne fungi.

This publication summarizes information on the biology, description, distribution and, briefly, the detection and management of cone and seed diseases in Canada, Mexico and the United States of America. For disease (pathogen) and host distributions listings, U.S. state and Canadian province names follow the official two-letter postal code abbreviations; Mexican state names are spelled out. Disease distribution maps are included for most major hosts, e.g., the conifer hosts of the rusts. Where possible, we have tried to point out those diseases that occur or are likely to occur in seed orchards, which will supply most of the future seed needs. Our publication is a sequel to the earlier North American Forestry Commission bulletin, Cone and Seed Insects of North American Conifers.

Each section of this publication gives the life history, symptoms, signs, damage, and distribution on various hosts of the major cone and seed diseases of North American conifers. Distribution maps are included for both hosts and diseases, and colored figures and scanning electron micrographs highlight the distinguishing features of the pathogens and the diseases that they cause. At first mention in each section, the scientific names of the host plants are provided. Authorities for the host species are given in lists of hosts by scientific and common name near the end of the publication. A table of cone and seed diseases of minor importance gives information on diseases whose importance is not yet well documented. A glossary is included to assist readers with various terms. References in the text are cited by number. The section on detection and management gives only a broad overview because circumstances vary with hosts, diseases, and geographic location. Readers should consult local publications for specific situations, particularly for disease management recommendations, which may change from year to year.

Cone Diseases Caused by Rust Fungi

Inland spruce cone rust [1]

Chrysomyxa pirolata Wint.

This disease affects spruce (*Picea* spp.) cones across the North Temperate Zone of North America and Eurasia (203). In North America, the disease has severely damaged spruce cone crops in most areas of Canada (203) and in certain areas of the western United States (132). Recent evidence indicates that losses in spruce seed orchards equal or exceed those in wild stands. In the latter, control is not practical, but in seed orchards the high value and accessibility of the crop mandates that management strategies be developed for the disease. In the future, the importance of this disease will increase as spruce seed orchards are developed in high risk areas where the pathogen and both its conifer and nonconifer hosts are abundant and where weather and cultural practices are conducive to the disease.

Life history (28, 132, 155, 206) Figure 1.

Chrysomyxa pirolata is a heteroecious, full-cycled rust fungus that is annual and systemic or partially systemic in spruce cones and perennial and systemic in plants (including rhizomes) of wintergreens (*Pyrola* spp.) and single-delight (*Moneses uniflora*), the alternate hosts. Pycnia and aecia are produced on spruce cone scales, while uredinia and telia develop on the underside of leaves of wintergreen and single-delight. The perennial mycelium in the nonconifer hosts, and their repeated infection via urediniospores, assure the survival and spread of the rust independent of spruces.

Basidiospores produced on the alternate hosts infect cones in early summer (June), about pollination time. Pycnia develop on infected cones in early to midsummer (June-July) and are followed by aecia and aeciospores from midsummer through early fall (July-September). The wind-disseminated aeciospores infect the alternate hosts in summer and early fall. The next growing season, uredinia develop on wintergreen and single-delight, and urediniospores are disseminated from spring to early fall (May-September). The rust overwinters in the alternate host, and mature telia capable of producing basidiospores are formed in late spring to early summer (May-June).

Symptoms (132, 155, 168, 206)

In middle to late summer, diseased cones become light brown, dry, and open prematurely, liberating yellow-orange aeciospores (Figure 2). Healthy cones are green at this time. Cones may be either completely or partially infected. When the latter condition occurs, cone scales open prematurely on only part of a cone or on depressed, resinous areas of reduced development on one side of the cone. Such cones are slightly twisted and their scales are distorted.

Diseased wintergreen, and perhaps single-delight, exhibit atrophy over several years, become slightly chlorotic, and develop leaves that are more upright and whose upper surface is less shiny (dull green-gray) than those of healthy plants (Figure 3A and 3B).

Signs (168, 206) Table 1 and Figure 4.

In midsummer, pycnia and accompanying pycnial ooze develop on cone scales (Figure 5). Aecia are formed 2-4 weeks later and the powdery, yellow-orange aeciospores are released (Figure 2A and 2B). During epidemics, masses of aeciospores may produce a yellow-orange dust under spruce trees. Yellow-orange uredinial pustules develop on the undersurface of wintergreen and single-delight leaves in summer and early fall. Telia are light orange, changing to brown, and form in early summer on the same leaves as uredinia (Figure 6A and 6B) or on leaves without uredinia.

Damage (36, 62, 114, 132, 168, 179, 206)

Chrysomyxa pirolata causes sporadic, localized epidemics in the western United States. In contrast, the disease severely damages cones across Alaska and

---

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA.

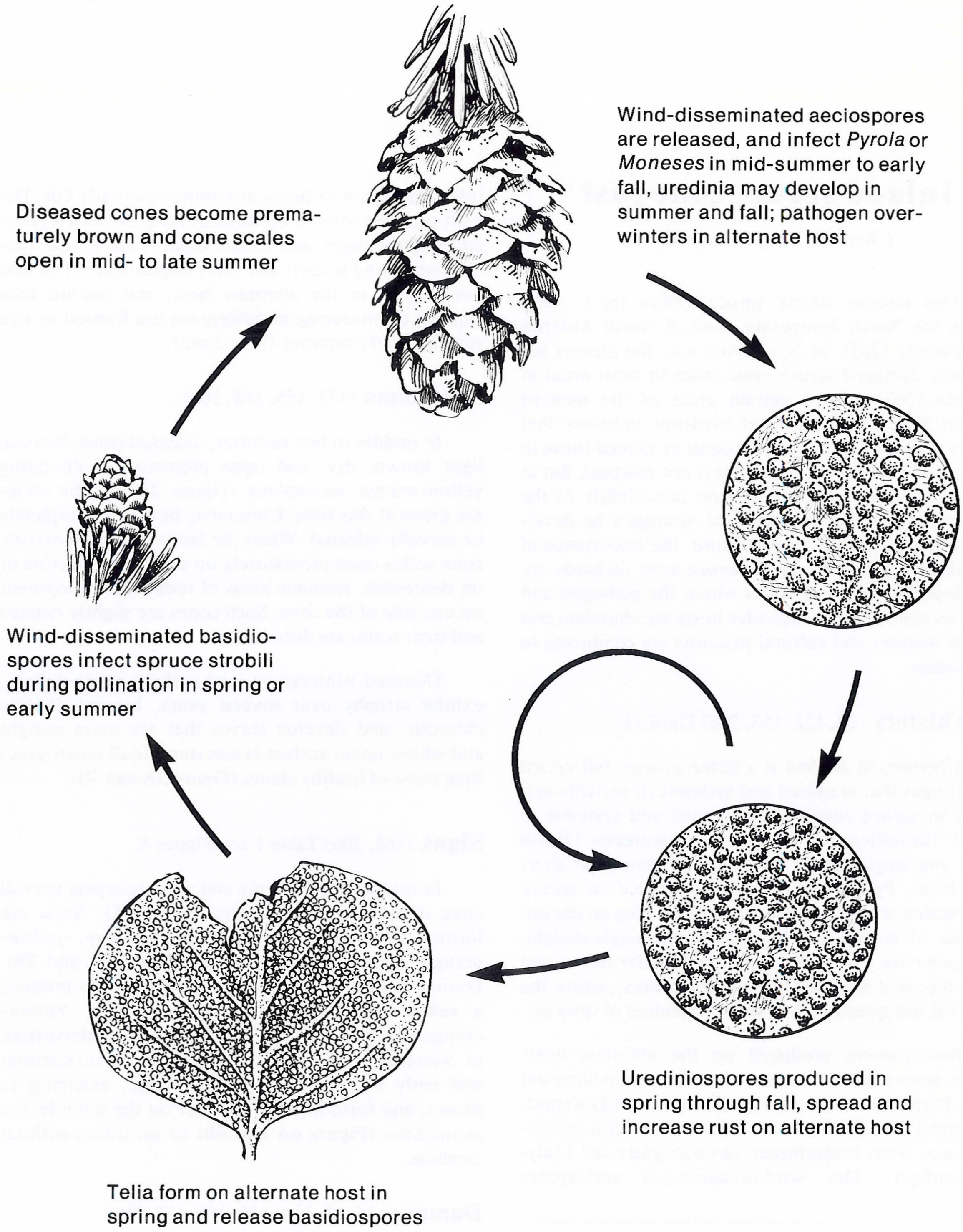


Figure 1. Disease cycle for Inland spruce cone rust, *Chrysomyxa pirolata*.

Figure 2. Inland spruce cone rust on white spruce cones. An open cone shedding yellow-orange aeciospores (A). Diseased cones dry out and open prematurely (B), shedding masses of yellow-orange aeciospores in middle to late summer, when healthy cones are still green (J.R. Sutherland, CFS).

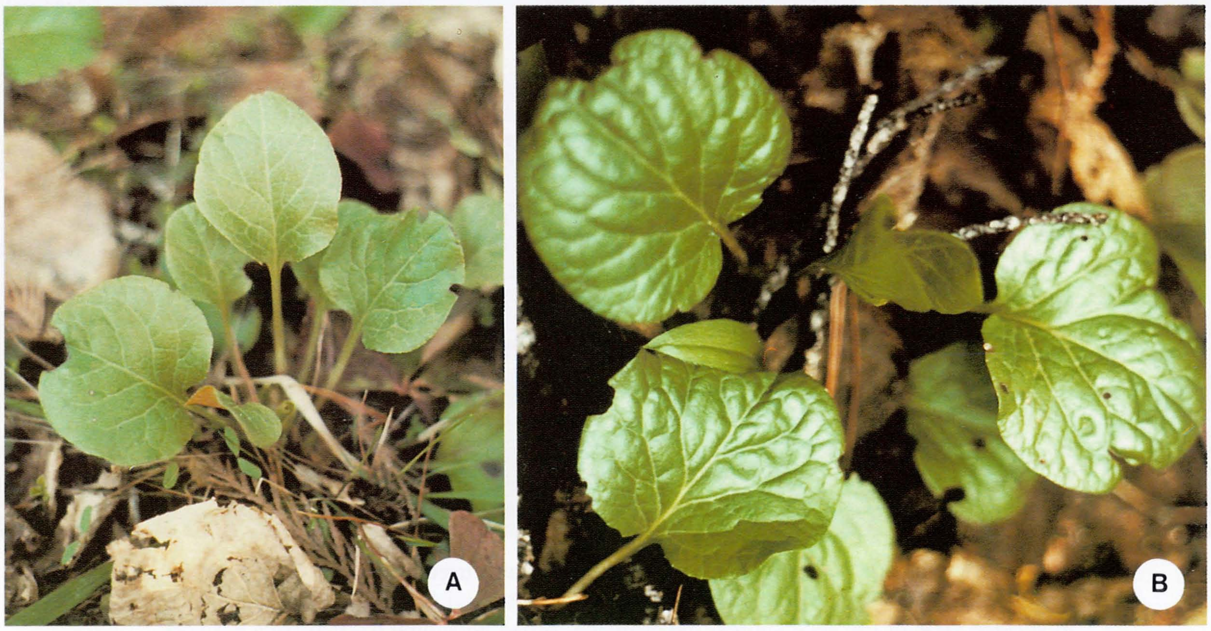


Figure 3. Inland spruce cone rust on *Pyrola asarifolia.* Diseased leaves (A) are slightly chlorotic, more erect, and the upper surface is less shiny than that of healthy (B) leaves (J.R. Sutherland, CFS).

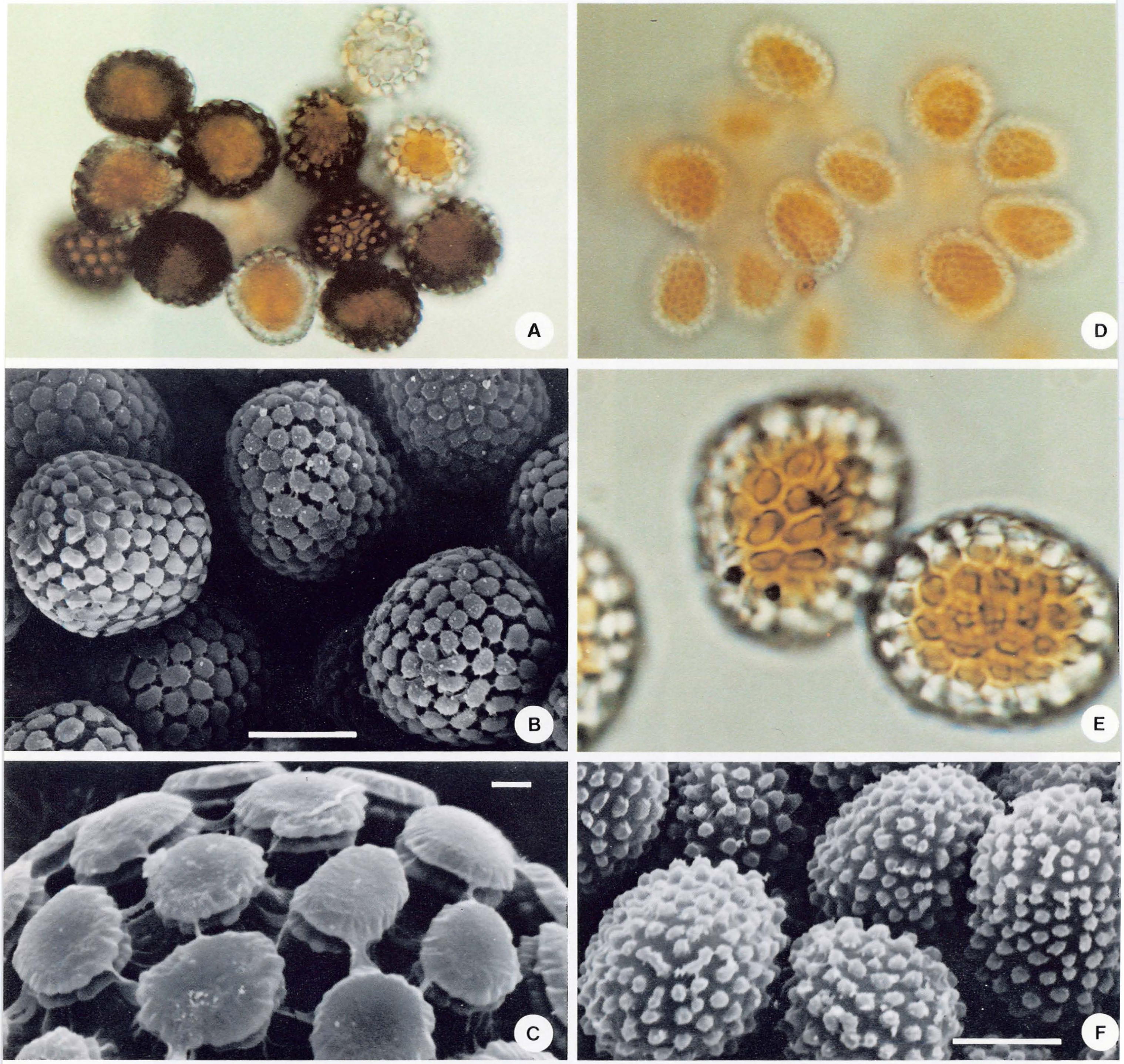


Figure 4. *Chrysomyxa pirolata* aeciospores (A,B and C) and urediniospores (D,E, and F). Note the short-columnar, crowded warts in median optical section of the aeciospores; in surface view of the aeciospores, the crowded, broad polygonal warts form a network (reticulum). Also note the similarities between aeciospores and urediniospores. Magnification: A=50X, B=2000X, bar is 10 μm long, C = 6600X, bar is 1 μm long, D = 50X, E = 125X and F = 2000X, bar is 10 μm long (J.R. Sutherland, CFS).

Figure 5. Yellow-orange spermagonia of Inland spruce cone rust on a white spruce cone. Ants and other insects may be involved in spermatization (J.R. Sutherland, CFS).

Canada, especially in western Canada. Light to severe damage (nearly all cones destroyed) is common in other Canadian provinces. Although damage may be localized, seed crops can be greatly reduced.

Usually no seeds form in diseased cones, but even when they are produced, cone malformation and resinosis hinder seed extraction or dispersal. Seeds from diseased white (*Picea glauca*) or blue (*P. pungens*) spruce cones weigh significantly less and have reduced or abnormal germination (Figure 7).

Distribution (28, 175, 206)

Chrysomyxa pirolata is holarctic, ranging from Greenland west to Alaska, throughout southern Canada and the northern United States, and southward in the western mountains to New Mexico, California, and Guatemala. It also occurs in Europe, Siberia (U.S.S.R.), Japan, and China.

Conifer hosts. This disease is common on Engelmann spruce (*Picea engelmannii*) in southcentral British

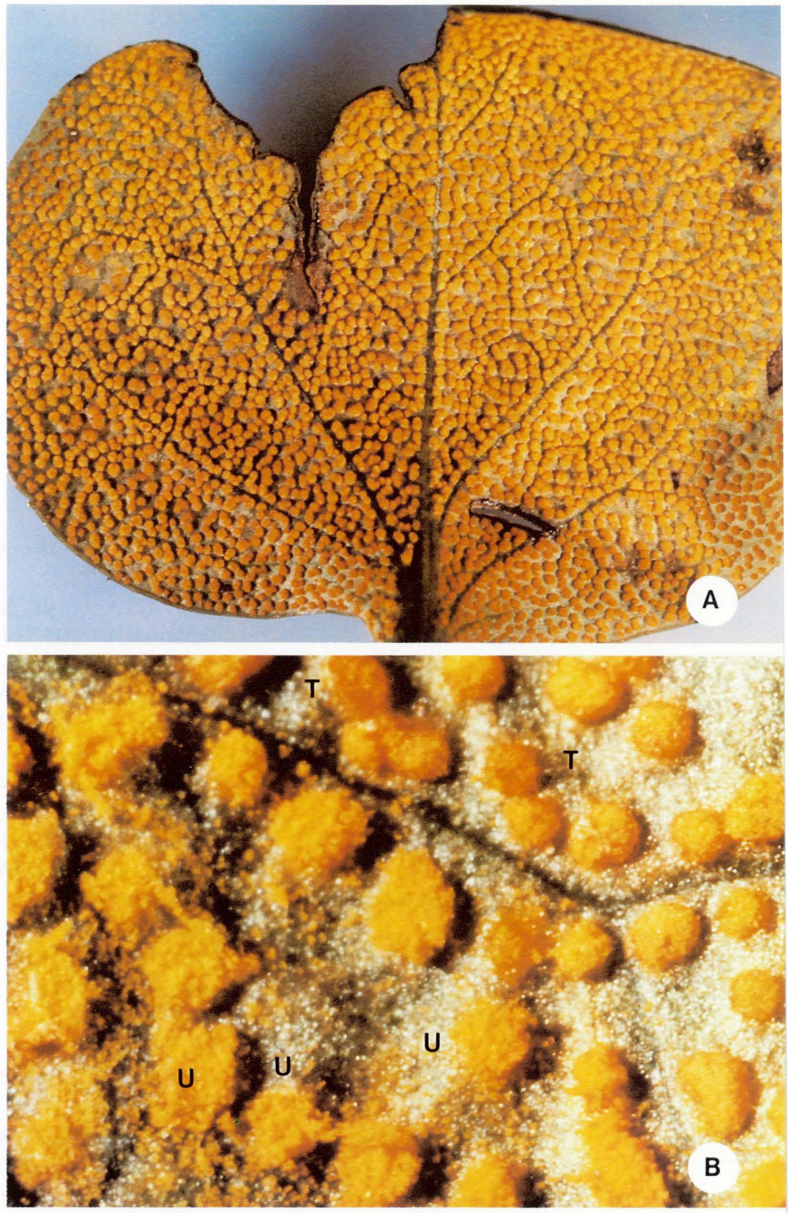


Figure 6. *Chrysomyxa pirolata* on *Pyrola asarifolia.* Undersurface of leaf with sori (A) (X0.85) and enlarged (B) (X2.5) showing uredinia (U) and telia (T) (J.R. Sutherland, CFS).

Figure 7. Abnormal germination of spruce seed from a cone affected by Inland spruce cone rust (J.R. Sutherland, CFS).

Columbia; southward in the Cascade Range to Oregon, and in the Rocky Mountains to Colorado (4, 37, 166, 188) Figure 8. On white spruce, it ranges from southern Alaska southward, mostly in the western mountains, to southeastern British Columbia and southwestern Alberta. The disease is rare on white spruce in the Canadian prairies and Quebec but common in the Great Lakes region, New Brunswick, Nova Scotia, and Prince Edward Island and Alaska (4, 37, 97, 188, 202). Figure 9. *Chrysomyxa pirolata* is scattered on black spruce (*P. mariana*) across Canada. It is most common on this host in central British Columbia, around the Great Lakes, and in the Atlantic provinces, but is reported occasionally in Alaska and New England (37, 97, 114, 168, 188) Figure 10. At times, the disease occurs on red spruce (*P. rubens*) in the Maritimes and New England states (4, 37, 188). Figure 11. It sometimes occurs on blue spruce in Alberta, British Columbia, and Utah (37, 132, 188) and infrequently on Sitka spruce (*P. sitchensis*) in coastal British Columbia and Alaska, including Kodiak Island (37, 39, 97). The disease has been reported on Norway spruce (*P. abies*) in Massachusetts (188).

Alternate or nonconifer hosts. Chrysomyxa pirolata is widespread on its alternate hosts in Canada and the northern and western United States. The nonconiferous hosts and distribution are:

Hosts	**Distribution**	**References**
Moneses uniflora	CANADA:AB,BC,MB,NT,PQ,YT	4,39,42,111,155
	USA:AK,CO,ID,ME,MI,MT, NM,WA,WY	166,188
Pyrola asarifolia	CANADA:BC,MB,NS,SK	4,9,39,111
	USA:AK,CA,CO,CT,DC,ID, MA,ME,MT,NH,NJ,NM, NY,OR,PA,UT,WA,WI	155,166
Pyrola dentata	CANADA:BC	9,111
Pyrola elliptica	CANADA:AB,MB,NS,ON,PQ	4,42,155
	USA:CT,IA,ME,MN,NH,NY,OH,PA	4,42,155
Pyrola grandiflora	CANADA:NT,YT	42,155,156
	USA:AK	39,42
Pyrola minor	CANADA:BC,PQ	4,39,142,155,166
	USA:AK,SD,WY	4,39,42
Pyrola picta	CANADA:BC	4,9,42,111,156,166
	USA:NM	28
Pyrola rotundifolia	CANADA:BC,MB,NS,ON,PQ,SK	4,9,42,111,155,166
	USA:MA,NH,NY	4,155
Pyrola secunda	CANADA:AB,BC,MB,NF,NS,NT,ON,PQ	4,9,39,42,111
	USA:AK,CO,ID,MI,MT,NM, NY,OR,PA,UT,WA	155,156,166
Pyrola virens	CANADA:AB,BC,NT,ON,PQ	4,9,39,42,66,111
	USA:AK,AZ,CO,MT,NY,WA,WY	155,156,166

Note: Reference (188) states that *Chrysomyxa pirolata* is widely distributed on pink wintergreen, *Pyrola asarifolia*; shinleaf, *P. elliptica*; Muguet de Bois, *P. rotundifolia*; and one-sided wintergreen, *P. secunda*, from Maine to Maryland, Iowa and Minnesota, and in the west from Montana to New Mexico, California and Alaska.

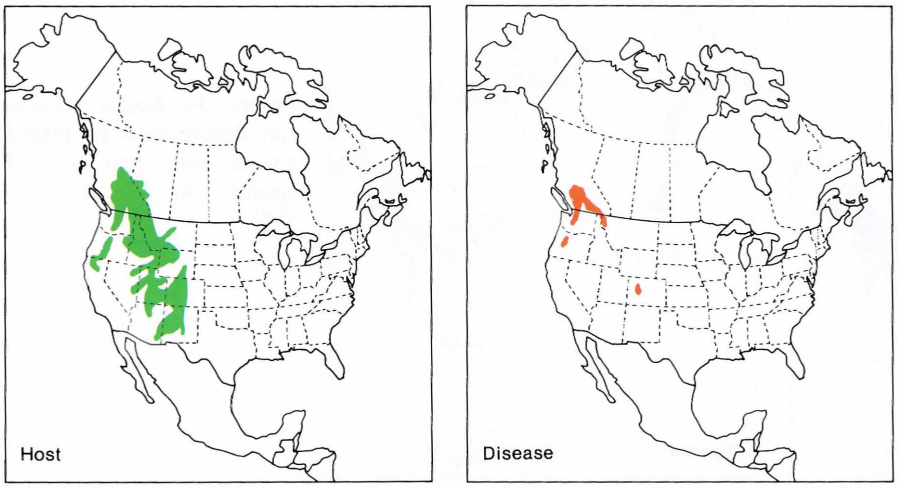


Figure 8. North American distribution of Inland spruce cone rust on Engelmann spruce. (4, 37, 90, 106, 166, 188).

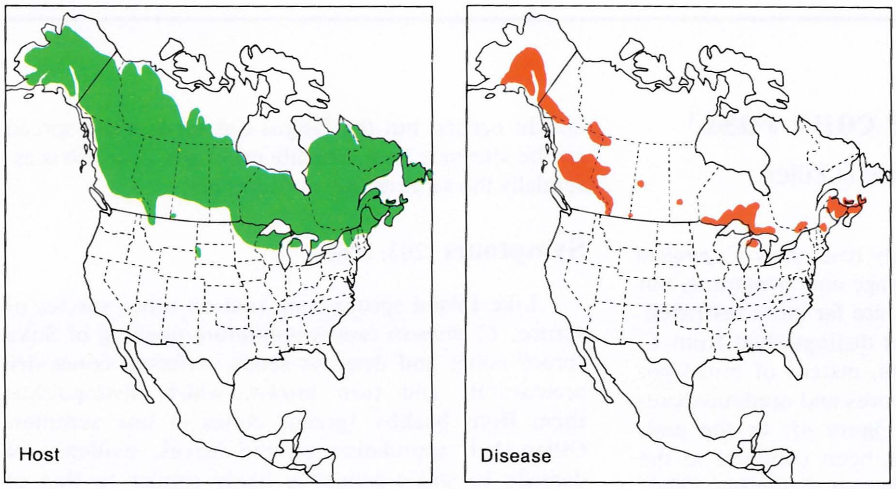


Figure 9. North American distribution of Inland spruce cone rust on white spruce. (4, 37, 74, 90, 97, 106, 107, 108, 133, 166, 202).

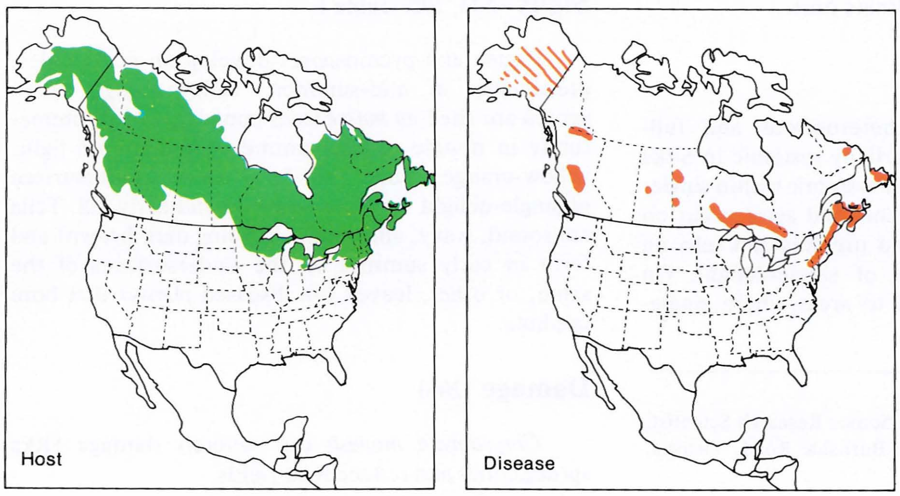


Figure 10. North American distribution of Inland spruce cone rust on black spruce. (37, 90, 97, 106, 114, 188).

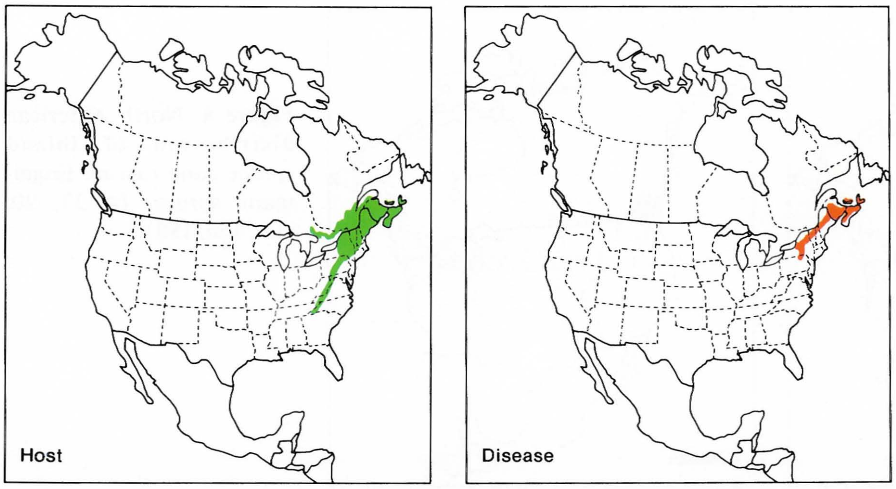


Figure 11. North American distribution of Inland spruce cone rust on red spruce. (4, 37, 90, 106, 188).

Coastal spruce cone rust[1]

Chrysomyxa monesis Ziller

Chrysomyxa monesis closely resembles *C. pirolata* in life history (Figure 1), damage and symptoms, but its host range and distribution are far more restricted. Morphologically, *C. monesis* is distinguished from *C. pirolata* by narrow fluted warts, instead of broad polygonal warts, on both aeciospores and urediniospores (Figure 12) (compare with Figure 4). In the past, losses from this disease have been confined to the Queen Charlotte Islands of British Columbia (206), but the disease may be considered a threat wherever Sitka spruce (*Picea sitchensis*) occurs naturally or is planted in proximity to the alternate host.

Life History (203, 206)

Chrysomyxa monesis is heteroecious and full-cycled, annual, systemic or partially systemic in Sitka spruce cones, and perennial and systemic within single-delight (*Moneses uniflora*). Pycnia and aecia occur on cone scales of Sitka spruce and uredinia and telia on the lower surface of leaves of single-delight. On spruce, the disease is limited to areas where single-delight occurs, but the fungus can survive and spread on the alternate host. The life cycle of *C. monesis* is essentially the same as that of *C. pirolata*.

Symptoms (203, 206)

Like Inland spruce cone rust on other species of spruce, *C. monesis* causes premature opening of Sitka spruce cones and destroys seeds. Affected cones dry prematurely and turn brown, which distinguishes them from healthy (green) cones in late summer. Other than sporulation on the leaves, evidence of damage to single-delight is likely similar to that of Inland spruce cone rust on its nonconifer hosts.

Signs (203, 206) Table 1.

Pycnia and pycniospores develop on cone scales, presumably in mid-summer. Yellow-orange aeciospores are shed *en masse* from cones that open prematurely in middle to late summer. Uredinia are light, yellow-orange, round, and form on the undersurface of single-delight leaves in summer and early fall. Telia are round, waxy, and yellow (turning dark brown) and form in early summer on the undersurfaces of the same, or other, leaves (on diseased plants) that bore uredinia.

Damage (206)

Chrysomyxa monesis can severely damage Sitka spruce cones and reduce seed yields.

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA.

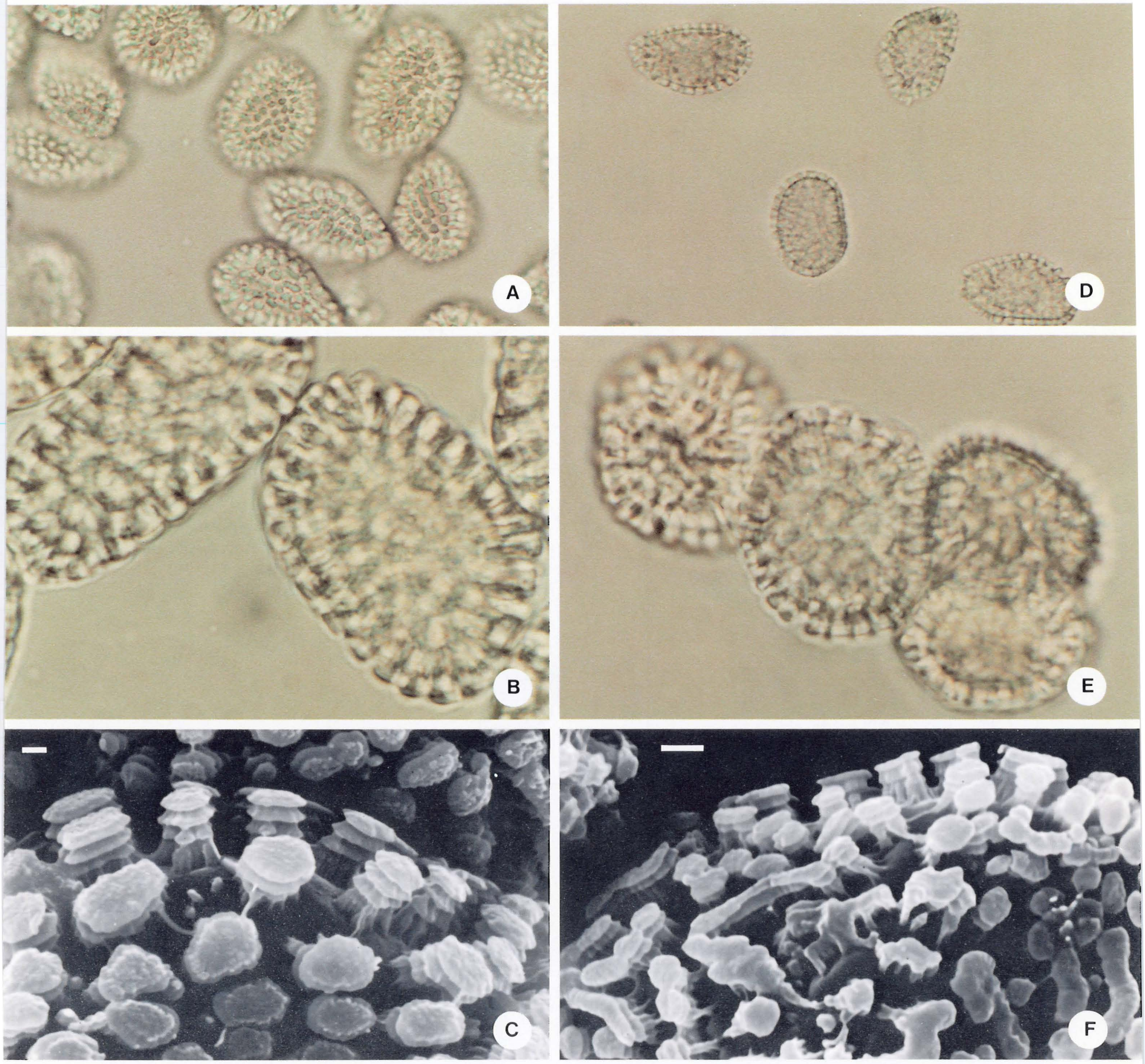


Figure 12. *Chrysomyxa monesis* aeciospores (A, B, and C) and urediniospores (D, E and F). Note the columnar, fluted and truncate warts in median optical section of the aeciospores; in surface view of the aeciospores the warts appear stellate or lobate. *Chrysomyxa monesis* is distinguished from *C. pirolata* by narrow fluted warts, instead of broad polygonal warts (Fig. 4) on both the aeciospores and urediniospores. Magnifications: A = 50X, B = 125X, C = 5000X, bar is 1 μm long, D = 50X, E = 125X, and F = 2000X, bar is 1 μm long (J.R. Sutherland, CFS).

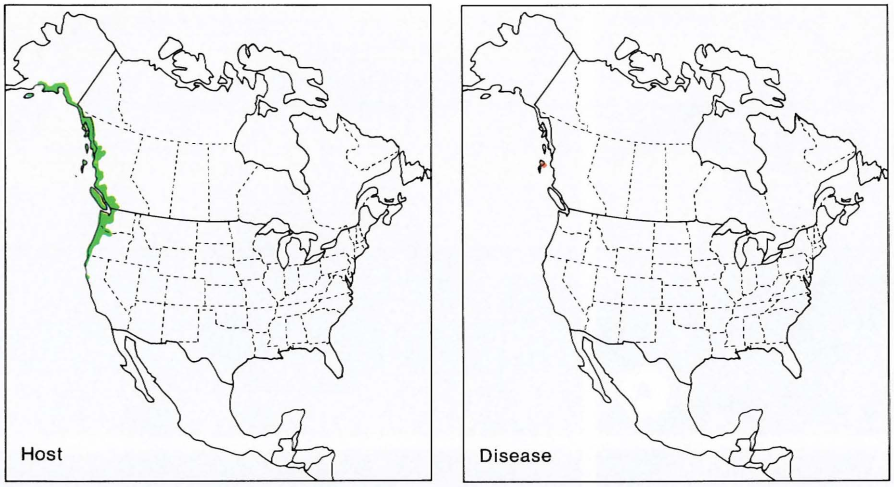


Figure 13. North American distribution of Coastal spruce cone rust on Sitka spruce. (9, 37, 82, 90, 106, 156, 203, 206).

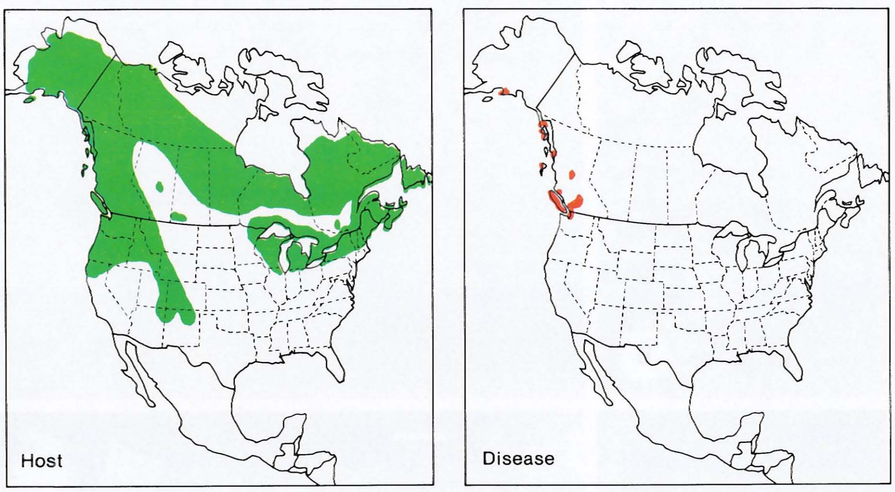


Figure 14. North American distribution of Coastal spruce cone rust on single-delight. (9, 37, 91, 156, 161, 203).

Distribution (9, 37, 82, 203)

Chrysomyxa monesis is a north Pacific coastal species, ranging from Alaska to southern British Columbia, and occasionally inland in British Columbia on its alternate host single-delight (156). On its sole conifer host, Sitka spruce, the disease occurs only in the Queen Charlotte Islands, British Columbia (206). Figures 13 and 14.

Southern pine cone rust [1]

Cronartium strobilinum (Arth.) Hedgc. & Hahn

This disease sporadically causes severe losses of first-year strobili of susceptible pine species in both natural stands and seed orchards in certain areas of the southern United States. The disease occurs only in those areas of the Atlanta and Gulf Coastal Plain where the susceptible pine hosts and the alternate hosts (evergreen *Quercus* sp.) grow in proximity. Southern cone rust has been known to occur in the southern U.S. for nearly 100 years, but only since the development of commercial pine seed orchards has its importance has been fully recognized. In addition to the direct losses caused by the disease, there is a destructive interaction with coneworms, which cause additional losses of both first- and second-year strobili.

Life History (77, 79, 80, 94, 120, 121) Figure 16.

Cronartium strobilinum is a heteroecious, full-cycled rust with pycnia and aecia produced annually on first-year female strobili of slash (*Pinus elliottii* var. *elliottii*) and longleaf (*P. palustris*) pines, and uredinia and telia produced annually on deciduous and evergreen oak leaves and perhaps perennially on the leaves of the evergreen species. The pathogen develops very rapidly in the strobili, and produces pycnia and aecia within 4 months of infection.

Under proper temperature and humidity conditions, basidiospores that are produced from telia on oak leaves may infect pine strobili in late winter (December-February), from the time strobili emerge from the bud scales until the scales close after pollination. Pycnia develop from 4-6 weeks after infection (March-April) followed by aecia and aeciospores, which are typically formed several weeks after the pycnia (April-May). At maturity, the aecia rupture through the infected scales, and the bright-orange aeciospores are exposed to wind and rain dissemination.

Susceptible leaves of both deciduous and evergreen oaks may be infected by the aeciospores in late spring and early summer. The disease is intensified on the oaks by the formation of urediniospores, which develop from early summer into the late fall. In some years, uredinia and urediniospores may still be present in the late winter, when pine strobili are forming. Telia first appear in early fall and reach full maturity on the evergreen oaks in winter (late November-January). The telia produce the basidiospores that infect susceptible strobili.

Symptoms (79, 94, 121)

Strobili infected by *C. strobilinum* undergo hypertrophy, rapidly becoming 3-4 times normal size (Figure 15); the internal tissues are disrupted, and the bases of adjoining scales become fused. Prior to aecial eruption, the infected cone scales become reddish-orange. After aeciospore production, the cones rapidly desiccate, turn reddish-brown and fall from the tree.

Signs (77, 79) Table 1 and Figure 17.

Pycniospores are exuded from enlarged cone scales in viscid, amber-colored droplets that are strongly attractive to certain insects. The aecia are formed in the tissues beneath the pycnia. The infected cones become highly visible when the aecia rupture the cone scales and expose the bright-orange aeciospores (Figure 15). The small, yellow-orange uredinia develop on the undersides of oak leaves and may be highly visible from early summer into late winter. The hair-like, brown telial columns develop on the underside of

Figure 15. Southern cone rust on first-year cone of slash pine with the ruptured cone gall surface exposing masses of yellow-orange aeciospores. Healthy cone at arrow. (T. Miller, USFS).

[1] Prepared by T. Miller, Research Plant Pathologist, USDA Forest Service, Southeastern Forest Experiment Station, Department of Forestry, University of Florida, Gainesville, Florida 32611, U.S.A.

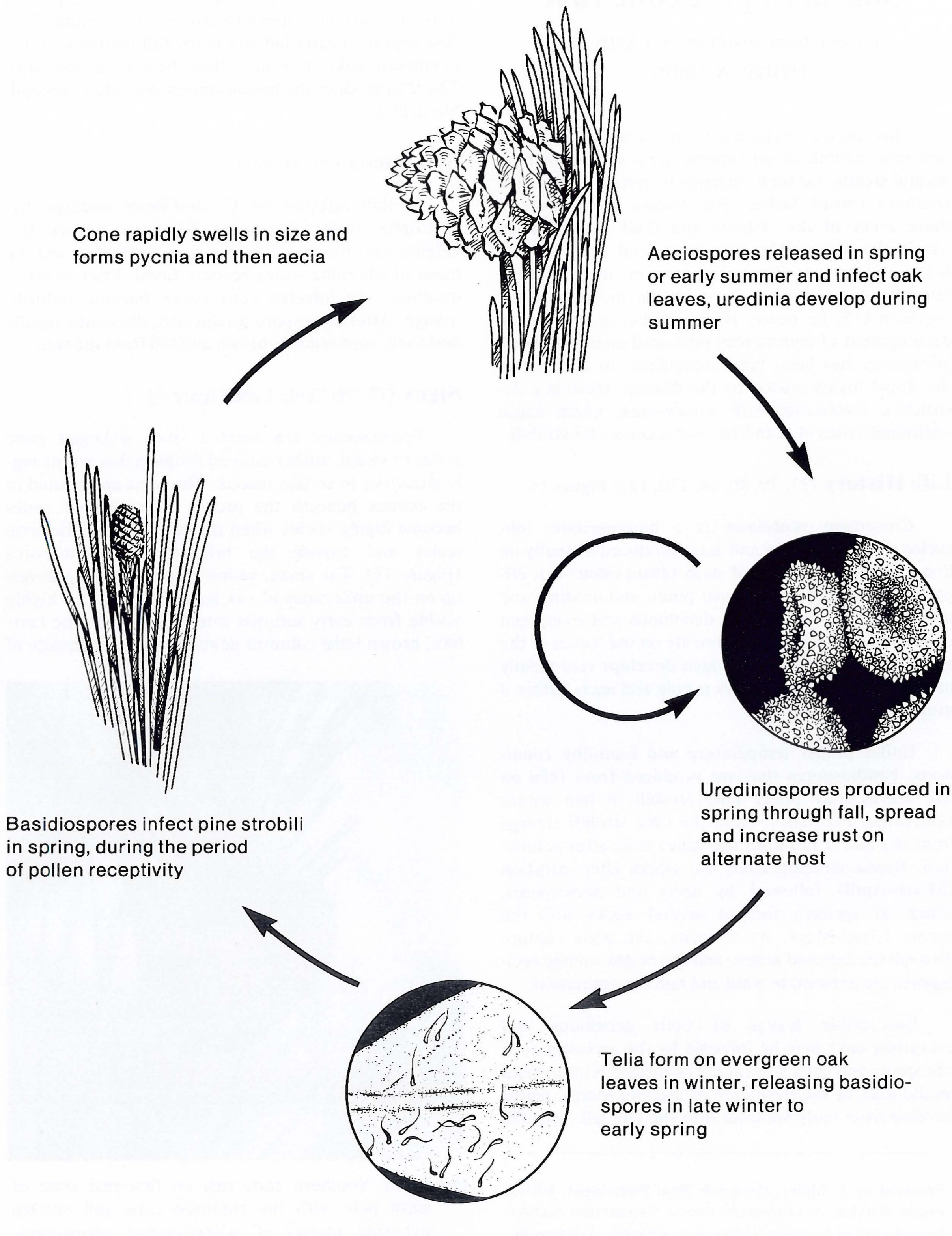


Figure 16. Disease cycle for southern pine cone rust, *Cronartium strobilinum.*

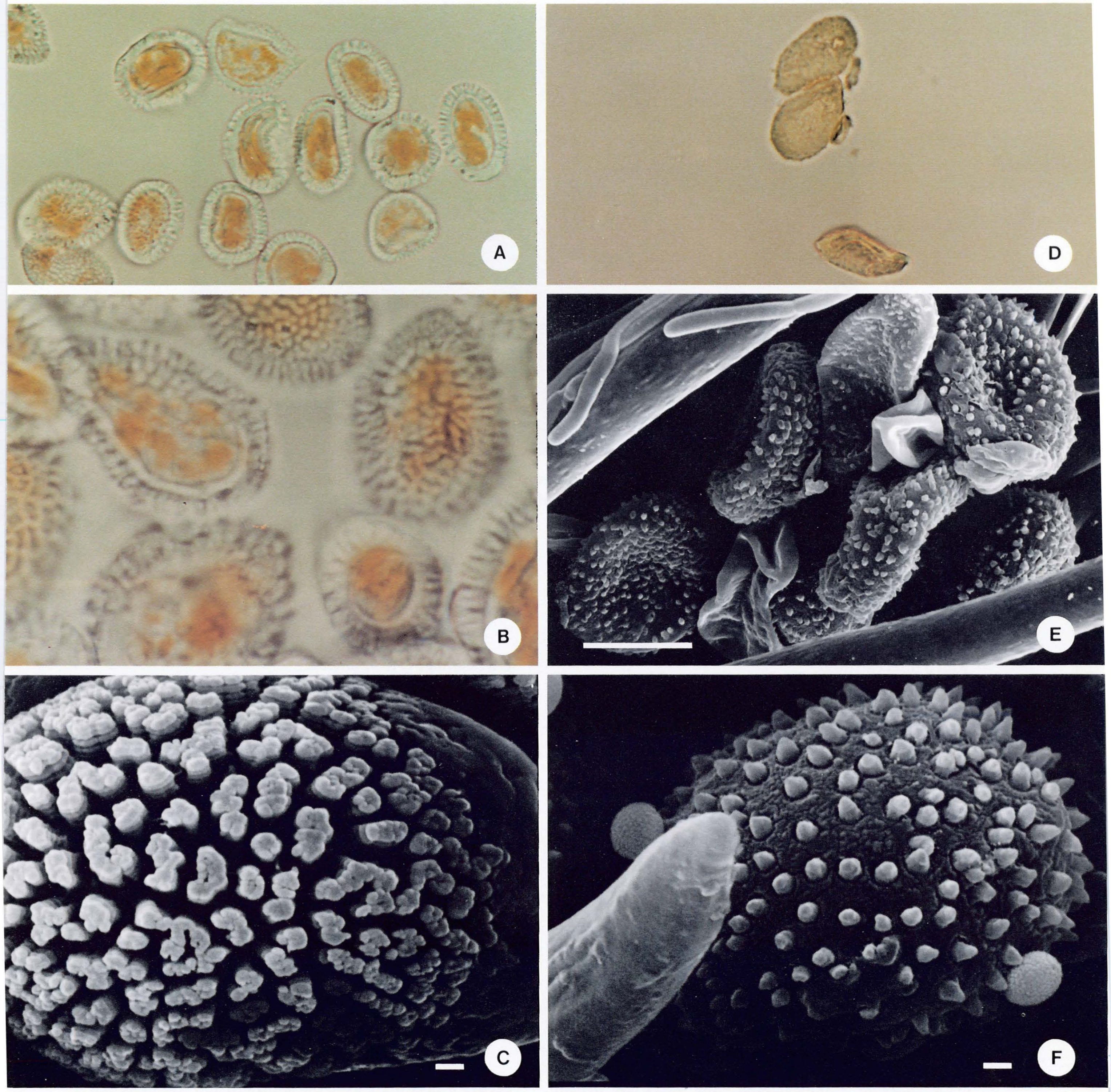


Figure 17. *Cronartium strobilinum* aeciospores (A, B and C) and urediniospores (D, E and F). Magnifications: A = 50X, B = 125X, C = 5000X, bar is 1 μm long, D = 50X, E = 2000X, bar is 10 μm long, and F = 5000X, bar is 1 μm long. The tubular structures in E and F are trichomes from oak leaves (J.R. Sutherland, CFS).

Figure 18. Brownish telia (at arrows) and yellow-orange uredinia of *Cronartium strobilinum* on the underside of a live oak leaf (A.T. Drooz, USFS).

the evergreen oak leaves and may be visible as early as October but reach maturity in late winter (Figure 18). Under proper conditions of humidity and temperature, the teliospores germinate to produce the basidiospores, which infect strobili.

Damage (77, 79, 117, 120, 121)

The ultimate damage caused by southern pine cone rust is the loss of potential seed production from infected cones. While the disease alone can cause cone mortality, equally important losses result from the interaction between the disease and coneworms (*Dioryctria* spp.), especially the south coastal coneworm, *D. ebeli* Mutuura & Munroe. Populations of this coneworm build up in rusted conelets, and larvae migrate throughout a tree attacking healthy cones.

In the southeastern United States, this disease can greatly reduce seed yields. Periodic losses of first-year slash pine cones in Georgia and Florida have been serious, averaging 20% in the 1960's, with losses sometimes up to 90%. Heavy losses elsewhere (Alabama and Mississippi Gulf Coast and further east) have been more sporadic. Longleaf pine cone losses are usually less severe. Epidemics occur where the susceptible pine species are associated with evergreen oaks, especially live oak (*Quercus virginiana* var. *virginiana*) and sand live oak (*Q. virginiana* var. *geminata*) and when temperature and humidity conditions are optimum for infection by the different spore forms.

Although infection of oak leaves may occur annually, damage is insignificant.

Distribution

Conifer hosts. Slash pine, south Florida slash pine (*P. elliottii* var. *densa*), and longleaf pine are affected in the southeastern United States. On slash pine and south Florida slash pine, the range is from southeastern South Carolina southwest along the Gulf Coast to southeastern Louisiana and central Florida (28, 77, 79, 82, 85, 94, 117, 120, 121, 122, 188). Figure 19. On longleaf pine, it ranges from eastern North Carolina southwest along the Gulf Coast to Louisiana (and Texas?) and central Florida (28, 77, 79, 82, 85, 94, 117, 120, 121, 122, 188). Figure 20. Distribution of *C. strobilinum* on pines is determined largely by the presence of the principal alternate hosts, live oak and sand live oak (82, 117, 186).

Alternate or nonconifer hosts. Cronartium strobilinum occurs widely on oaks in the southern and southeastern U.S. and uredinia of the fungus have been identified on certain species in the central U.S.. The nonconifer hosts and distributions are:

Hosts	Distribution	References
Quercus alba	USA : AR,IL,LA,MS,NC	79,188
Quercus bicolor	USA : NC	79
Quercus chapmanii	USA : FL	79
Quercus ilicifolia	USA : GA,NC; Southeastern and Gulf Coast	79,85,117
Quercus incana	USA : NC,TX	79
Quercus laevis	USA : MS	79
Quercus laurifolia	USA : FL	79,188
Quercus macrocarpa	USA : IA,KS,MO	79,188
Quercus myrtifolia	USA : FL	79
Quercus nigra	USA : FL,MS,TX	28,79,188
Quercus phellos	USA : Southeastern and Gulf Coast	82
Quercus prinus	USA : VA	79
Quercus stellata	USA : AR,FL,MS,NC,SC,TX	79,188
Quercus virginiana var. *virginiana*	USA : FL,LA,MS,NC,TX	79
Quercus virginiana var. *geminata*		79

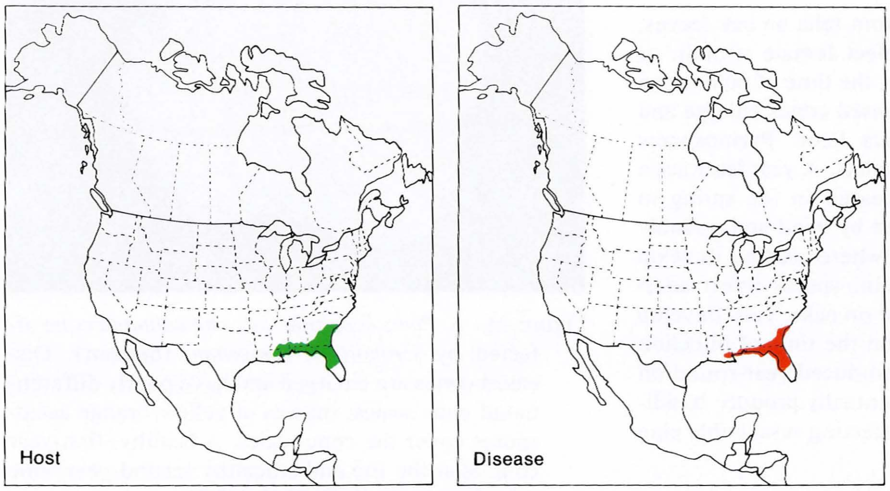


Figure 19. North American distribution of southern pine cone rust on slash pine. (28, 77, 79, 82, 85, 94, 106, 117, 120, 121, 188).

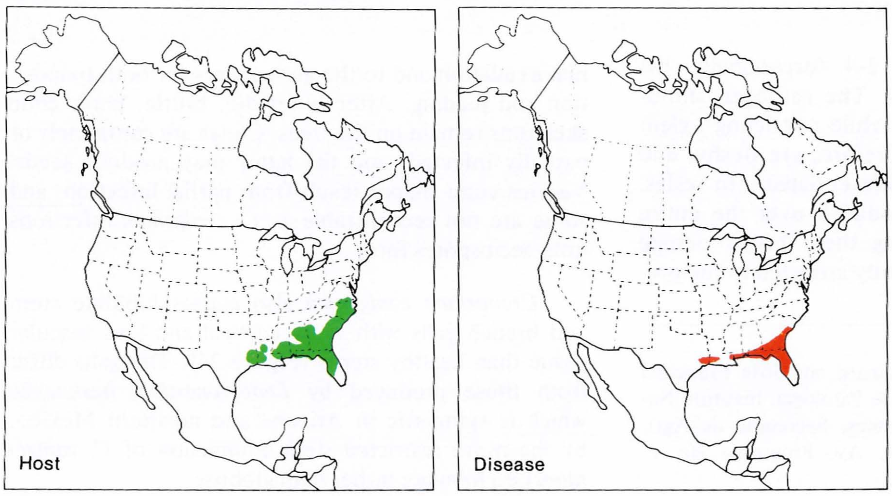


Figure 20. North American distribution of southern pine cone rust on longleaf pine. (28, 77, 79, 82, 85, 94, 106, 117, 120, 121, 188).

Southwestern pine cone rust[1]

Cronartium conigenum Hedgc. & Hunt

This disease, which affects cones, branches and stems, is the only major cone disease in Mexico. To date, the disease has been reported only on trees in the forest, but it has the potential to cause severe losses in seed orchards because it attacks both the cones and vegetative growth of its hosts.

Life History (78, 79, 146, 157) Figure 22.

Cronartium conigenum is heteroecious and full-cycled, with pycnia and aecia on cones or stems, and uredinia and telia on oak leaves. Cone infections are thought to be biennial and completely or partially systemic while stem and branch infections are often perennial. The pathogen is systemic in both deciduous and evergreen oak leaves.

Basidiospores, produced from telia on oak leaves, are wind-disseminated, and infect female strobili, or pine stems, in the spring, about the time of pollination and shoot elongation. The diseased cones enlarge and pycnia are produced 1-2 years later. Pycniospores exude from cones in viscid droplets. A year later aecia form. The aeciospores are released in the spring to early summer and disseminated by wind and possibly by rain. They infect oak leaves, where uredinia develop during the summer. The urediniospores infect additional leaves and spread the rust on oaks. Telia develop in summer or fall, depending on the time of infection by urediniospores, which are produced year-round on evergreen oak leaves. Telia eventually produce basidiospores, which are capable of infecting susceptible pine tissues.

Symptoms (78, 79, 143, 146)

Diseased cones become 2-4 (occasionally 10) times normal size (Figure 21). The pathogen stimulates parenchyma production, while restricting xylem and sclerenchyma. Cones, therefore, are fleshy, and their surface is only slightly differentiated into scales. Aecia and aeciospores are produced over the entire surface area of cones, making them bright orange (Figure 23). Insects are frequently attracted to the pycnial exudation and to the aeciospores for both oviposition and feeding. After cones die, brittle, hard, cone skeletons remain on the trees. Cones are completely or partially infected, and the latter may produce seeds. Various cone shapes result from partial infection, and some are not recognizable as *C. conigenum* infections until aeciospores form.

Figure 21. A *Pinus leiophylla* var. *chihuahuana* cone affected by *Cronartium conigenum* (bottom). Diseased cones are enlarged and have poorly differentiated cone scales; masses of yellow-orange aeciospores cover the cone scales. A healthy, first-year cone is at the top and a healthy second-year cone is in the middle (B.H. Ebel, USFS).

Cronartium conigenum also causes lobulate stem and branch galls with more cortical and less vascular tissue than healthy stems (Figure 24). The galls differ from those produced by *Endocronartium harknessii*, which is sympatric in Arizona and northern Mexico, by the more restricted stem connection of *C. conigenum*; i.e., lobulate rather than globose.

[1] Prepared by Rodolfo Salinas Quinard and Jose Francisco Resendiz Martinez, Laboratoro de Patologia, Instituto Nacional de Investigaciones Forestales, Secretaria de Agricultura y Recursos Hidraulicos, Av. Progresso No. 5, Coyoacan 21, D.F., MEXICO.

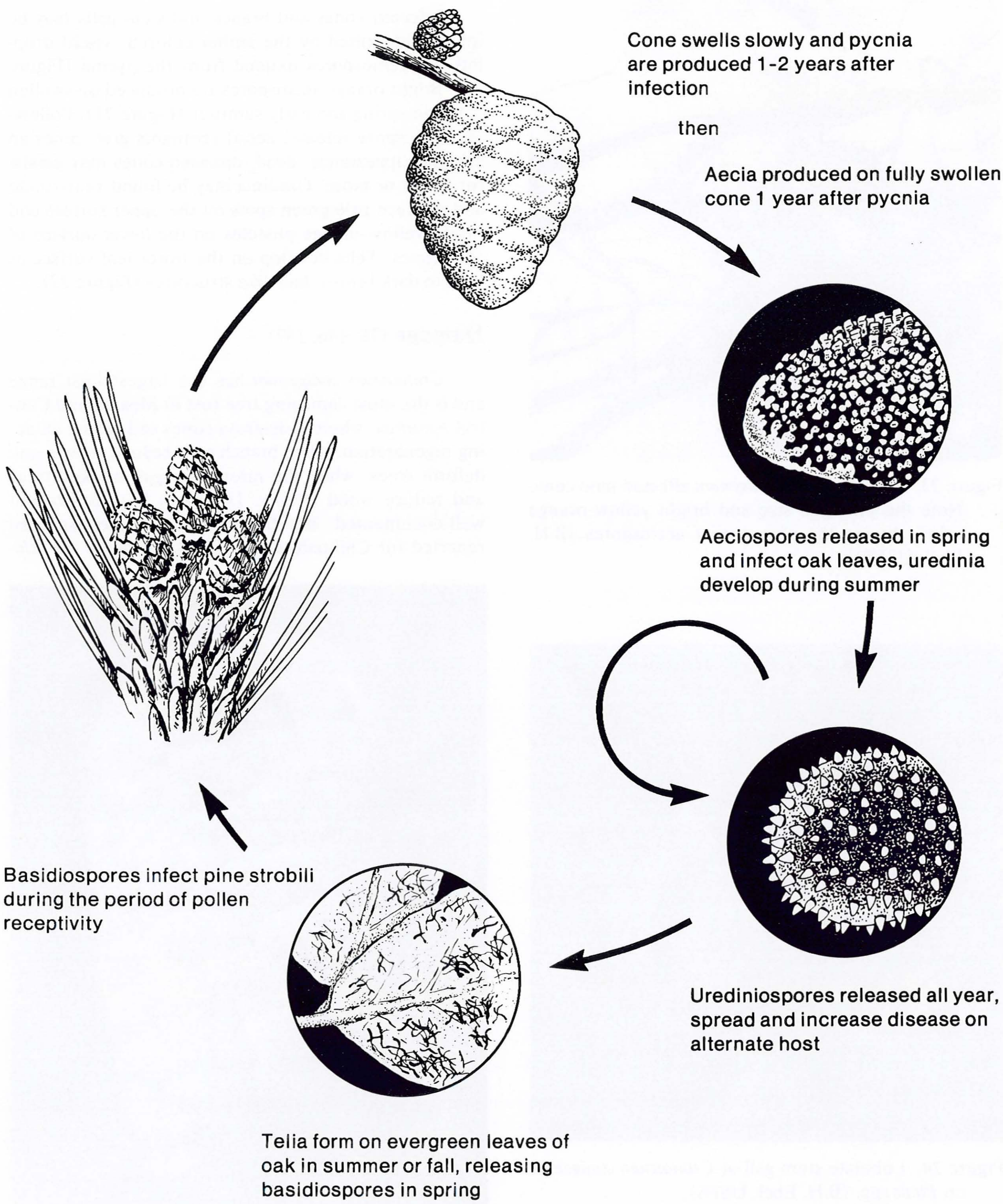


Figure 22. Disease cycle for southwestern pine cone rust, *Cronartium conigenum.*

Figure 23. A *Cronartium conigenum* affected pine cone. Note the enlarged size and bright yellow-orange color, due to the presence of aeciospores (B.H. Ebel, USFS).

Figure 24. Lobulate stem gall of *Cronartium conigenum* on *Pinus* spp. (B.H. Ebel, USFS).

Signs (78, 157) Table 1 and Figure 26.

Infected cones and branch and stem galls may be initially identified by the amber-colored, viscid droplets of pycniospores exuded from the pycnia (Figure 25). Bright orange aeciospores are produced on swollen cones in spring and early summer (Figure 21). Following aeciospore release, aecial remnants give cones an ash gray appearance; dead, diseased cones may persist for a year or more. Uredinia may be found year-round and produce pale-green spots on the upper surface and bright yellow-orange pustules on the lower surface of oak leaves. Telia develop on the lower leaf surface as light to dark brown, hair-like structures (Figure 27).

Damage (78, 146, 157)

Cronartium conigenum has the largest host range and is the most damaging tree rust in Mexico and Central America, where it destroys cones and seeds, reducing regeneration. Also, branch galls reduce growth and deform trees, while the rarer stem gall weaken trees and reduce wood quality. Losses in Mexico are not well-documented, but heavy cone damage has been reported for Chihuahua pine (*Pinus leiophylla* var. *chi-*

Figure 25. *Cronartium conigenum* pycniospores exude in droplets (arrows) 1 – 2 years after cone infection (B.H. Ebel, USFS).

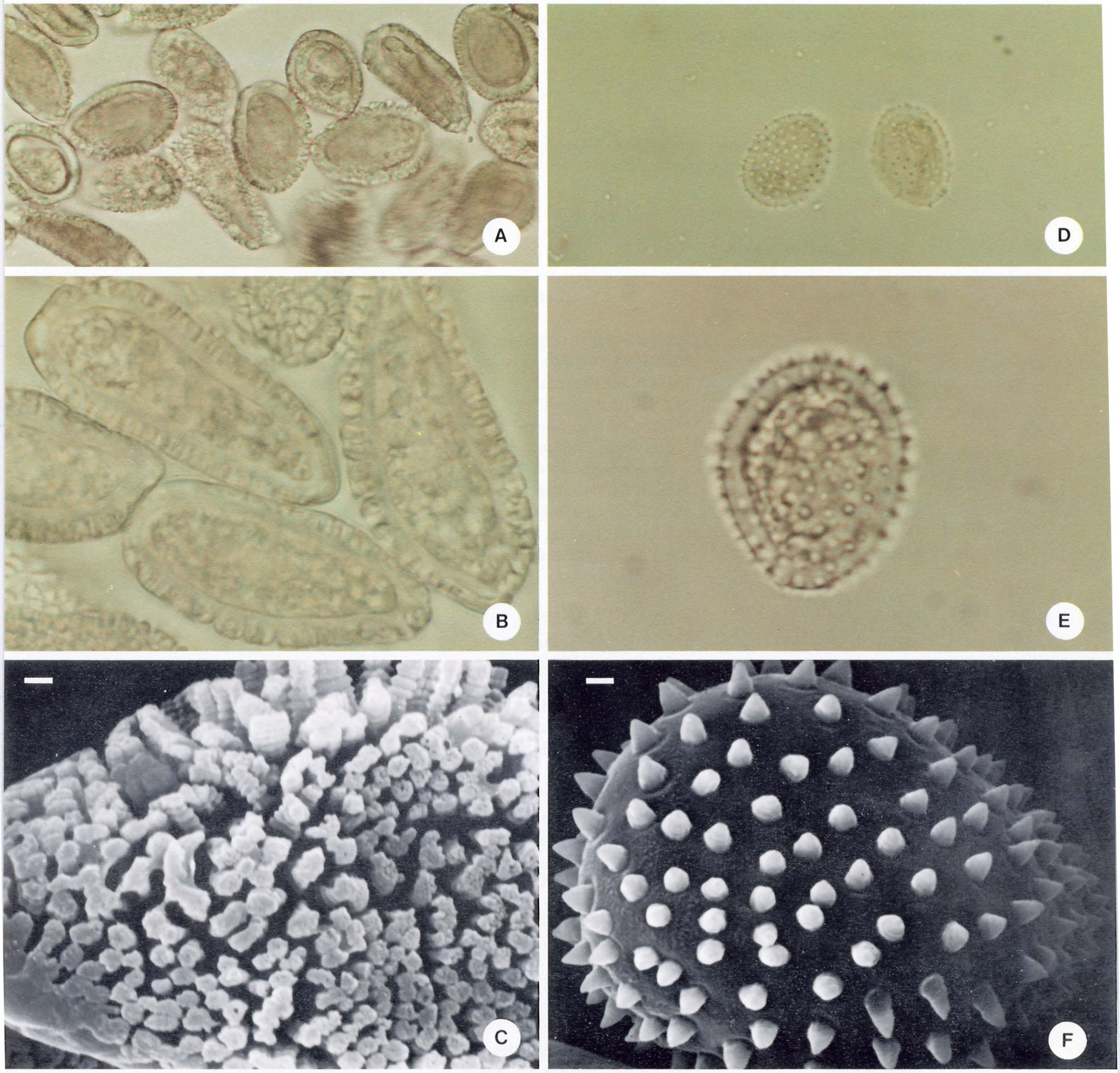


Figure 26. *Cronartium conigenum* aeciospores (A, B and C) and urediniospores (D, E and F). Note the thick cell wall on both types of spores and that annuate knobs consist of numerous cushion-like discs stacked on top of one another (upper portion of C and middle of F). Magnifications: A = 50X, B = 125X, C = 5000X, bar is 1 μm long, D = 50X, E = 125X and F = 5000X, bar is 1 μm long (J.R. Sutherland, CFS).

huahuana) in Arizona, and Montezuma pine (*P. montezumae*) and wheelbarrow torchwood pine (*P. oocarpa*) in Guatemala.

Distribution

Cronartium conigenum occurs throughout Mexico and Central America on many pines and oaks (41, 56, 79, 146, 175). In the United States it is restricted to southern Arizona on Chihuahua pine and several oaks. (66, 78, 79, 82, 144, 146, 188). The most common Mexican host is Chihuahua pine. Figure 28. Although documentation is poor, the hosts and general distribution are:

Conifer hosts

Hosts	Distribution	References
Pinus attenuata	MEXICO : Baja California Sur	152
Pinus ayacahuite	MEXICO : Hidalgo, Veracruz	152
Pinus cembroides	MEXICO : Veracruz	152
Pinus cooperi	MEXICO : Durango	56,146
Pinus durangensis	MEXICO : Michoacan, Sonora Durango, Chihuahua	146
	(also British Honduras)	(59)
Pinus engelmannii	MEXICO : Durango	152
Pinus greggii	MEXICO : Coahuila	152
Pinus hartwegii	MEXICO : Puebla, D.F., Mexico,	56,146,152
Pinus lawsonii	MEXICO : Michoacan, Guerrero Puebla, Oaxaca	146
Pinus leiophylla var. *chihuahuana*	USA : AZ	28,56,66,78,79,82
	MEXICO : Chihuahua, Durango, Hidalgo, Mexico, Michoacan, Puebla	144,146,152,175,188
	(also Guatemala)	(175)
Pinus lumholtzii	MEXICO : Chihuahua, Durango, Zacatecas	56,146,152
Pinus michoacana	MEXICO : Michoacan	146,152
Pinus montezumae	MEXICO : Coahuila, Mexico, Morelos, Puebla	146,152,175
	(also Guatemala)	(45,146,157,175)
Pinus oocarpa	MEXICO : Chiapas, Durango, Guerrero, Oaxaca	56,146,152,175
	(also Guatemala, Honduras, and Nicaragua)	(45,59,146,157,175)
Pinus patula	MEXICO : Hidalgo, Mexico	56,146,152
Pinus pinceana	MEXICO : Coahuila	152
Pinus ponderosa var. *arizonica*	MEXICO : Coahuila, Chihuahua, Durango	56,146,152
Pinus pseudostrobus	MEXICO : Hidalgo, Michoacan, Oaxaca, Tlaxcala, Veracruz	56,146,152,175
	(also El Salvador)	(112)
Pinus rudis	MEXICO : Coahuila, Mexico, Veracruz	152
Pinus teocote	MEXICO : Chiapas, Coahuila, Hidalgo, Mexico, Michoacan	56,146,152

Note: All of the above pines are affected in Mexico (146,152), where *C. conigenum* occurs in the Sierra Madre Occidental, Sierra Madre Oriental, and in southern Mexico; it ranges from Chihuahua and Coahuila at least as far south as Oaxaca and Chiapas.

Alternate or nonconifer hosts

Hosts	Distribution	References
Quercus arizonica	USA : AZ	66,79,188
Quercus chrysolepis	USA : AZ	79
Quercus dunnii	USA : AZ	66
Quercus emoryi	USA : AZ	28,66,78,79,188
Quercus grisea	USA : AZ	28,66,79
Quercus hypoleucoides	USA : AZ	78,79,188
Quercus oblongifolia	USA : AZ	66,79
Quercus rugosa	USA : AZ	66,79

Note: The oak species affected by *Cronartium conigenum* in Mexico are not well defined.

Figure 27. *Cronartium conigenum* telial horns on the underside of *Quercus* sp. leaves (R. Salinas Quinard, Sec. Agr. Re. Hid.).

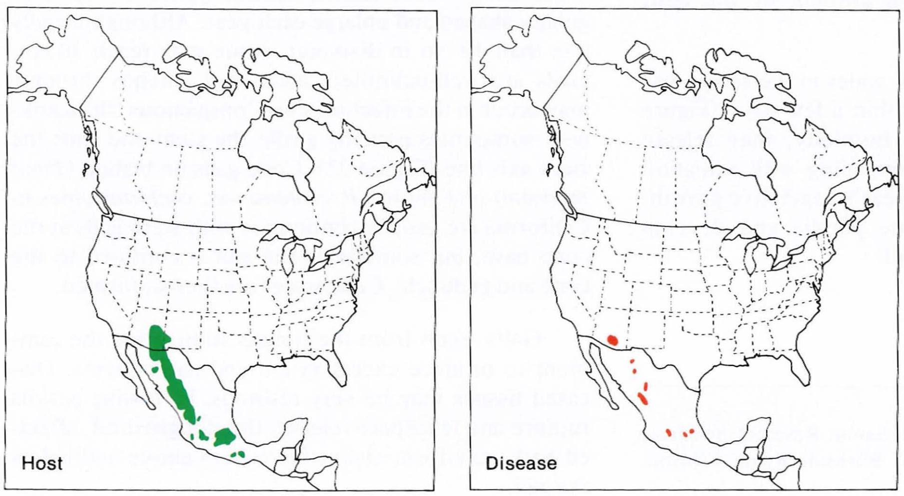


Figure 28. North American distribution of southwestern pine cone rust on its main host, Chihuahua pine. (41, 44, 45, 56, 59, 66, 78, 79, 112, 118, 130, 144, 146, 152, 157, 175, 188).

Western gall rust[1]

Endocronartium harknessii (J.P. Moore) Y. Hiratsuka

This disease causes branch and stem galls on numerous hard (two and three needle) pines throughout western North America. Except for two pine species in California (34), the disease rarely occurs on cones; however, it has the potential to severely damage cones, cone-bearing branches, and the boles of host trees in seed orchards where cultural practices such as irrigation could favor the disease.

Life History (29, 86, 126, 141, 173, 204, 205, 206) Figure 30.

Endocronartium harknessii is widespread on North American hard pines, sometimes affecting their cones. The pathogen is autoecious, and usually produces teliospores that have morphological characteristics of aeciospores. They germinate directly and infect other pines. Although pycniospores may be produced on some pines, their function is questionable.

Infection of hosts of all ages is by wind-disseminated teliospores in spring to early summer, especially during rainy periods. The pathogen enters through succulent current year's needles, and infection spreads to stems or ovulate cones. A gall or canker forms at the infection site later the same year, or the next.

The rust is perennial and often long-lived. Teliospore production on galls or cankers begins 2-4 years after infection and usually continues annually until the tree or branch dies following girdling by the rust, secondary fungi, or insects.

Aecia develop under bark scales in the spring and early summer, and mature within a few days (Figure 29). During periods of high humidity, they release teliospores for 3-8 weeks, coinciding with initiation and elongation of the current year's vegetative growth. When present, pycnia precede peridia and develop within the bark covering the gall.

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA.

Figure 29. A stem and cone infection of Bishop pine by *Endocronartium harknessii*; note the salmon colored peridia (arrow) on the gall (J.W. Byler, USFS).

Symptoms (29, 34, 135, 140, 143, 173, 205)

Perennial, woody galls form at infection sites on stems, branches, or cones (Figure 31). Galls are globose, subglobose, hemispherical, pyriform, or irregularly shaped and enlarge each year. Although usually less than 10 cm in diameter, some may reach 30 cm. Galls are well-delimited, and small witches' brooms may occur at the infection site. Conspicuous "hip cankers" sometimes partially girdle the stem and shift the stem axis line (Figure 32). Cone galls on bishop (*Pinus muricata*) and shore (*P. contorta* var. *contorta*) pines in California are usually continuous with stem galls at the cone base, but sometimes the gall is confined to the cone and peduncle. Cone scales are then deformed.

Galls result from the fungus stimulating the cambium to produce excess xylem and parenchyma. Diseased tissues may be very resinous. Following peridia rupture and teliospore release, the sloughed off, affected bark may form distinctive collars above and below the gall.

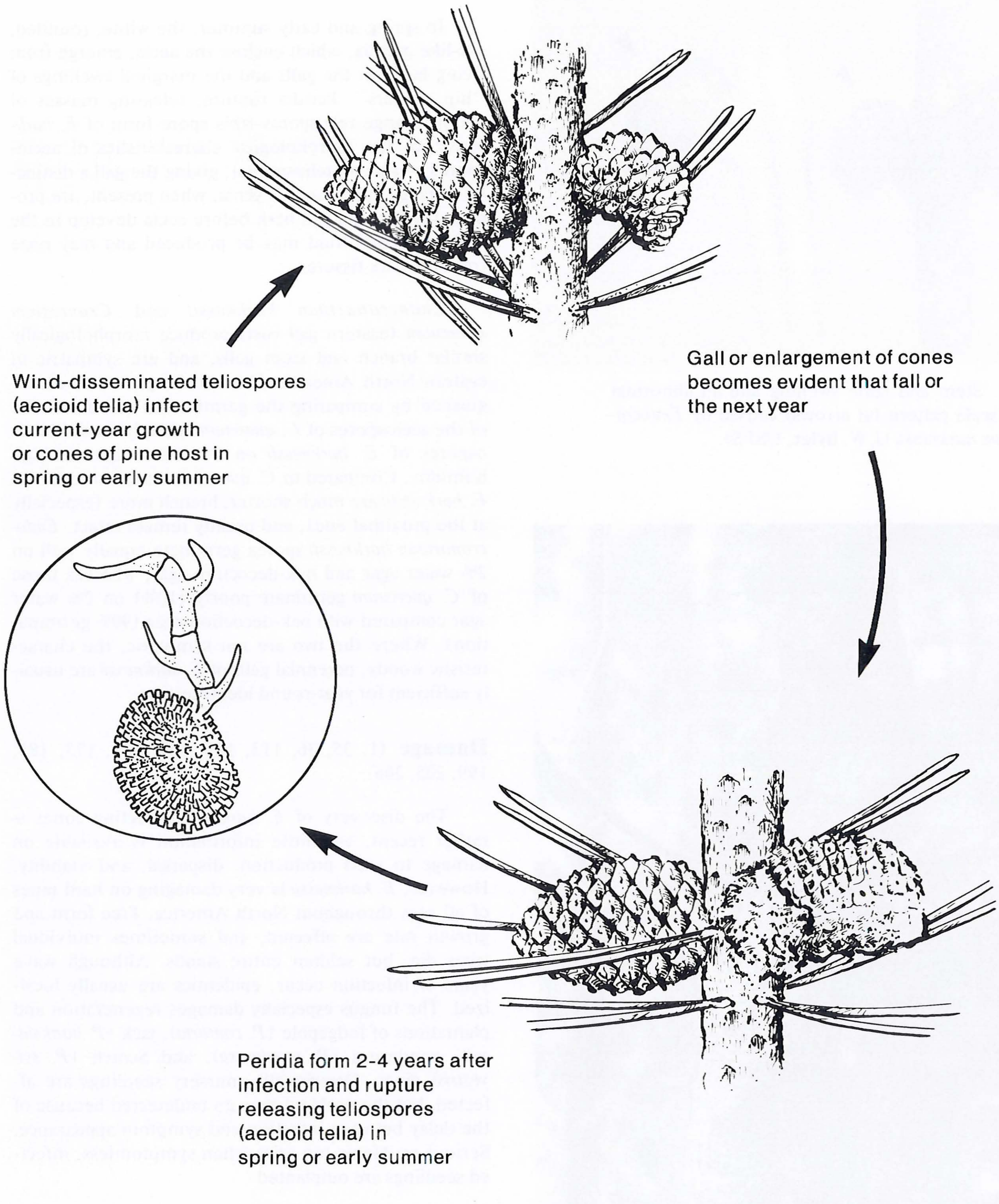


Figure 30. Disease cycle for western gall rust, *Endocronartium harknessii*, on pine cones.

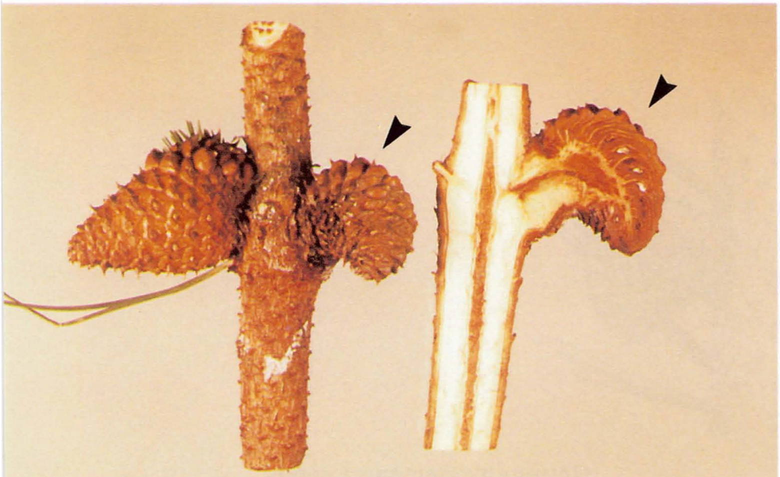


Figure 31. Stem and cone swelling and an abnormal cone scale pattern (at arrows) caused by *Endocronartium harknessii* (J.W. Byler, USFS).

Figure 32. An *Endocronartium harknessii* "hip canker" on a pine stem; the canker causes the stem axis to shift (J.W. Byler, USFS).

Signs (141, 173, 205, 206) Table I and Figure 33.

In spring and early summer, the white, rounded, sac-like peridia, which enclose the aecia, emerge from living bark on the galls and the marginal swellings of "hip cankers". Peridia rupture, releasing masses of yellow-orange teliospores (this spore form of *E. harknessii* has the morphological characteristics of aeciospores = aecioid teliospores), giving the gall a distinctive orange appearance. Pycnia, when present, are produced within the gall bark before aecia develop in the spring. Pycnial fluid may be produced and may ooze from the bark fissures.

Endocronartium harknessii and *Cronartium quercuum* (eastern gall rust) produce morphologically similar branch and stem galls, and are sympatric in eastern North America. The two fungi can be distinguished by comparing the germination characteristics of the aeciospores of *C. quercuum* with the aecioid teliospores of *E. harknessii* on 2% water agar at high humidity. Compared to *C. quercuum* the germ tubes of *E. harknessii* are much shorter, branch more (especially at the proximal end), and usually remain intact. *Endocronartium harknessii* spores germinate equally well on 2% water agar and oak-decoction agar, whereas those of *C. quercuum* germinate poorly (10%) on 2% water agar compared with oak-decoction agar (90% germination). Where the two are not sympatric, the characteristic woody, perennial galls of *E. harknessii* are usually sufficient for year-round identification.

Damage (1, 35, 36, 113, 135, 141, 145, 173, 181, 199, 205, 206)

The discovery of *E. harknessii* affecting cones is rather recent, and little information is available on damage to seed production, dispersal, and viability. However, *E. harknessii* is very damaging on hard pines of all ages throughout North America. Tree form and growth rate are affected, and sometimes individual trees die, but seldom entire stands. Although wave years of infection occur, epidemics are usually localized. The fungus especially damages regeneration and plantations of lodgepole (*P. contorta*), jack (*P. banksiana*), ponderosa (*P. ponderosa*), and Scotch (*P. sylvestris*) pines. Occasionally, nursery seedlings are affected, but the problem may go undetected because of the delay between infection and symptom appearance. Serious problems can arise when symptomless, infected seedlings are outplanted.

Distribution

The disease is widespread on hard pines, ranging from southern Alaska, Yukon Territory, and southwestern Northwest Territories southward in the west to California, New Mexico, and Arizona. It is abundant across Canada to the Maritime Provinces, in the Lake States, and from the Eastern States south to Virginia (1, 5, 37, 86, 113, 143, 144).

Western gall rust's general distribution follows that of its most important hosts: jack pine, lodgepole pine, ponderosa pine, and shore pine (49, 125, 199). This disease affects cones of jack pine in Manitoba and Ontario (37), shore pine in British Columbia and California (34, 37), and bishop pine and Monterey pine (*P. radiata*) in California (35). Since it has such a limited host and geographic distribution on cones, no disease distribution map is given. The hosts and distribution are:

Hosts	**Distribution**	**References**
Pinus attenuata	USA : CA	86,123
Pinus banksiana	CANADA : AB,MB,NB,NS,NT, ON,PQ,SK	3,17,37,38,75, 86,104,113,192
	USA : ID,MI,MN,WI	138,143,195
Pinus canariensis	USA : ?	86
Pinus contorta	CANADA : AB,BC,NB,NS,NT,ON, PQ,SK,YT	8,34,37, 47,86,111,148
	USA : AK,CA,CO,ID,MT,OR, SD,UT,WA,WY	5,48,73,89,141,143, 145,166,188
Pinus coulteri	USA : CA	86,123,141,143,188
Pinus halepensis	USA : ?	6
Pinus jeffreyi	USA : CA,MI,NV,OR,WA	99,143,188
Pinus mugo	CANADA : AB,BC,NB	37,86,111,166
	USA : MN	17
Pinus muricata	CANADA : BC	86,111,166
	USA : CA	34,35
Pinus nigra	CANADA : BC,ON,PQ	37,86,111,166
Pinus pinaster	CANADA : BC	37,86,111,166
Pinus ponderosa	CANADA : BC,ON	29,37,73,86,105
	USA : AZ,CA,CO,ID,MA,MT, ND,NE,NM,NV,OR, SD,UT,WA,WY	5,138,143,145,166 188,194,199
Pinus radiata	CANADA : BC	34,35,86,111
	USA : CA, OR, WA	135,136
Pinus resinosa	CANADA : NB,PE	37
Pinus sabiniana	USA : CA,WA	143,188
Pinus strobus	CANADA : PQ	37
Pinus sylvestris	CANADA : AB,BC,MB,NB,NS, ON,PE,PQ,SK	29,37,86,111
	USA : ID,MD,MI,MN,ND, NK,NY,PA,SD,VA,WA, WI	75,109,125,126,138,143,166, 169,194
Pinus thunbergii	USA : ?	86

Note: Besides the above hosts, *Endocronartium harknessii* affects, via artificial inoculation: Japanese red pine (*Pinus densiflora*), slash pine (*P. elliottii* var. *elliottii*) and South Florida slash pine, *P. elliottii* var. *densa*, Apache pine, *P. engelmannii*, planted pine, *P. pinea*, loblolly pine, *P. taeda* and Virginia pine, *P. virginiana* (149, 201, 206). Apparently, the rust occurs in northern Mexico, but host records and distribution are not documented.

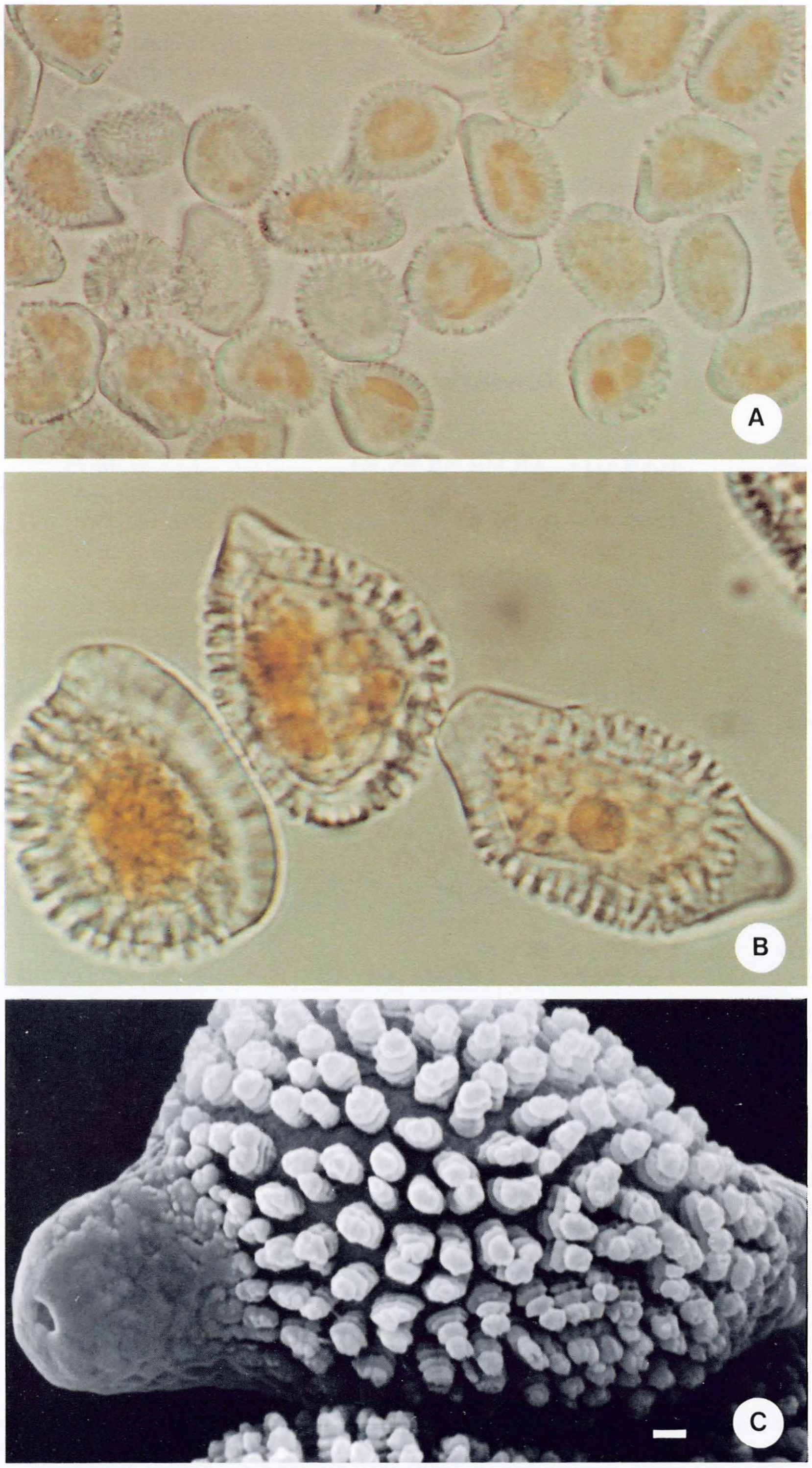


Figure 33. *Endocronartium harknessii* aecioid teliospores are verrucose with annulated processes and form in chains (not shown). Magnifications: A = 50X, B = 125X, and C = 5000X, bar is 1 μm long (J.R. Sutherland, CFS).

Table 1. Summary Table for the Life Histories and the Morphology and Morphometrics of the Spores of the Rust Fungi affecting Cones

Stages	*Chrysomyxa pirolata* *,206	*Chrysomyxa monesis* 203,206	*Cronartium strobilinum* 77,79,80	*Cronartium conigenum* 78,79,146,157	*Endocronartium harknessii* 206
Pycnia					
frequency:	annual	annual	annual	biennial	rare or absent
season:	June-July	June-July	March-April	May-June (Arizona)	spring
Pycniospores					
shape:	indeterminate	—	obovoid to ellipsoid or oblong to ovoid	oblong to obovoid or ovoid	ovoid
size (μm):	—	—	1.9 × 2.8	2 × 3.6	—
color:	golden	—	white	—	—
Aecia					
frequency:	annual	annual	annual	biennial	none
season:	July-September	July-September	March-June	March-July	
Aeciospores					
shape:	broadly ellipsoid, obovoid or rhomboid	fusiform and clavate to oblong and broadly ovoid	obovate to ellipsoid, rarely globoid	sphaeroid to obovoid or ellipsoid	none
size (μm):	—	—	15.3 × 26.0	17.3 × 31.2	
size range (μm):	17-35 × 25-37	17-25 × 29-45	13-17 × 23-29	15-20 × 27-35	
wall diameter (μm):	2 - 4.7	1 - 2	3.2	3.3	
color:	yellow-orange	yellow-orange	cadmium yellow to capucine yellow	bright orange	
Uredinia					
season:	May-September	May-September	all year	all year	none
sorus color:	yellow-orange	yellow-orange	salmon orange to grenadine red	pale green	
Urediniospores					
shape:	ellipsoid to obovate	ellipsoid or obovoid	globoid to ovoid or ellipsoid	sphaeroid to obovoid, rarely ellipsoid	none
size (μm):	—	—	14.7 × 22.4	17.7 × 24.7	
size range (μm):	18-27 × 13-24	15-22 × 23-34	13-17 × 20-26	16-20 × 21-28	
wall diameter (μm):	0.4 - 1.0	0.5 - 1.0	2.3	2.6	
color:	orange-yellow	orange-yellow	cadmium yellow	capucine yellow	
Telial					
season:	May-June	May-June	December-February	June-July (Arizona)	May-June
Teliospores					
shape:	irregularly oblong or ellipsoid	irregularly oblong or ellipsoid	fusiform-oblong to fusiform	oblong to fusiform	subglobose to long-ellipsoid
size (μm):	—	—	14.8 × 30.5	15.6 × 34.3	—
size range (μm):	7-9 × 12-19	6-12 × 12-22	10-18 × 23-41	10-23 × 20-55	17-24 × 23-34
color:	(telia are light orange, turning brown later)	(telia are yellow, turning dark brown later)	brownish	brownish	orange
Basidial					
season:	May-June	May-June	January-February	—	none
Basidiospores					
shape:	round-globoid	round-globoid	—	—	none
size (μm):	—	—	—	—	
size range (μm):	5-7	5-7			
color:	—	—	—	—	

See reference numbers in Literature cited, except * = Sutherland, J.R., S.J. Hopkinson and S.H. Farris. 1984. Inland spruce cone rust, *Chrysomyxa pirolata*, in *Pyrola asarifolia*, and cones of *Picea glauca*, and morphology of the spore stages. Can. J. Botany 62: 2441-2447; All ranges given for *Cronartium* spp. are extreme ranges. All size measurements are averages. (—) indicates data unavailable.

Cone and Seed Diseases Caused by Fungi Other than Rusts

The seed or cold fungus[1]

Caloscypha fulgens (Pers.) Boud.

This seed-borne pathogen was first found causing pre-emergence losses of seeds in Ontario (58) and then in English forest nurseries (153) on seeds imported from western North America. The pathogen acquired its common names because it is seed-borne (seed fungus) and because it spreads from diseased to healthy seeds during cold periods such as when seeds are stratified or when they are sown in cold soils (153). Salt (153) in England described and named the fungus *Geniculodendron pyriforme* Salt. Subsequently the fungus was isolated from stored seeds in British Columbia (178), Oregon and Washington (76). Paden *et al.* (139) related the anamorph (imperfect state) of *G. pyriforme* to its teleomorph (perfect state), *Caloscypha fulgens.* Seeds acquire the fungus when cones contact forest litter, where *C. fulgens* lives.

Life History (58, 67, 127, 139, 154, 177, 180, 181, 197, 200) Figure 35.

Caloscypha fulgens is an operculate discomycete with bright-orange (exterior often stained blue-green), cup-shaped fruiting bodies (1-5 cm diameter). It grows under conifers and fruits in the spring, especially soon after snowmelt (Figure 34). Ascospores and conidia apparently function only in dissemination of the fungus in the forest, since seed infection results from mycelium inhabiting forest litter.

Cones that contact infested forest duff or soil are invaded; thus, ground-collected cones, particularly from squirrel caches, most often contain diseased seeds. The fungus should not be present in seedlots from seed orchards where cones are picked from trees

Figure 34. Cup-shaped Ascocarps of *Caloscypha fulgens.* These cup-shaped structures appear on forest litter (A) in early spring, they have an orange hymenium and exterior (B), portions of the latter frequently stain-blue green (J.R. Sutherland, CFS).

---

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA.

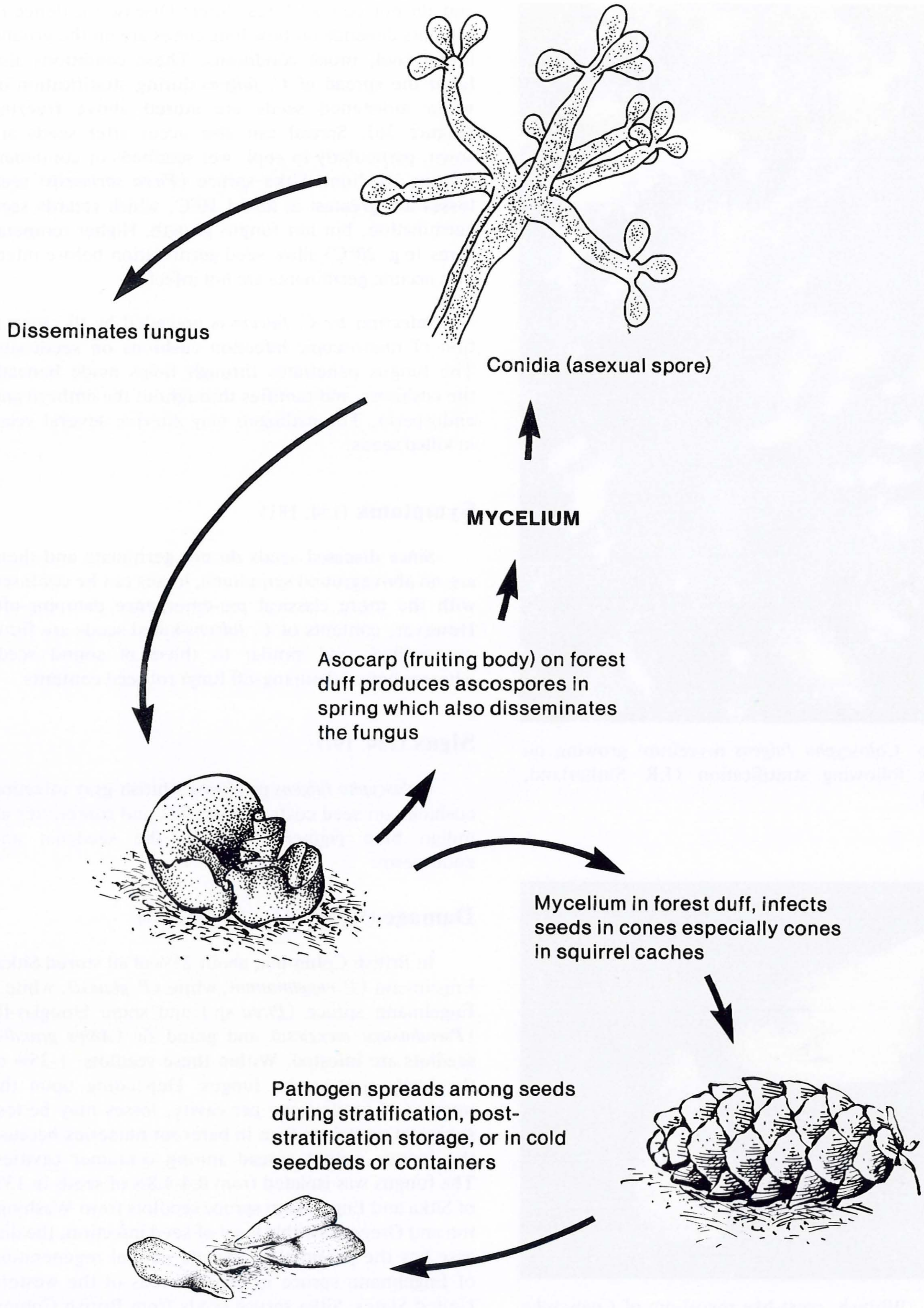


Figure 35. Disease cycle for the seed or cold fungus, *Caloscypha fulgens*.

Figure 36. *Caloscypha fulgens* mycelium growing on seeds following stratification (J.R. Sutherland, CFS).

Figure 37. Whitish, crust-like mycelium of *Caloscypha fulgens* on the seedcoats of spruce seeds (J.R. Sutherland, CFS).

and do not contact forest litter. Disease incidence in seedlots depends on how long cones are on the ground under cool, moist conditions. These conditions also favor the spread of *C. fulgens* during stratification or when moistened seeds are stored above freezing (Figure 36). Spread can also occur after seeds are sown, particularly in cool, wet seedbeds or container-nursery medium. Sitka spruce (*Picea sitchensis*) seed losses are greatest at about 10°C, which retards seed germination, but not fungus growth. Higher temperatures (e.g. 20°C) allow seed germination before infection occurs; germinants are not infected.

Infection by *C. fulgens* is preceded by the formation of microscopic infection cushions on seedcoats. The fungus penetrates through holes made beneath the cushions, and ramifies throughout the embryo and endosperm. The pathogen may survive several years in killed seeds.

Symptoms (154, 181)

Since diseased seeds do not germinate and there are no aboveground symptoms, losses can be confused with the more classical pre-emergence damping-off. However, contents of *C. fulgens*-killed seeds are firm, mummified, and similar to those of sound seed, whereas typical damping-off fungi rot seed contents.

Signs (154, 197)

Caloscypha fulgens produces whitish-gray infection cushions on seed coats (Figure 37) and sometimes an indigo blue pigment between the seedcoat and endosperm.

Damage (58, 76, 154, 178, 181, 197)

In British Columbia, about 25% of all stored Sitka, Engelmann (*P. engelmannii*), white (*P. glauca*), white x Engelmann spruce (*Picea* sp.) and some Douglas-fir (*Pseudotsuga menziesii*) and grand fir (*Abies grandis*) seedlots are infested. Within these seedlots, 1-35% of the seeds contain the fungus. Depending upon the number of seeds sown per cavity, losses may be less severe in container than in bareroot nurseries because the fungus cannot spread among container cavities. The fungus was isolated from 0.4-4.8% of seeds in 13% of Sitka and Engelmann spruce seedlots from Washington and Oregon. At this level of seed infection, the disease has the potential to impede natural regeneration of Engelmann spruce in certain areas of the western United States. Sitka spruce seeds from British Columbia contained 0-5% diseased seeds and caused patchy emergence in British bareroot nurseries during cool

Figure 38. Indigo-colored mycelium of *Caloscypha fulgens* growing from Sitka spruce seed on water agar (J.R. Sutherland, CFS).

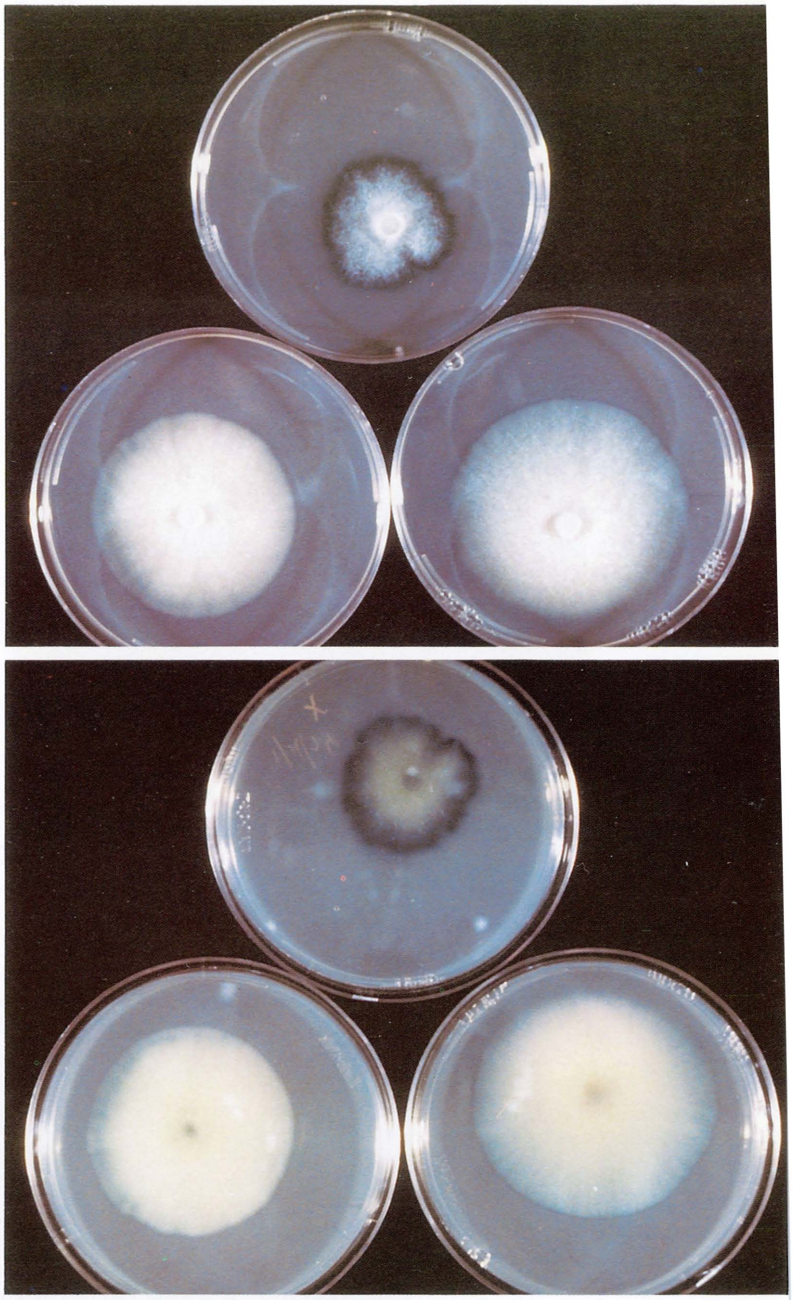


Figure 39. Cultures of *Caloscypha fulgens* on potato-dextrose agar; surface view (above) showing whitish mycelium and indigo pigment, reverse view (below) showing indigo and pale orange pigments (J.R. Sutherland, CFS).

springs, especially when sowing was abnormally early. In Ontario bareroot nurseries, white spruce, red spruce (*P. rubens*) and eastern white (*Pinus strobus*) and Scotch (*P. sylvestris*) pine seed germination was reduced by up to 98%.

Isolation (178, 197)

Caloscypha fulgens can be isolated by plating surface-sterilized (30% hydrogen peroxide for 30 minutes) seeds on 1.5% water agar and incubating at 15-20°C. Cultures produce an indigo or orange pigment, or both (Figures 38 and 39) and the hyphae, which usually branch at a right angle, are thick and verrucose (Figure 40). Conidiophores and conidia are distinct (Figure 41). The cultural (139) and conidiophore characteristics are:

CULTURES

Surface: texture loose cottony, sometimes tufted; orange in the center, fading to hyaline at the margin or multi-colored (blue-green-grayish) throughout; margin somewhat diffuse or uneven.

Reverse: pale orange or blue-green; center fading to cream at margin; no diffusion zone.

CONIDIOPHORES, CONIDIA AND HYPHAE

Conidiophores: from aerial hyphae 200 – 550 μm high; smooth pale yellow to yellow-brown below; in

Figure 40. Verrucose hyphae of *Caloscypha fulgens*; note right-angle branching (J.R. Sutherland, CFS).

diameter 8 – 17 μm broad below, tapering to 3.6 – 6 μm above, unbranched up to 220 μm, then more or less dichtomously branched; hyaline above.

Conidiogenous cells: sympodulae; in verticils of three or four, or paired, rarely single; 16 – 50 μm long; 3.2 – 5.2 μm broad below; taping to 2.4 – 8 μm.

Conidia: 4.6-7.6 × 3.2-4.0 μm; holoblastic; smooth, hyaline, obovate, dry.

Hyphae: hyaline when young; older hyphae with greenish-blue or brownish tinge, granular, right-angle branching, septum near base of each branch, cells 71-190 × 10-18 μm.

Distribution

Caloscypha fulgens is widespread in North America. Ascocarps are common in the Rocky Mountains during early spring on soil or litter under conifers (67, 70, 103, 127, 164, 170, 187). Canadian records are from: AB, BC, MB, NB, ON, and PQ (37, 58, 67, 103, 111, 153, 154, 178, 181). In the United States, *C. fulgens* is reported from New York to the Pacific Coast (162, 164), but records are poor for central, southern and eastern states. Records are for: AK, AZ, CA, CO, ID, MT, NY, OR, UT, WA, WY (43, 76, 103, 150, 153, 154, 162, 197). Figure 42.

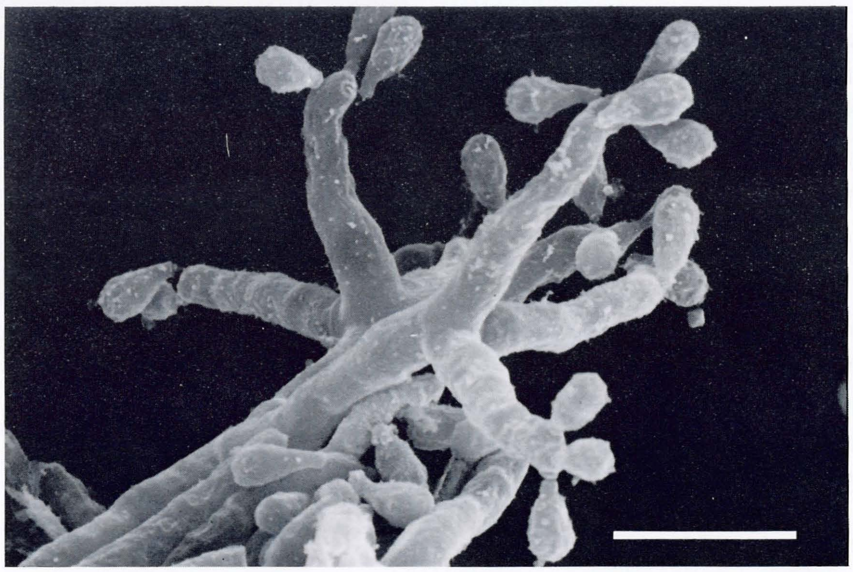


Figure 41. *Caloscypha fulgens* conidiophore and conidia (X 2400), bar is 10 μm (J.R. Sutherland, CFS).

The fungus affects conifer seeds in Ontario, Utah, Idaho, and along the Pacific Coast from Alaska to Oregon (see following list). However, because of its wide distribution on litter, it may affect seeds elsewhere. The hosts and distributions are:

Hosts	Distribution	References
Abies grandis	CANADA:BC	181
	USA:Pacific Northwest	43
Abies lasiocarpa	USA : ID,UT	197
Picea engelmannii	CANADA : BC	76,178,181
	USA : ID,OR,UT,WA	197
Picea glauca	CANADA : BC, ON	58,178,181
Picea sitchensis	CANADA : BC	154,178,181,200
	USA : AK,OR,WA	76
Pinus contorta	CANADA : BC	37
Pinus resinosa	CANADA : ON	58
Pinus strobus	CANADA : ON	58
Pinus sylvestris	CANADA : ON	58
Pseudotsuga menziesii	CANADA : BC	178,181

Note: Besides natural occurrences, *Caloscypha fulgens* infects artificially inoculated seeds of: jack pine, *Pinus banksiana*; Norway spruce, *Picea abies*; black spruce, *P. mariana* (58); Japanese larch, *Larix kaempferi*; and western hemlock, *Tsuga heterophylla* (153).

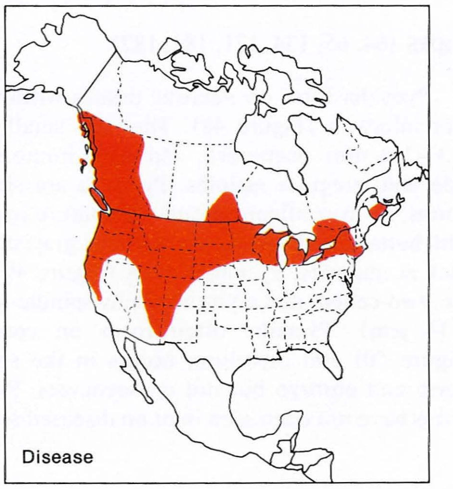


Figure 42. North American distribution of the seed or cold fungus on all hosts. (37, 43, 58, 67, 70, 76, 103, 111, 127, 150, 153, 154, 162, 163, 164, 170, 178, 181, 187, 197).

Sirococcus blight[1]

Sirococcus strobilinus Preuss

Sirococcus blight, caused by *S. strobilinus*, is a disease of the North Temperate Zone, where it affects numerous conifer species in nurseries, young regeneration, and sometimes older trees (65). Funk (65) lists numerous taxonomic synonyms of *S. strobilinus*. In 1982, the disease was reported to be seed-borne on spruce (*Picea* spp.) in container nurseries in coastal British Columbia (182). It is thought that seeds become infected when the pathogen invades old cones, and seedlots become contaminated with infected seeds when old cones are inadvertently included in cone collections. To date, seedlots from spruce seed orchards have been *Sirococcus*-free, probably because the cones are removed each year.

Life History (64, 65, 160, 172, 181, 182, 183, 193) Figure 43.

Sirococcus strobilinus is a sphaeropsid coelomycete; with only pycnidiospores known to occur. It is seed-borne on Sitka (*Picea sitchensis*), white (*P. glauca*), Engelmann (*P. engelmannii*), and white × Engelmann spruce (*Picea* sp.) in British Columbia container nurseries. In cones, the fungus apparently infects fully developed seeds, but the mode of infection is not known. In container cavities, it probably spreads from diseased to healthy seeds prior to germination. Post-germination spread occurs from disease foci originating from seed-borne inoculum. Because *S. strobilinus* has no other known spore type, each new outbreak in nurseries apparently originates from inoculum on seeds or comes into the nursery by wind-blown rain.

The disease affects young shoots and seedlings during periods of high humidity, mild temperature, (10-20°C), and low light intensity, which are common in forests and nurseries where the disease occurs. Symptoms appear 2-4 weeks after inoculation, and shoot-tip or seedling death and subsequent sporulation occur as little as 3 weeks later. Pycnidia on necrotic tissues produce masses of pycnidiospores, which are disseminated by rain or nursery irrigation. The fungus overwinters in diseased tissues and sporulates the following spring.

Symptoms (64, 160, 165, 171, 172, 181, 182, 183)

Sirococcus strobilinus causes tip-dieback and branch and stem cankers on current year's growth (Figure 44). The fungus enters at the base of newly developed needles and spreads rapidly into the stem. A resin drop is often exuded at the site of infection. Distal foliage droops, turns yellow or brownish-red, and, within a month, needles die from the base distally. Elongate, sunken, purplish cankers may develop at the infection site, restricting stem growth locally and causing a crook of the shoot tip. Killed seedlings remain upright (Figure 45).

In container nurseries, hosts include Sitka, white, Engelmann, and white × Engelmann spruces (Figures 46 and 47). Because the primary inoculum is seed-borne, symptoms usually appear on random germinants of specific seedlots from emergence through secondary needle formation and leader development. In bareroot nurseries, the same seedling species are affected as in container nurseries plus others, especially pines such as lodgepole (*Pinus contorta*) and Douglas-fir (*Pseudotsuga menziesii*). In bareroot nurseries, primary inoculum appears to come from nearby diseased trees and cones or windbreaks rather than from infested seed. On bareroot stock, symptoms usually appear in late summer through fall on 1 + 0 seedlings or in the spring on 2 + 0 plants. Fall symptoms can be confused with frost damage. Lodgepole pine susceptibility may vary by provenance. Seeds infected by *S. strobilinus* often have shrunken contents.

Signs (64, 65, 134, 171, 181, 182)

Pycnidia form on necrotic tissues within 3 weeks after infection (Figure 48). They are small, rounded (0.3 – 1.0 mm diameter), and semi-immersed, with wide and irregular ostioles. Pycnidia are singular, in groups, or in confluent groups. Immature pycnidia are light butterscotch color, but become grayish-green or black at maturity. Pycnidiospores (Figure 49) are hyaline, two-celled, and asymmetrically spindle-shaped (3×15 μm). Pycnidia often form on cone scales, (Figure 50) and mycelium occurs in the seed endosperm and embryo but not on seedcoats. Pycnidia or spores have not been seen in or on diseased seeds.

Damage (36, 64, 93, 115, 160, 172, 182, 183, 190, 196)

Damage occurs in nurseries and juvenile stands throughout much of the North Temperate Zone of North America. Multiple infections may kill or deform seedlings and trees. Damage to the current year's

---

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA

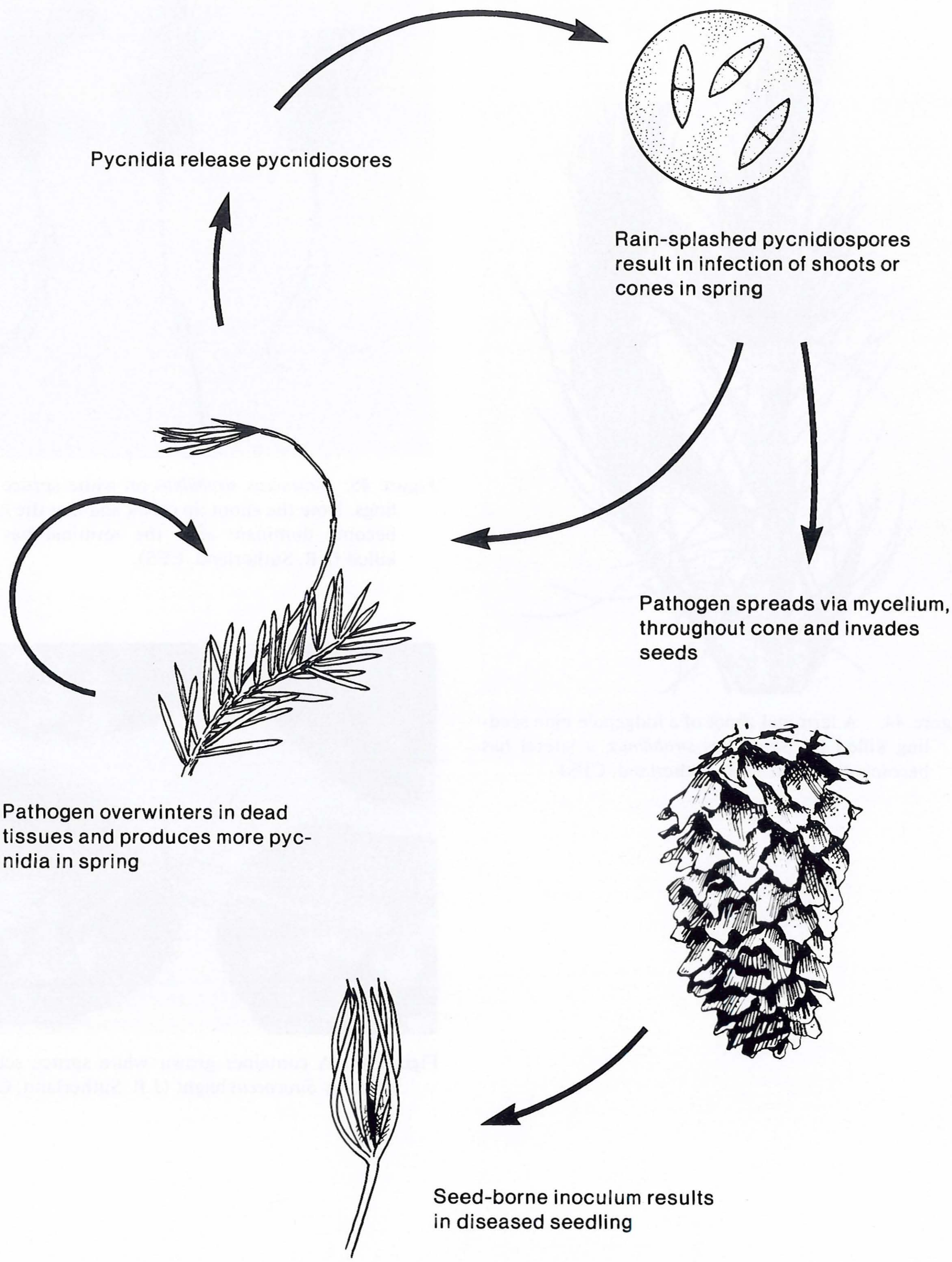


Figure 43. Disease cycle for *Sirococcus* blight, *Sirococcus strobilinus.*

Figure 44. A terminal shoot of a lodgepole pine seedling killed by *Sirococcus strobilinus*; a lateral has become dominant (J.R. Sutherland, CFS).

Figure 45. *Sirococcus strobilinus* on white spruce seedlings. Note the shoot tip crook and that the laterals become dominant after the terminal has been killed (J.R. Sutherland, CFS).

Figure 46. A container grown white spruce seedling killed by *Sirococcus* blight (J.R. Sutherland, CFS).

Figure 47. White spruce killed by *Sirococcus strobilinus.* Note the three stages of symptom development (left, initial, right, advanced); needles are killed from the base outward (J.R. Sutherland, CFS).

shoots and cones adversely affects growth or seed production. The disease also affects regeneration and mature trees. Western hemlock (*Tsuga heterophylla*) regeneration has been extensively and severely damaged in southeastern Alaska for over a decade (Figure 51). Elsewhere, damage in natural stands appears light. Red pine (*P. resinosa*) plantations in Nova Scotia and New Brunswick recently suffered up to 70% mortality from multiple infection of crown branches. Douglas-fir branch mortality of 10-50% has been reported in British Columbia.

In nurseries, losses are due to seedling mortality and culling. Serious mortality (>50%) of ponderosa pine (*P. ponderosa*) seedlings in scattered patches in Idaho seedbeds and black spruce (*P. mariana*) seedlings (17-24% seedling loss) in Newfoundland has been reported, as has up to 25% infection of lodgepole pine in Pacific Northwest nurseries. Sitka and white spruces and lodgepole and ponderosa pines are affected in British Columbia, and the incidence has increased recently with increased spruce production.

In British Columbia, *S. strobilinus* was found in 57% of seedlots of Sitka, white, Engelmann, and white × Engelmann spruces, and 0.3-3.1% of the seeds were diseased. The pathogen was especially prevalent in seeds with shrunken contents (Figure 52).

Figure 48. Globose, black pycnidia of *Sirococcus strobilinus* on killed lodgepole pine seedling (J.R. Sutherland, CFS).

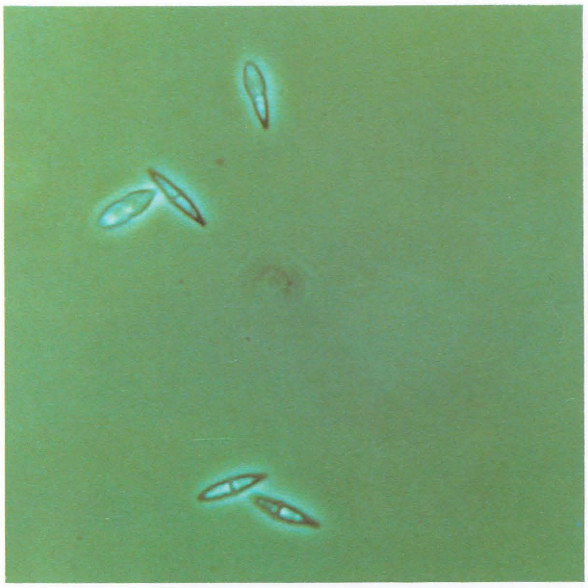


Figure 49. Spindle-shaped, single-septate pycnidiospores (X200) of *Sirococcus strobilinus* (J.R. Sutherland, CFS).

Isolation (64, 165, 182)

The pathogen can be isolated by surface-sterilizing seeds with 0.5% sodium hypochlorite for 5 minutes or 30% hydrogen peroxide for 30 minutes, rinsing twice in sterile distilled water, plating on 2% malt agar, and incubating at 20°C (8 hours light). The fungus grows from diseased seeds or sporulates on germinants. *Sirococcus* can be isolated from diseased seedling or cone tissues after surface-sterilization in 0.5% sodium hypochlorite for 1-2 minutes, followed by three sterile-distilled water rinses, plating on a nutrient agar medium, and incubating as above. Figure 53 shows cultures of the fungus. The cultural and conidiophore characteristics (65) are:

CULTURES

Surface: texture downy-felty; yellowish-green to greenish-gray with hyaline border; margin somewhat uneven to bayed.

Reverse: yellowish-green to greenish-gray at center, fading to hyaline at border; no diffusion zone.

Figure 50. Small, black pycnidia (at arrows) of *Sirococcus strobilinus* on Sitka spruce cone scales (J.R. Sutherland, CFS).

Figure 51. *Sirococcus* blight on western hemlock regeneration (T.H. Laurent, USFS).

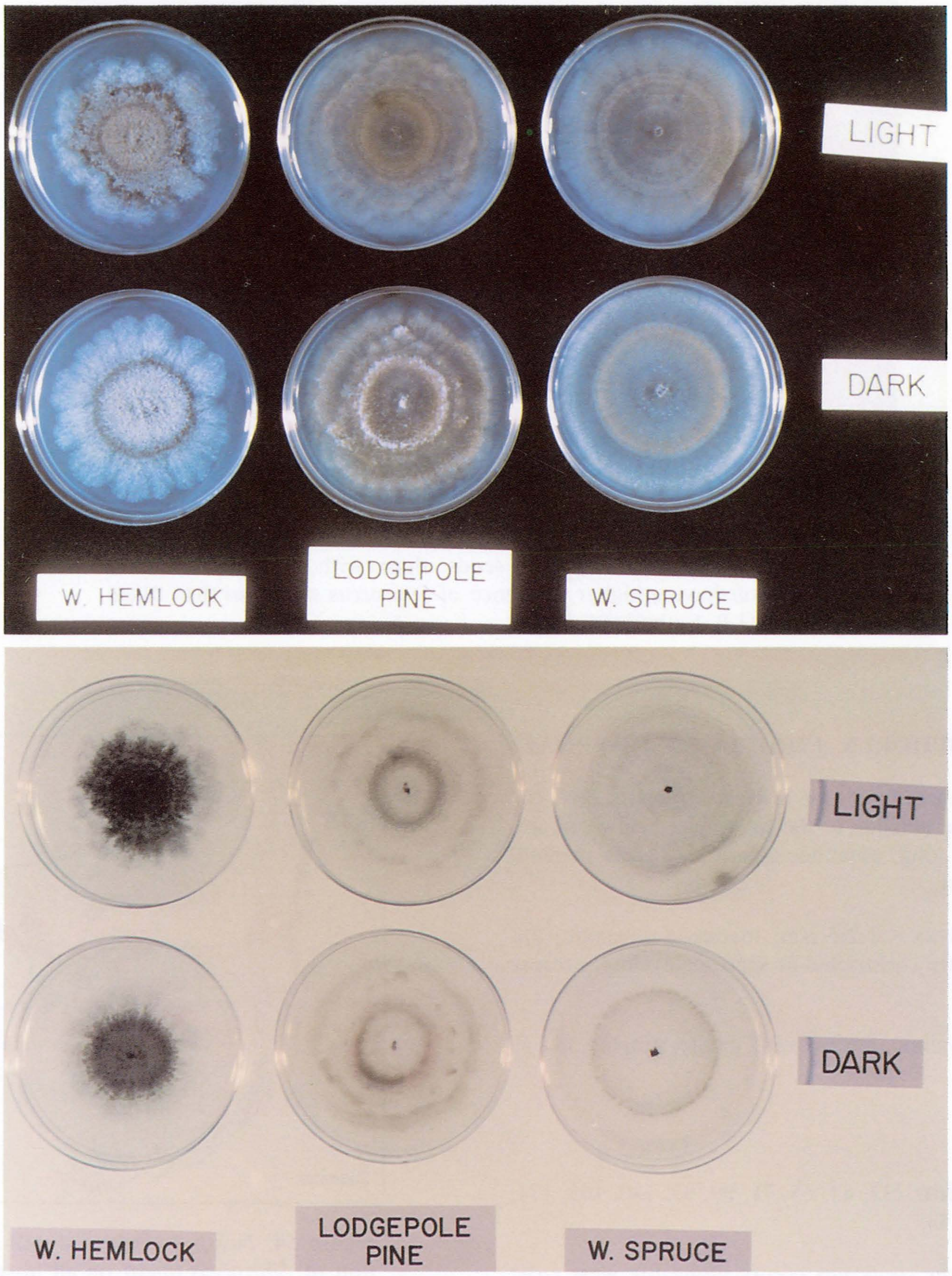


Figure 52. Cultural characteristics of *Sirococcus strobilinus* from different hosts may vary; (above) surface view and (below) reverse. Cultures were reared in either the light or dark. (J.R. Sutherland, CFS).

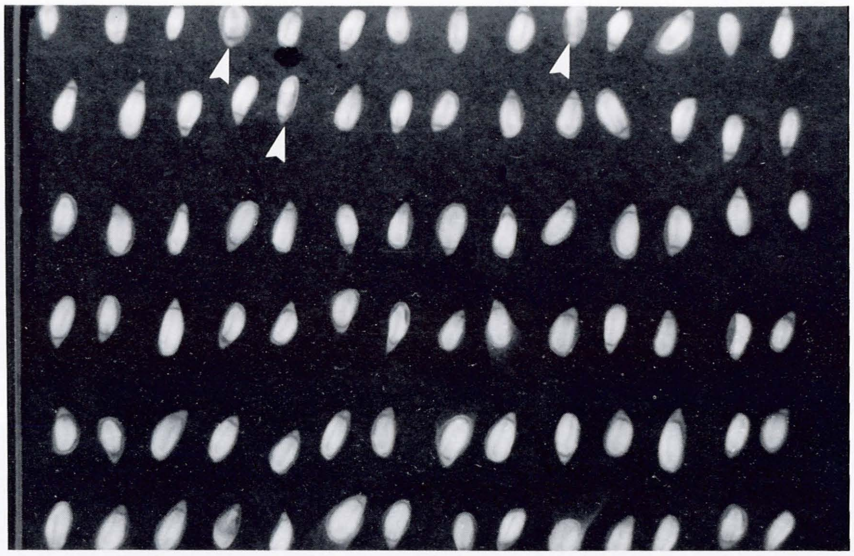


Figure 53. Radiograph of spruce seeds, those with shrunken contents (arrows) have a higher incidence of *Sirococcus strobilinus* than filled seeds (J.R. Sutherland, CFS).

CONIDIOPHORES, CONIDIA AND HYPHAE

Conidiophores: simple or branched septate, each cell with a single phialide at the tip or just below septum, 10 – 45 μm long; phialides tapering, sharply pointed, 6-12 × 2 μm.

Conidia: 13-15 × 2-2,5 μm; medianly 1-septate, tips acute, slightly constricted at septum; hyaline, acerose to fusiform.

Hyphae: hyaline, interwoven; cavity simple; 30 – 50 μm thick.

Distribution (37, 43, 65, 71, 89, 93, 140, 165, 171, 182) Figure 54.

Sirococcus strobilinus occurs along the west coast from California to Alaska and in the interior of British Columbia. Damage is prevalent in the Great Lakes region, southern Quebec, New Brunswick, Nova Scotia, and Prince Edward Island, and scattered in the central and eastern United States.

The pathogen has been reported on seeds or cones of Engelmann spruce in British Columbia (182), white × Engelmann spruce in British Columbia (182), white spruce in Alberta, Saskatchewan, Manitoba, Nova Scotia and British Columbia (37, 182), black spruce

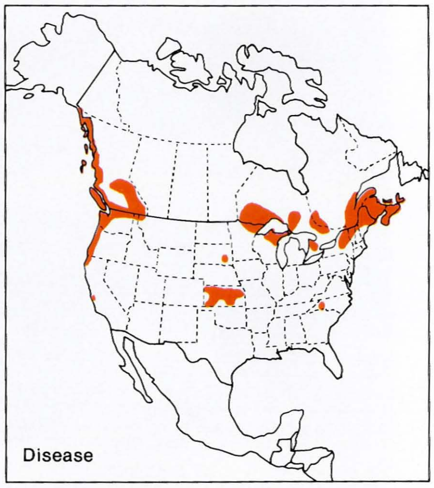


Figure 54. North American distribution of *Sirococcus* blight on all hosts. (7, 33, 37, 46, 64, 71, 87, 93, 110, 111, 115, 116, 134, 137, 138, 160, 165, 166, 171, 173, 182, 184, 185, 189, 191, 193, 196).

(*P. mariana*) in Manitoba, New Brunswick and Nova Scotia (37), Sitka spruce in British Columbia (182), red pine (*P. resinosa*) in Nova Scotia (37), and Scotch pine in (*P. sylvestris*) New Brunswick (37). All British Columbia records are from forest nurseries. The hosts and distribution are:

Hosts	Distribution	References
Larix laricina	CANADA : PQ	37
Libocedrus decurrens	CANADA : BC	111,166
Picea abies	CANADA : PQ	37
	USA : KS,NC	71,165
Picea engelmannii	CAN : BC	37,111,182
Picea glauca	CANADA : AB,BC,MB,NB,NS,PE,PQ,SK	37,111,116,182 and J. Sutherland, unpublished data
Picea mariana	CANADA : MN,NB,NS,PE,PQ	37,116,193
Picea pungens	CANADA : NB,ON,PQ	37
	USA : KS	165
Picea rubens	CANADA : NS	37
	USA : NC	71
Picea sitchensis	CANADA : BC	37,182
	USA : AK,CA	7,171
Pinus albicaulis	CANADA : BC	37
Pinus banksiana	CANADA : NB,ON	37
Pinus contorta	CANADA : AB,BC	37,93,110
	USA : AK,CA,MT,OR,WA	7,171
Pinus coulteri	USA : CA	171
Pinus jeffreyi	USA : CA	33,171,174,184
Pinus lambertiana	USA : CA	171
Pinus ponderosa	CANADA : BC	37,87
	USA : CA,ID	160,171
Pinus resinosa	CANADA : NB,NS,ON,PE	33,37,115,134,137
	USA : MI,NB,WI	185
Pinus strobus	CANADA : NB,NS,ON	37
Pinus sylvestris	CANADA : NB	37
Pinus thunbergii	CANADA : NB	37
Pseudotsuga menziesii	CANADA : BC	37

Pitch canker[1]

Fusarium moniliforme Sheld.
var. *subglutinans* Wollenw. & Reink.

The pitch canker disease damages pine plantations and seed orchards in the southeastern United States. Seed orchards supply the genetically improved seeds required for reforestation in this region. Disease impacts are increasing in spite of (and sometimes because of) the specialized practices used to produce the crop. During the approximately 19 months between production of female strobili and maturation of pine seeds, there are numerous potential opportunities for the causal pathogen to reduce seed yields. At this time, determination of a complete disease cycle on pine reproductive structures awaits further investigation, therefore no disease cycle is presented for this disease.

Life History (10, 20, 25, 53, 54, 55, 63, 68, 96, 101, 119, 128, 159, 198)

Fusarium moniliforme var. *subglutinans* [*F. subglutinans* (Wollenw. & Reinking) Nelson, Toussoun & Marasas comb. nov.] infects a variety of vegetative and reproductive structures at different stages of maturity, and produces a diversity of symptoms on southern pine species. Disease symptoms include pitch canker, shoot dieback, abortion of strobili and conelets, cone necrosis, and seed deterioration. Since the pitch canker disease occurs sporadically in time and space, only the peak and recovery phases of epidemics are well documented.

Inoculum of *F. moniliforme* var. *subglutinans* is airborne, and maximum dispersal occurs during precipitation in turbulent air. Theoretically, the pathogen could be introduced into strobili by wind or by contaminated pollen in spring when the scales are open, but these mechanisms have yet to be demonstrated. The pathogen normally requires a fresh wound as an infection court. Outbreaks of shoot dieback are usually initiated from late summer through fall.

Harvesting of slash (*Pinus elliottii* var. *elliottii*) and loblolly (*P. taeda*) pine cones produces wounds during the optimum infection period in the fall and can result in multiple infections throughout the tree. In slash pine seed orchards, trunk cankers often develop at injuries caused by mechanical tree shakers. In loblolly pine seed orchards, tearing cones from branches creates infection courts in the crown.

An array of insects feed on female strobili throughout their growth and maturation period and possibly create infection courts for the pathogen. These insects may also transmit the pathogen into the cones. The deodar weevil (*Pissodes nemorensis* Germar) and pine tip moth (*Rhyacionia* spp.) create wounds on shoots that may become infected by airborne spores of the pathogen. Deodar weevils, their associated galleries, and chip cocoons are frequently contaminated by *F. moniliforme* var. *subglutinans.*

Weather-related injuries caused by wind and hail also serve as entry points. Hurricanes and tornadoes have contributed to the intensification of pitch canker in seed orchards of loblolly, shortleaf (*P. echinata*), and Virginina (*P. virginiana*) pines.

Various stress factors predispose trees to infection. Drought and late-summer applications of ammonium nitrate to promote flowering are implicated in increasing the trees' susceptibility to the pathogen.

Symptoms (15, 30, 54, 55, 83, 128, 129)

Fusarium moniliforme var. *subglutinans* causes mortality of female flowers and mature cones (Figure 55), and the deterioration of seeds in slash and loblolly pines (Figure 56). Infected loblolly pine cones tend to be misshapen and smaller than normal (Figures 57 and 58). Scales on infected green cones of slash and loblolly pine at harvest time have a purple discoloration (Figures 55 and 59). Some infected loblolly cones have a necrotic tip characterized by internal resin pockets. External resinous lesions colonized by *F. moniliforme* var. *subglutinans* are also observed on some loblolly pine cones.

Internal seed tissues infected by *F. moniliforme* var. *subglutinans* range from potentially sound (based on a radiograph) to badly deteriorated (Fig. 60) to mummified (Figure 56). Radiographs of many infected seeds show the gametophyte shrunken from the seedcoat and a slight deterioration of the embryo. Microscopic examination reveals a lack of cellular organization of the tissue and the presence of hyphae throughout the seed (Figure 61).

The two primary symptoms on vegetative structures are pitch canker and shoot dieback. Pitch canker is characterized by a bleeding, resinous canker on the trunk or large branches. The canker is usually sunken and the bark is retained, while the wood beneath the

---

[1] Prepared by Jane B. Barrows-Broaddus, Research Plant Pathologist, Southeastern Forest Experiment Station, USDA Forest Service, Carlton Street, Athens, Georgia 30602, U.S.A.

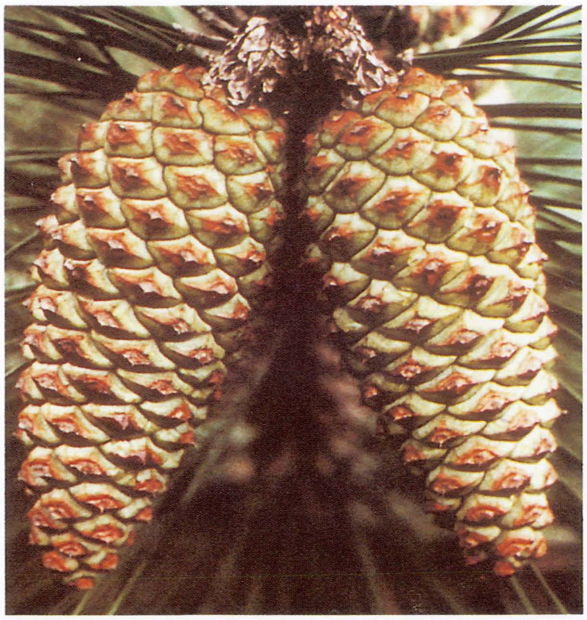


Figure 55. Slash pine cones, healthy (above) and with pitch canker natural infection (below); differences in cone size are not due to the disease (T. Miller, USFS).

Figure 56. A slash pine seed infected with the pitch canker fungus (whitish, cottony growth) (T. Miller, USFS).

canker is deeply pitch-soaked. Pitch-soaking of the underlying wood and the absence of swelling or callus help separate pitch canker from the other canker diseases of pines.

Shoot dieback in the upper crown results from lesions forming on the late-summer flushes of growth (Figure 62). In autumn, fully developed needles on infected shoots turn yellow to reddish brown. These "flags" continue to appear during winter into spring. Spread of the cankers down the lateral shoots is frequently arrested at one of the lower nodes. In the spring, new shoots may be fully expanded before they are killed by girdling in the older tissue. Needles that remain on the dead shoots eventually turn gray to grayish brown. Witches' brooms develop in some trees when shoots form in response to repeated infection and dieback.

Figure 57. *Fusarium moniliforme* var. *subglutinans* hyphae on loblolly pine cones, note cone distortion (J.B. Barrows-Broaddus, USFS).

Figure 58. Healthy loblolly pine cone and a cone stunted by *Fusarium moniliforme* var. *subglutinans* affected (stunted) (L.D. Dwinell, USFS).

Figure 59. Necrosis of loblolly pine cones caused by *Fusarium moniliforme* var. *subglutinans* (L.D.. Dwinell, USFS).

Figure 60. Radiograph of slash pine seed infected by *Fusarium moniliforme* var. *subglutinans* showing deterioration of gametophyte tissues and embryo (T. Miller, USFS)

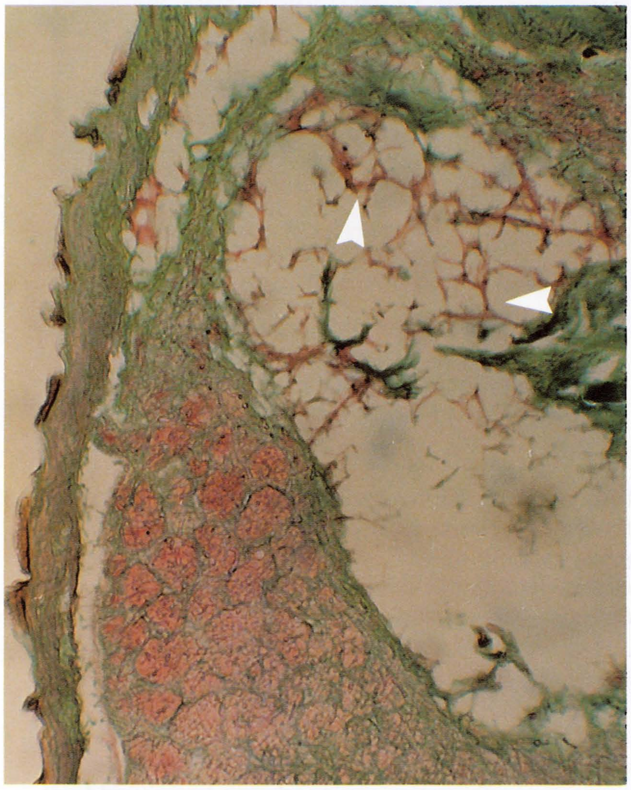


Figure 61. *Fusarium moniliforme* var. *subglutinans* hyphae (arrows) in the gametophyte tissue of a loblolly pine seed (J.B. Barrows-Broaddus, USFS).

Figure 62. Shoot dieback in a loblolly pine seed orchard caused by *Fusarium moniliforme* var. *subglutinans* (J.B. Barrows-Broaddus, USFS).

Figure 63. Sporodochia (arrows) of *Fusarium moniliforme* var. *subglutinans* on needle scars on an infected slash pine branch; sporodochia have also been observed on infected cones of slash pine (G.M. Blakeslee, University of Florida, U.S.A.).

Signs (12, 13, 14, 16, 22, 52, 53, 101, 102)

Mycelium is often present on the outer surfaces of badly deteriorated loblolly pine cones (Figure 57). Sporodochia of *F. moniliforme* var. *subglutinans* occur routinely on infected, small diameter branches (Figure 63). These fruiting bodies are found during all seasons of the year and are most frequently located in fascicular scars. Sporodochia range from 1 – 3 mm in diameter and are a light salmon-orange color (*sensu* Ridgeway). Except for supporting conidiophores, the sporodochia normally contain macroconidia (Figure 64).

Microscopic sporodochia (0.06 – 0.2 mm in diameter) occur on dead shoots. On Virginia pines, microscopic sporodochia are also observed on the surfaces of infected needles and in the axils and sheaths of buds emerging directly below a dead shoot.

Spores of *F. moniliforme* var. *subglutinans* are present throughout the year and can be recovered from dead branches in the crown, from rainwater falling through infected trees, and from the air. *Fusarium moniliforme* var. *subglutinans* is also isolated from forest soils, surfaces of pine needles, branches, boles, and

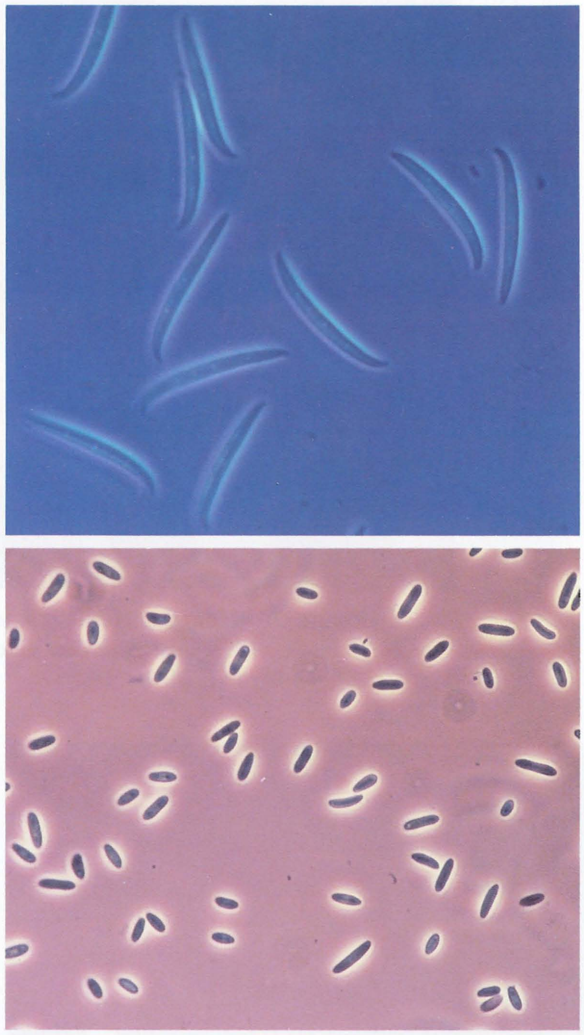


Figure 64. Two types of conidia produced by *Fusarium moniliforme* var. *subglutinans*; (top) macroconidia, (bottom) microconidia (400X) (G.M. Blakeslee, University of Florida, U.S.).

from bark and debris adhering to tree-shaker pads. Pathogenicity tests of these isolates on slash and loblolly pines indicate that *F. moniliforme* var. *subglutinans* occurs naturally in mixed populations of pathogenic and saprophytic strains.

Damage (2, 23, 53, 54, 101, 128, 129, 147, 158)

Damage to southern pines by *F. moniliforme* var. *subglutinans* includes tree mortality, growth suppression, stem deformation, seed and cone losses, and loss of seedlings in affected nursery beds.

Screening of selected loblolly pine seedlots has shown internal contamination by *F. moniliforme* var. *subglutinans* ranging from 0 – 11%. Preliminary observations on slash pine indicate that the amount of infection in a given seedlot may vary from 0 – 98%. Infection of the seeds by the pathogen decreases viability and causes post-emergence damping-off. At this time, it is not known if seedling mortality attributed to pitch canker in forest tree nurseries and movement of the disease from nurseries into field sites are due to infections originating in contaminated seeds.

Loblolly pines generally recover from outbreaks of shoot dieback, but at the height of an epidemic, considerable loss of the cone crop may occur. The impact of the disease on cone yield, however, varies from orchard to orchard. For example, most of an 86% decline in cone yield in one loblolly pine seed orchard was attributed to shoot dieback, while in another loblolly pine orchard, cones initiated during an epidemic resulted in a record cone and seed crop. Damage assessment of shoot dieback should include the relative susceptibilities of individual clones and their cone production histories, since both vary by genotype.

In slash pine seed orchards, where main stem cankers are common, the primary damage occurs when the trees break at the canker during snow and ice storms. Removal of diseased trees for sanitation shortens the life span of a seed orchard.

Isolation (15, 128)

To isolate *F. moniliforme* var. *subglutinans* from seeds, the seeds are soaked in 2% hydrogen peroxide for 5 minutes, then washed twice (3 minutes each time) in deionized, sterile water and blotted dry on sterile, absorbent paper. Under aseptic conditions, the seedcoats are removed with a sterile razor blade and forceps and plated three to six seeds per petri dish on a *Fusarium*-selective culture medium. The plates are incubated at 24°C with a 12 hour photoperiod for 5-7 days. Cultural and conidiophore characteristics (102 and Booth, C. 1971. The genus *Fusarium*. Commonwealth Mycol. Institute, Kew, Surrey, England) are illustrated in Figures 65 and 66 and described below:

CULTURES

Surface: texture cottony to felty and generally dense; color white to greyish white, pink to purple, margins even.

Reverse: buff to wine-red becoming purple to dark purple; no diffusion zone.

CONIDIOPHORES, CONIDIA, AND HYPHAE

Conidiophores: phialides (monophialides and polyphialides) may be formed either on unbranched conidi-

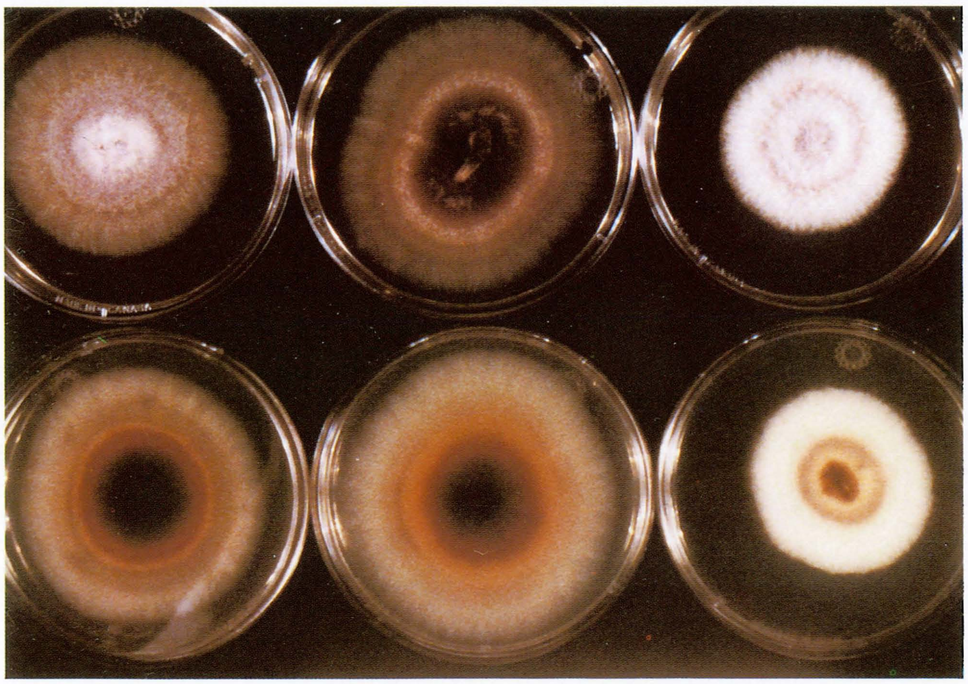


Figure 65. *Fusarium moniliforme* var. *subglutinans* cultures, surface view (above) and reverse (below) (J.R. Sutherland, CFS).

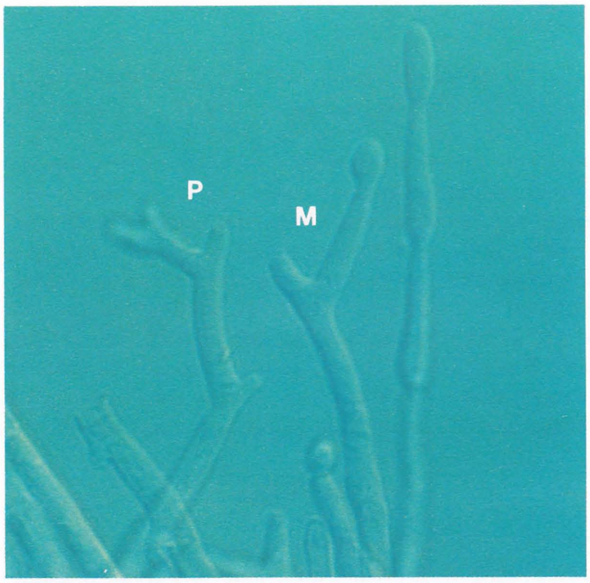


Figure 66. *Fusarium moniliforme* var. *subglutinans* forms both mono- (M) and polyphialides (P), (J.R. Sutherland, CFS).

ophores or as cells (phialides, polyphialides, and phialophores) in complex branching patterns; microconidia only in false heads, never in chains.

Conidia: microconidia 0 – 3-septate, 8-12 × 2.5-3.0 μm, hyaline, oval to obclavate; macroconidia thin-walled, sickle-shaped, 3 – 5 septate, 32-53 × 3-4.5 μm.

Hyphae: hyaline when young, becoming pink and finally purple.

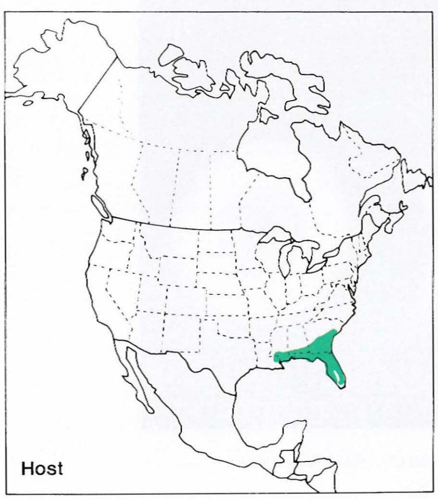
Distribution (6, 11, 13, 19, 21, 26, 51, 53, 54, 55, 81, 82, 83, 84, 95, 100, 101, 147) Figures 67 and 68.

Pitch canker of southern pines now extends from Virginia to southern Florida and west to eastern Texas. An outbreak of shoot dieback on loblolly and pond (*Pinus serotina*) pines in plantations in eastern North Carolina is currently causing concern. Since 1974, the disease has been confirmed on loblolly, longleaf (*P. palustris*) , shortleaf, slash, and Virginia pines in approximately 50 seed orchards.

Stem and branch cankers are found most frequently on slash, south Florida slash (*P. elliottii* var. *densa*), longleaf, Virginia, shortleaf, and eastern white (*P. strobus*) pine. Infrequent stem cankers on loblolly pine contain only narrow wedges of pitch-soaked tissue. Shoot dieback occurs primarily on planted slash and sand (*P. clausa*) pines in Florida and on loblolly pine in seed orchards throughout the southeastern United States.

Other hosts include pitch (*P. rigida*) and Table Mountain (*P. pungens*) pine in the United States and Western Indian pine (*P. occidentalis*) in Haiti. Monterey (*P. radiata*) and Scotch (*P. sylvestris*) pines, which are not native to the southeastern United States, become diseased and produce sporodochia when seedlings are artifically inoculated.

The relative susceptibility of inoculated seedlings of southern pine species varies as follows: Virginia and shortleaf pines, highly susceptible; slash, loblolly, and pitch pines, moderately susceptible; and pond and eastern white pines, relatively resistant. These rankings



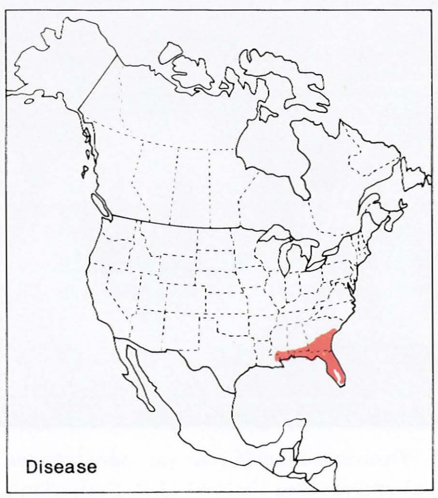


Figure 67. North American distribution of pitch canker on slash pine. (10, 19, 22, 24, 33, 98, 106, 128, 137, 147, 158, 184).

often change in field trials; species ranked as relatively resistant may develop a high incidence of disease under the influence of environmental stress and inoculum pressure. The hosts and distribution are:

Hosts	Distribution	References
Pinus clausa	USA : FL	26
Pinus echinata	USA : AL,NC,MS,TN,VA	51,95,176
Pinus elliottii var. *densa*	USA : FL	19
Pinus elliottii var. *elliottii*	USA : FL,GA	10,51,54,147
Pinus occidentalis	Haiti	84
Pinus palustris	USA : GA	51
Pinus pungens	USA : NC,VA	18
*Pinus radiata**		81
Pinus rigida	USA : NC,VA	18
Pinus serotina	USA : NC	100
Pinus strobus	USA : VA	6
*Pinus sylvestris**		82
Pinus taeda	USA : GA,AL,MS,NC,SC,TX	15,55,95,96,100
Pinus virginiana	USA : TN,AL,NC	11,14,83,95,176

* Seedlings artifically inoculated with *F. moniliforme* var. *subglutinans* developed symptoms of pitch canker disease.

Note: In general, disease distribution follows natural ranges of susceptible, southern pine species.

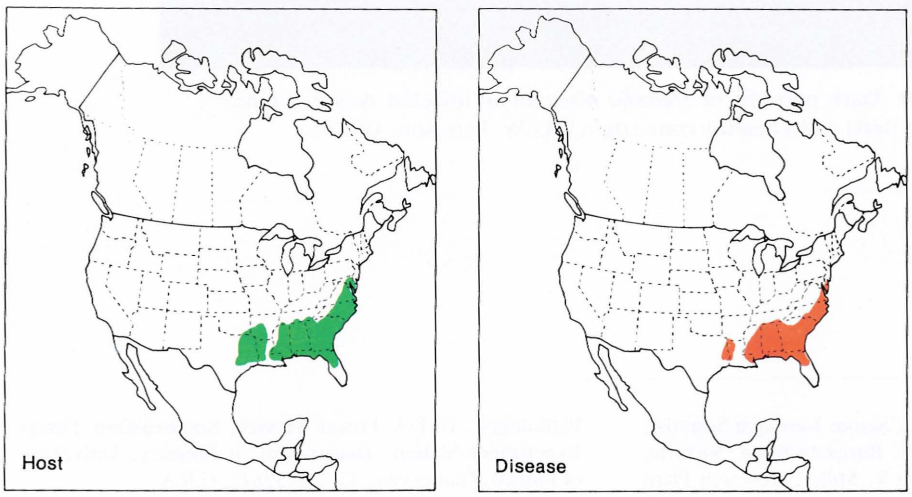


Figure 68. North American distribution of pitch canker on loblolly pine. (50, 54, 96, 101, 106, 128, 137, 188).

Cone and Seed Diseases of Minor Importance[1]

Table 2 contains diseases that up to now have only been documented to cause minor damage to seeds or cones. However, the importance of any of the diseases can increase in localized areas when conditions such as weather are favorable. The importance of some of these fungi could increase as cones and seeds of their hosts are produced in seed orchards where cultural or other conditions could enhance damage. Perhaps many of these fungi are classed as being of minor importance simply because they have not been well studied.

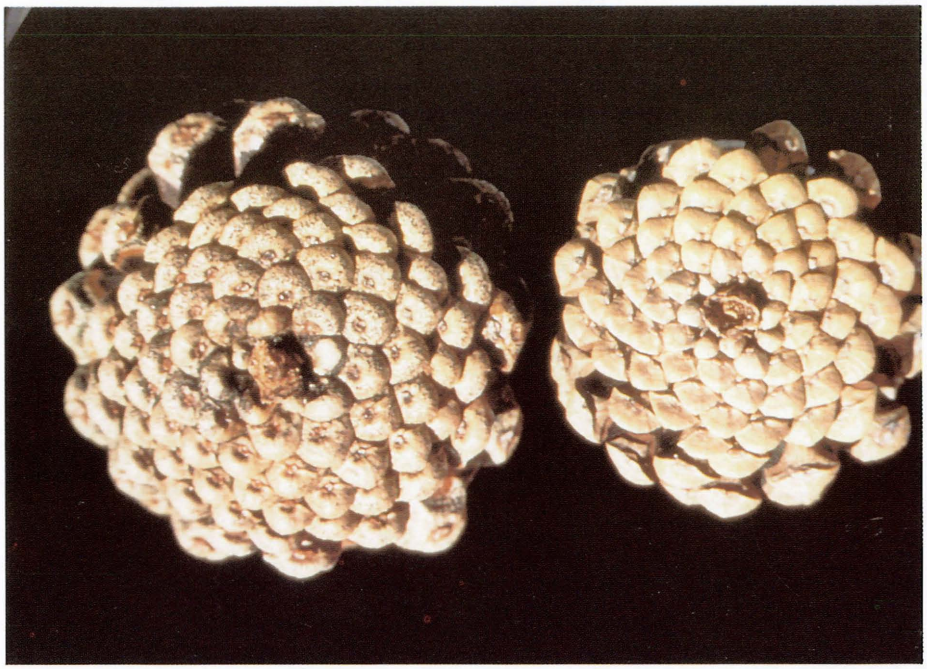


Figure 69. Dark pycnidia of *Diplodia pinea* on an infected Austrian pine cone (left) and a healthy cone (right) (G.W. Peterson, USFS).

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA and T. Miller, Research Plant Pathologist, USDA Forest Service, Southeastern Forest Experiment Station, Department of Forestry, University of Florida, Gainesville, Florida 32611, U.S.A.

Figure 70. Yellow-whitish aecia of *Pucciniastrum americanum* on white spruce cones (Maritime Forest Research Centre, CFS).

Table 2. Cone and Seed Diseases of Minor Importance in North America

Pathogen	Host(s)	Location	Remarks	References
Chrysomyxa woroninii Tanz	*Picea glauca* *P. mariana*	USA:AK	Found on ovulate strobili	Phytopathology 74: 456-461.
Cronartium quercuum (Berk.) Miyabe (*Peridermium cerebrum* Peck) Eastern gall rust	*Pinus banksiana* *Quercus* spp.	USA : MI	Reduces cone size, increases cone abortion. Widespread as a stem and branch gall of many pines.	28, 194
Lasiodiplodia theobromae (Pat.) Griff & Maubl. (*Diplodia gossypina* Cke.)	*Pinus elliottii* var. *elliottii*	USA : FL, GA	Extensively damages nearly mature cones and seeds of some slash pine seedlots. Causes tip dieback in southern forest tree nurseries.	128, 151
Diplodia pinea (Desm.) Kickx Figure 69.	*Pinus sylvestris* *P. nigra* *P. muricata* *P. sabiniana* *Pseudotsuga menziesii*	CANADA:ON USA: NE, CA	Fruits on second year Scotch pine cones. Widely distributed in Canada and the United States as a shoot tip blight or shoot canker on many pine species and Douglas-fir. Damage rating is moderate.	36: 1977-79, 1981; 72, 88, 92 G. Peterson, personal communication
Discella strobilina Died.	*Picea mariana*	CANADA:ON	Fruits on black spruce cone scales.	36:1967; 37
Elliottinia (*Sclerotinia*) *kerneri* (Wettst.) Kohn	*Abies balsamea*	CANADA:ON,PQ	Causes abnormally dense branching of twigs and staminate flower buds on apical stems of balsam fir. Black sclerotia in staminate flowers. Damage information unavailable.	57, 72
Fusarium oxysporum Schlecht.	*Pseudotsuga menziesii*	USA:OR	In Douglas-fir seeds and on seedcoats; causes pre-emergence damping-off.	69
Hericium abietis (Weir ex Hubert) Harr.	*Tsuga mertensiana*	CANADA:BC	A white pitted decay of mountain hemlock cones.	36:1956; 37
Melampsora abietis-canadensis (Farl.) Ludwig Conifer-aspen rust	*Tsuga canadensis* *Populus* spp.	CANADA:ON USA:from New England to PA,WI and NC	Widespread on eastern hemlock twigs and cones. Low damage rating. Pycnia and aecia on hemlock; uredinia and telia on foliage of various poplars. In early summer, produces golden-yellow powdery masses of spores on cone surface. These dry up, blacken, and adhere to twigs. Seeds nonviable.	36:1978-79; 62, 131, 188

Table 2. (continued). Cone and Seed Diseases of Minor Importance in North America

Pathogen	Host(s)	Location	Remarks	References
Melampsora medusae Thuem. Conifer-aspen rust	*Pseudotsuga menziesii* *Larix laricina* *Populus deltoides* *P. tremuloides*	CANADA:BC, ON	On Douglas-fir and tamarack cones. Widely distributed in Canada and USA as a very damaging needle rust of larch, fir, spruce, pine, and Douglas-fir. Pycnia and aecia (with pale to orange-yellow aeciospores) are produced on current-year needles or cones; uredinia and telia on poplar foliage.	131 36:1978, 1981; 131, 206
Pucciniastrum americanum (Farl.) Arth. American spruce-raspberry rust Figure 70.	*Picea engelmannii* *P. glauca* *Rubus* spp.	CANADA:BC, NB, MB USA: on alternate host and spruce cones in MN	Affects current-year needles, and rarely spruce cone scales, in Canada. Damage rating usually low. Pycnia and aecia (with orange-yellow aeciospores) on spruces; uredinia and telia on red raspberry.	188, 206
Pucciniastrum epilobii Otth Fir-fireweed rust	*Abies amabilis* *A. balsamea* *A. concolor* *A. grandis* *A. lasiocarpa* *Epilobium* spp.	Widespread throughout host distribution in Canada and USA	Widespread on current-year needles and fir cone scales. Damage rating low to moderate. Pycnia and aecia (with pale to orange-yellow aeciospores) on firs; uredinia and telia on fireweed.	36:1978; 72, 188, 206
Schizophyllum commune Fr.	*Pseudotsuga menziesii*	USA:WA	White mycelial mats on Douglas-fir cones or cone clusters. Mats frequently hinder seed extraction and may deteriorate seeds in cones stored at high moisture and temperatures near 20°C.	167
Trichoderma viride Pers.	*Pseudotsuga menziesii*	CANADA:BC	Hyphae in the seed coat of healthy Douglas-fir seeds, but not observed in endosperm or embryo.	27

Disease-Insect Interactions[1]

Both diseases and insects damage cones and seeds of North American conifers, but the potential for disease-insect interactions destroying cones and seeds has received little research attention. Certain destructive disease-insect complexes are documented, while others are suspected. Several insects are attracted to the exudation produced by the pycnial stage of rust fungi on infected cones. In the case of southern pine cone rust (124), coneworms (*Dioryctria* spp.) are attracted to infected, hypertrophied conelets for oviposition and feeding. Populations of coneworms increase rapidly in the rusted conelets, with several times more larvae developing in rusted than healthy conelets. After the diseased conelets die, the increased population of coneworms causes increased damage to second-year cones. A similar relationship is likely for the southwestern pine cone rust. Coneworms also feed on cones damaged by Inland spruce cone rust in British Columbia, (Figure 71), indicating that their association with rust-infected cones is widespread. Insects which may occur incidentally on pycnia-bearing cones could be involved in spermatization of rusts.

Two seedbugs, *Leptoglossus corculus* (Say) and *Tetyra bipunctata* (H.-S.) are thought to be involved in the fungal deterioration of slash pine seeds, either as vectors or by creating wounds that permit entry of the fungi. The two pathogens that damage slash pine cones and seed, *Fusarium moniliforme* var. *subglutinans* and *Lasiodiplodia theobromae*, are frequently present in both cone and seed tissues. The mode of infection of these two pathogens is still unknown, but a relationship with cone and seed insects is a distinct possibility.

Although the magnitude of disease-insect interactions affecting seed production is still incompletely understood, managers need to be aware of known or suspected disease-insect complexes so that they can follow available recommendations for preventing or reducing losses.

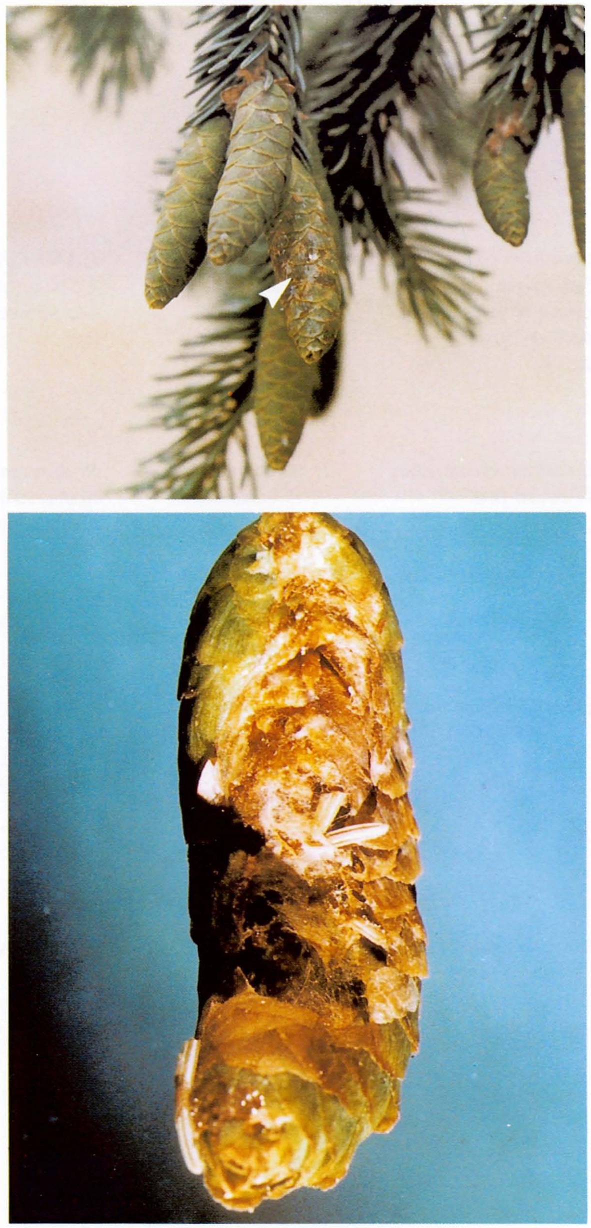


Figure 71. White spruce cones affected by Inland spruce cone rust were subsequently attacked by coneworms (arrow on upper cone). Note yellow-orange cone rust spermatia on the lower cone (J.R. Sutherland, CFS).

---

[1] Prepared by T. Miller, Research Plant Pathologist, USDA Forest Service, Southeastern Forest Experiment Station, Department of Forestry, University of Florida, Gainesville, Florida 32611, U.S.A. and Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA.

Cone and Seed Problems Caused by Abiotic Factors[1]

Also known as nonpathological or physiological diseases, abiotic diseases, as the name implies, are not caused by pathogens. Examples range from damage caused by environmental factors such as frost and drought to physiological abnormalities arising from nutrient deficiencies or excesses and reactions to phytotoxic chemicals, including pesticides. Abiotic diseases are typically characterized by one or more of the following: (i) They do not spread from affected to unaffected plants or tissues because no pathogen is involved; consequently, there is no sign (e.g. sporulation or mycelium) of a pathogen. (ii) Damage often results in chlorosis, abnormal discoloration, stunting, or twisting rather than death; if killed, tissues often desiccate. (iii) Damage develops rapidly after exposure to a phytotoxic chemical (Figure 72) or following a frost (Figure 73). (iv) Damage may follow a distinct pattern on a tree or within a seed orchard, e.g., most severe damage nearest the source of a phytotoxic chemical or on the windward side of a tree affected by a drifting chemical. (v) Several different plant species may be affected, including ground cover plants. Evidence of feeding or physical damage, which usually characterizes insect or animal damage, is absent for abiotic diseases. Ordinarily, young strobili from the bud stage through pollination would be most affected by abiotic diseases. Affected strobili may cease development, abort, or both, while external evidence of damage to older cones is less noticeable. In older cones, however, seed size and viability could be reduced. Normally, abiotic damage is not confined to cones or male flowers, but is also associated with needles and perhaps woody tissues.

Prevention is the best management strategy for reducing losses to abiotic diseases in seed orchards. Damage caused by climatic extremes is impossible to eliminate completely, but it may be reduced by careful attention to where seed orchards are established, e.g., not locating an orchard in a frost pocket, and not establishing a seed orchard for a given species beyond its natural range. Seed orchards should not be established

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA.

Figure 72. Douglas-fir flowers damaged by an unidentified chemical (D.S. Ruth, CFS).

Figure 73. Frost damaged Douglas-fir conelets (R.S. Hunt, CFS).

near sources of toxic chemicals.

Soil and moisture relationships are important considerations in preventing abiotic diseases in seed orchards. Locating a seed orchard on soils that are droughty, poorly drained, or excessively acid or alkaline can predispose trees to extreme physiological stress or render them susceptible to attack by pathogens and insects.

The intensive management generally imposed on seed orchards may require the use of an array of chemicals, including fertilizers, insecticides, and herbicides. Considerable care is required to assure that the proper chemical or formulation is applied at the rate, time, and growth phase recommended for a particular plant or pest. It is important to remember that cones and foliage of different phenological ages may vary in susceptibility to potential chemical damage. Finally, great care should always be given to assuring that insecticides and herbicides are directed only at the target pest or plant species. Many chemicals can become dangerous environmental hazards to nontarget organisms, including man, when applied improperly.

Detection and Management of Cone and Seed Diseases[1]

Detection

The first step in detecting cone and seed diseases is to obtain an inventory of the diseases, and other potential pests, such as insects, that occur on the orchard's species in the area where a seed orchard is to be, or has been, established or in the locality where cones will be collected from native stands. For diseases, this information is usually available from local forest pathologists. An inventory will identify the diseases that have affected cones, and perhaps seeds, in the past and may indicate their relative importance. In both forest stands and seed orchards, the importance of a particular disease may vary from year to year, depending upon factors, such as weather, which affect both hosts and pathogens. An additional consideration in seed orchards is that cultural practices such as application of fertilizers and irrigation, which influence the abundance or phenology of cone crops, may affect disease severity. Seed orchard trees of non-local origin or exotic species may be affected more severely by a disease than are indigenous trees. Estimates of cone losses due to diseases and other factors may be obtained at the same time that estimates are made of orchard productivity. Procedures have been published for estimating cone productivity (31,32) and both cone productivity and pest damage (60, 61) in southern U.S. pine seed orchards. Similar procedures need to be developed and implemented elsewhere in North America, incorporating many of the features developed in the southern U.S. However, because of differences in factors such as tree species, cone phenology (e.g., 1- versus 2-year cones), climate, and pests, it is likely that many different monitoring systems will evolve across North America to meet local requirements.

[1] Prepared by Jack R. Sutherland, Senior Research Scientist, Pacific Forestry Centre, 506 W. Burnside Road, Victoria, B.C. V8Z 1M5, CANADA; David L. Bramlett, Research Plant Physiologist, USDA Forest Service, Southeastern Forest Experiment Station, Route 1, Box 182A, Dry Branch, Georgia 31020, U.S.A.; and Carl W. Fatzinger, Research Entomologist, USDA Forest Service, Southeastern Forest Experiment Station, Olustee, Florida 32672, U.S.A.

While diseases of cones are most likely to be noticed when the cones are on the trees, diseases of seeds and seed-borne pathogens are usually first observed after radiography and seed stratification, during germination tests or after germination in the nursery. While the role that certain seed-associated fungi play in seed health is known, the importance of the many so-called saprophytes, such as *Penicillium* and *Aspergillus*, which are often prevalent during seed germination testing, is not well defined. Indeed, many of these fungi may simply be indicators of poor quality seeds rather than being the cause of deterioration. Seed-borne fungi often can be detected under the low-power magnification (10-20X) of a hand lens or stereomicroscope; however, a mycologist or plant pathologist should identify the fungi. The reliability of a particular assay technique depends upon the abundance of the fungus and the number of seeds that are examined. After preliminary observations are made to estimate the relative abundance of the fungus, a biometrician can determine the sizes of the seed samples needed to detect the fungus at specific confidence levels. For example, based on preliminary data, it was determined that a 500-seed sample is required from each seedlot to detect the seed fungus (see earlier chapter). With that size of sample, there is a 5% probability that *C. fulgens* will not be detected when the infestation level is 1% or less. The standard procedure for detecting seed-borne fungi is to plate the seeds on a nutrient medium (see earlier sections). Since this technique is very time consuming and unreliable when the pathogen infestation level is low, immunological assays are being developed for detecting certain seed-borne pathogens of conifers. Their main advantages are their specificity, rapidity, and greater accuracy because seed sample size can be increased many fold.

Sometimes seed-borne pathogens are first noticed in the nursery affecting germinants or young seedlings, e.g. *Sirococcus* blight. A seed-borne pathogen can be suspected when a particular disease appears on germinants or young seedlings of a specific seedlot, especially over several years, and in localities where inoculum is not available from nearby sources, such as windbreak trees. Some seed-borne pathogens, such as the seed fungus, may cause abnormally high pre-emergence losses.

Management

Cone and seed diseases are best managed by using an integrated approach consisting of orchard monitoring, cultural practices, and application of fungicides. Other factors being equal, a seed orchard site often can be selected to avoid certain diseases. For example, in British Columbia, Inland spruce cone rust affects up to 60% of the cones in a spruce seed orchard near Salmon Arm, but the disease does not occur in spruce orchards 50 km south at Vernon, where the drier and hotter summer climate excludes the rust's alternate hosts. Similarly, locating slash (*Pinus elliottii* var. *elliottii*) and longleaf (*P. palustris*) pine orchards out of the range of southern pine cone rust would be an effective strategy. Locating seed orchards in areas that are as free as possible of major pests should be a criterion in selecting seed orchard sites. An alternative is to rid the area immediately around the orchard of diseased trees and the alternate hosts of rusts. For example, removing trees infected with western gall rust for 275 m around hard pine orchards should alleviate losses from this disease. Areas that may be subject to high levels of toxic or injurious chemicals in the air should not be selected for seed orchards. When establishing an orchard, disease-free stock should be used to prevent introducing diseases into the orchard. Sanitation practices, including roguing and destroying diseased and old cones, should be helpful in control of some diseases. Because cone pathogens such as the pitch canker fungus enter cones via wounds, precautions should be taken to minimize wounding of cones, including that done by insects.

Although cultural and related practices will help alleviate losses to cone and seed diseases, fungicides may need to be applied either occasionally or routinely, depending upon the regularity and severity with which a disease occurs. To date in North American seed orchards, only southern pine cone rust and Inland spruce cone rust have consistently caused enough damage to warrant application of fungicides (122 and J. Sutherland, unpublished). The specific fungicide that is used for disease control will depend upon numerous criteria, including efficacy, possible phytotoxicity, cost, and timing. Based on experience with southern cone rust and Inland spruce cone rust, fungicides should be applied to protect during the infection period, which is from emergence of strobili through scale closure after pollination. Systemic fungicides hold particular promise for control of rusts and other diseases of cones because they may allow a considerable reduction in the number of fungicide applications required and less critical timing of applications and because they may eradicate already established fungi as well as protecting cones from pathogens.

Glossary of Cone and Seed Disease Terms

Aborted ovule: First year: Any potential seed that aborts (ceases development) during the first growing season or conelet stage of development. Second year: Any potential seed that aborts during the second growing season.

Abscission: Separation of leaves, flowers, or fruit from plants, generally associated with deterioration of a specialized layer of thin-walled cells.

Aecioid teliospores: Teliospores with the morphological characteristics of aeciospores produced by other rust fungi, e.g. the genus *Endocronartium.*

Aeciospore: One of the spore types produced by a rust fungus. Formed in and released from fruiting structure called an aecium.

Aecium (Aecia, plural): A structure in which aeciospores are produced; develops after the spermogonium (pycnium) and before the uredinium in the life cycle of a rust fungus.

Alternate host: One or the other of the two unlike host plants parasitized by a heteroecious fungus, such as a typical rust fungus.

Alternation: Successive occurrence of a rust fungus on its two alternate hosts during its life cycle.

Ascomycete: A large group of fungi producing their sexual spores, ascospores, within a structure termed an ascus (asci, plural).

Asexual stage (state) or spore: Either a vegetative stage or a reproductive stage in the life cycle of a fungus in which nuclear fusion is absent and in which reproductive spores are produced by mitosis or simple nuclear division. Synonym: imperfect stage, anamorph.

Atrophy: Underdevelopment in size or function of a plant part or organ.

Autoecious (of a rust): Completing its life cycle on one host plant; the opposite of heteroecious.

Axis (of a cone or strobilus): The central, rod-like core of a cone (strobilus) to which scales and bracts are attached.

Basidiomycete: A large group of fungi, including the rusts, which are characterized by the production of spores, typically four, on a basidium.

Basidiospore: The spore produced by the sexual stage of the basidiomycetes. Basidiospores are wind-disseminated and spread a disease by causing new infections.

Blight: A general term for a plant disease causing rapid death or dieback.

Bract: A thin, leaf-like structure interspersed with the scales of cones. In certain cones, bracts are very noticeable, e.g., Douglas-fir.

Canker: A definite, relatively localized, necrotic lesion primarily of the bark and cortical tissues of stems and roots.

Catkin: A male strobilus which produces pollen.

Chlorosis: An abnormal yellowing of foliage.

Chlorotic: Abnormally diffused or patterned yellowing of normally green plant parts.

Cone: A female strobilus of pines during the second season of development, or of other conifers that produce mature cones and seed in a single season.

Conelet: A female strobilus of: (a) pines during the first season of development following pollination, and (b) early stages of cone development of conifers in which cones develop in one season.

Cone stalk: The pedicel, or stem-like structure attaching a cone to the branch.

Conidium (Conidia, plural): Asexual spore of a fungus, typically produced terminally on a specialized hypha termed a conidiophore.

Contaminants: Impurities; specifically spores, cells, or hyphae present on pollen, seeds, or strobili that can, under proper conditions, grow, spread, and cause damage.

Controlled pollination: Transfer of pollen from a known source to receptive flower parts of a known seed parent, all other pollen being excluded.

Cotyledons: First leaves developed in the embryo of a seed.

Culture: The process of securing the growth of fungi or other microorganisms upon artificial media (isolation), or of parasitic organisms (like rusts) upon host plants; the organism or organisms resulting from the culturing process.

Decay: The decomposition of plant tissue by fungi and other microorganisms.

Dieback: The progressive dying of stems and branches from the tip downward.

Disease: Unfavorable change of the function or form of a plant from normal; caused by a pathogenic agent, unfavorable environment, or phytotoxic chemical.

Disease cycle: The chain of events involved in disease development, including the stages of development of the pathogen and the effect of the disease on the host.

Dormancy (in spores): Resting stage in which germination may be delayed until the spores become mature and viable and external conditions are favorable.

Dormant: Being in a state of dormancy, such as perennial plants and teliospores of certain rusts during winter.

Endemic: Native to the country or region; the regular occurrence of a disease with little variation in abundance.

Endocyclic (of rusts): Having a life cycle with spermogonial and aecial spore stages only, in which the spores that appear to be aeciospores function as teliospores to produce basidiospores, may be referred to as aecidioid telia or telial aecia.

Endosperm: In conifers, the haploid (1n) material (gametophyte tissue) surrounding the embryo, which provides food reserves for the seed.

Epicotyl: Portion of the axis of a plant embryo or seedling stem above the cotyledons.

Epidemic: Pertaining to a disease that has built up rapidly and reached injurious levels over a large area.

Epiphytotic: Suddenly and destructively affecting plants in a locality, as an epiphytotic disease.

Etiology: In pathology, that phase in the study of a disease which deals with the causal factor, the pathogen, and its relations with the host.

Female flowers: The female strobili of conifers prior to and during pollination.

Fertile scale: A cone scale that is capable of producing seed.

Filled seed: Mature ovule containing an embryo and nutritive (gametophyte) tissue enclosed in layers of protective tissue (seedcoat), capable of development into a plant similar to the one that produced it. (See potentially sound seed).

Fruit body (fruiting body): A spore-producing or spore-bearing structure; e.g., an aecium, uredinium, or telium of the rust family.

Fungus (Fungi, plural): An undifferentiated plant lacking chlorophyll and conductive tissues.

Gall: A pronounced swelling on a plant caused by certain fungi, bacteria, insects, or nematodes.

Germ tube: The hypha produced by a germinated fungus spore which, with continued growth, develops into a mycelium.

Gymnosperm: A division in the classification of plants; a plant that bears naked seeds, as the conifers.

Habit: The general, external, and characteristic appearance or manner of growth of animals or plants (e.g. fungi).

Habitat: The natural place of growth of a fungus or other organism.

Haustorium (Haustoria, plural): A specialized projection of hyphae of a parasitic fungus, which penetrates a host cell and serves as an absorbing organ, characteristic of rust fungi.

Heteroecious (of a rust): Completing its life cycle on two unrelated plants (alternate hosts); compare with autoecious.

"Hip canker": A canker on one side of the trunk of pine, partially or almost completely grown over, caused by western gall rust (*Endocronartium harknessii*).

Host: The plant on or in which a pathogen or parasite exists.

Host-range: All hosts that a particular pathogen attacks.

Hyperplasia: Abnormal production of cells, causing enlargement of some part of a plant.

Hypertrophy: Abnormal enlargement of cells, causing enlargement of some part of a plant.

Hypha (Hyphae, plural): One of the filamentous threads that make up the mycelium (the fungus body).

Hypocotyl: That part of the axis of an embryo or stem of a seedling between the cotyledons and the radicle.

Imperfect state (or stage), anamorph: A phase of the life cycle of a fungus in which asexual spores (e.g. aeciospores, urediniospores) are produced.

Infect: To invade and cause a disease.

Infest: To be present within an area (or plant or soil) in such numbers as to be a disease hazard.

Inoculate: To place a pathogen on or in a host in a position in which it is capable of infecting.

Inoculum: The spores, mycelium, sclerotia, or other propagules of a pathogen which initially infect a host or crop.

Latent infection: An established infection that does not show its presence.

Lesion: A defined area of necrotic (dead) cells or tissue.

Life cycle (of rust fungi): The stages (states) between one spore form and the development of the same spore form again. There are commonly five spore stages in the life cycle of tree rusts (the spermogonial or pycnial, aecial, uredinial, telial, and basidial stages, denoted by the numerals O, I, II, III, IV), but there may be no development, or no knowledge, of one or more of the stages.

Life history: The stages involved in the development, progression, and spread of a disease, including spore production by the pathogen, infection of the host(s), and development of the disease (compare to life cycle).

Lobulate: Having small lobes.

Long-cycled: See macrocyclic.

Macrocyclic, long-cycled (of rusts): Having a life cycle involving the aecial, telial, basidial, and usually the spermogonial and uredinal spore states.

Male flowers: The male strobili (catkins) of conifers which produce pollen.

Microcyclic, short-cycled (of rusts): Having a life cycle involving only the telial and basidial (and sometimes the spermogonial) spore stages.

Micropyle: A minute opening into an ovule through which the pollen grain normally passes to reach the pollen chamber.

Mold (Mould): Any profuse or woolly fungus growth on damp or decaying matter or on the surface of plant tissue.

Mycelium: A mass of hyphae that forms the vegetative, filamentous body of a fungus.

Necrosis: Death of cells, especially when tissues become dark; commonly a symptom of infection and disease.

Ovule: The female tissue of a seed that develops into a seed after fertilization by pollen.

Parasite: An organism living on and nourished by another living organism.

Pathogen: An organism capable of causing disease.

Pathogenic: Producing disease or capable of doing so.

Perfect state (or stage), teleomorph: A phase of the life cycle of a fungus in which spores (e.g. basidiospores) are formed after nuclear fusion; the telial stage in rust fungi.

Peridermium: An aecium with a blister-like, tongue-shaped, or cylindric peridium.

Peridium (of rusts): The outer, enveloping membrane of fruit bodies.

Phenology: Relations between plant functions and seasonal climatic changes, such as temperature or day length, especially as such changes affect periodic phenomena such as leafing, flowering, and dormancy.

Pollen sac: The structure in which developing pollen of a coniferous male flower (strobilus) is enclosed.

Pollen tube: An outgrowth of a germinating pollen grain through which the sperm passes to fertilize the egg.

Pollination: The transfer of pollen to a receptive female flower.

Potentially sound seed: Seed filled with apparently undamaged tissue on which viability has not been tested.

Pycnidiospore: An asexual (anomorph) spore or conidium produced within a pycnidium.

Pycnidium (Pycnidia, plural): An asexual (anamorph) type of fruiting body, typically flask-shaped, in which asexual spores or conidia are produced.

Pycniospore: A spore (also called a spermatium) produced in the fruit body of rust fungi called a pycnium.

Pycnium (Pycnia, plural): A fruit body containing pycniospores, produced after the basidium and before the aecium in the life cycle of a rust (also called a spermogonium).

Radicle: That portion of the axis of an embryo from which the root develops.

Rot: See decay

Rust: Parasitic fungi of the order Uredinales; the disease caused by a fungus of the order Uredinales.

Saprophyte: An organism using dead organic material as food.

Scale: The structures of a cone upon which the seeds are borne.

Sclerotium (Sclerotia, plural): A firm, frequently rounded, multicellular resting stage produced by certain fungi.

Seedcoat: The hard covering of a seed.

Seed orchard: A plantation of clones or seedlings from selected trees cultured for seed production.

Seed potential: Two times the number of fertile cone scales or the maximum number of seeds a cone is capable of producing.

Serotinous: Pertaining to cones that remain closed on the tree for several months to a year or more after maturity.

Sexual stage (state): The stage in the life cycle of a fungus in which spores are produced after sexual fusion. Synonym: perfect stage, teleomorph.

Short-cycled: See microcylic.

Sign: The pathogen or its parts or products seen on the host plant.

Sorus (sori, plural): A compact mass of spores or fruiting structure found especially in the rusts and smuts.

Spermogonium: See pycnium.

Spore: The reproductive structure of the fungi and other lower plants.

Sporodochium (Sporodochia, plural): A mass of conidiophores on a mound or mass of hyphae; occurs in the fungus genus *Fusarium.*

Sporulate: To produce and release spores.

Strobilus (strobili, plural): The male and female reproductive structures of conifers.

Susceptible: Vulnerable to attack by an organism or damage by a non-living agent.

Symptom: The evidence of disturbance in the normal development and function of a host plant, e.g., chlorosis, necrosis, and galls.

Systemic: Spreading internally throughout the plant body, said of a pathogen or a chemical.

Teliospore: The spore stage of the rust fungi from which basidia and basidiospores are produced.

Telium (Telia, plural): A fruit body containing teliospores, produced after the uredinium and before the spermogonium in the life cycle of a rust.

Urediniospore: Spore borne in a uredinium, and capable of infecting the same host on which it originated; also called urediospore.

Uredinium (Uredinia, plural): A fruit body containing urediniospores, produced after the aecium and before the telium in the life cycle of a rust; also called uredium.

Virulence: Degree of being pathogenic.

Wilt: A type of plant disease characterized by the sudden loss of turgor and collapse of the succulent parts of the affected plants.

References for Glossary

Agrios, G.N. 1969. Plant pathology. Academic Press, New York, 629 p.

Bramlett, D.L., E.W. Belcher, Jr., G.L. DeBarr, G.D. Hertel, R.P. Karrfalt, C.W. Lantz, T. Miller, K.D. Ware, and H.O. Yates III. 1977. Cone analysis of southern pines - a guidebook, USDA For. Serv., Southeast. For. Exp. Stn., Gen. Tech. Rep. SE-13. 28 p.

Franklin, E.C. (ed.). 1981. Pollen management handbook. USDA For. Serv., Agric. Handbk. No. 587. 98 p.

Hedlin, A.F., H.O. Yates III, D.C. Tovar, B.H. Ebel, T.W. Koerber, and E.P. Merkel. 1980. Cone and seed insects of North American conifers. Canadian Forestry Service/United States Forest Service/Secretaria de Agricultura y Recursos Hidraulicos, Mexico, 122 p.

Peterson, G.W. and R.S. Smith, Jr. (eds.). 1975. Forest nursery diseases in the United States. USDA For. Serv., Agric. Handbk. No. 470. 125 p.

Schopmeyer, C.S. (ed.). 1974. Seeds of woody plants in the United States. USDA For. Serv., Agric. Handbk. No. 450. 883 p.

Snyder, E.B. 1972. Glossary for forest tree improvement workers. USDA For. Serv., South. For. Exp. Stn., New Orleans, LA, 22 p.

Ziller, W.G. 1974. The tree rusts of Western Canada. Can. For. Serv., Pacific For. Res. Centre, Victoria, B.C., Publ. No. 1329. 272 p.

List of Cone and Seed Disease Hosts by Scientific Name

(40,44,74,106,107,108,118,130,152,161,188)

Scientific name	Common name
Abies Mill.	fir
Abies amabilis (Dougl.) Forbes	Pacific silver fir
Abies balsamea (L.) Mill.	balsam fir
Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.	white fir
Abies grandis (Dougl. ex D. Don)	grand fir
Abies lasiocarpa (Hook.) Nutt.	subalpine fir
Epilobium L.	fireweed
Larix Mill.	larch
Larix kaempferi (Lamb.) Carr.	Japanese larch
Larix laricina (Du Roi) K. Koch	tamarack
Libocedrus decurrens Torr.	incense-cedar
Moneses uniflora (L.) Gray	single-delight
Picea A. Dietr.	spruce
Picea abies (L.) Karst.	Norway spruce
Picea engelmannii Parry ex Engelm.	Engelmann spruce
Picea glauca (Moench) Voss	white spruce
Picea mariana (Mill.) B.S.P.	black spruce
Picea pungens Engelm.	blue spruce
Picea rubens Sarg.	red spruce
Picea sitchensis (Bong.) Carr.	Sitka spruce
Pinus L.	pine
Pinus albicaulis Engelm.	whitebark pine
Pinus attenuata Lemm.	knobcone pine
Pinus ayacahuite Ehrenb.	Mexican white pine
Pinus banksiana Lamb.	jack pine
Pinus canariensis Smith	Canary Island pine
Pinus cembroides Zucc.	Mexican pinyon (pine)
Pinus clausa (Chapm. ex Engelm.) Vasey ex Sarg.	sand pine
Pinus contorta Dougl. ex Loud.	lodgepole pine
Pinus contorta Dougl. ex Loud. var. *contorta*	shore pine
Pinus cooperi Blanco	Cooper pine
Pinus coulteri D. Don	Coulter pine
Pinus densiflora Sieb. & Zucc.	Japanese red pine
Pinus durangensis Martinez	Durango pine
Pinus echinata Mill.	shortleaf pine
Pinus elliottii var. *densa* Little & Dorman	South Florida slash pine
Pinus elliottii Engelm. var. *elliottii*	slash pine
Pinus engelmannii Carr.	Apache pine
Pinus glabra Walt.	spruce pine
Pinus greggii Engelm.	Gregg pine

Scientific name	Common name
Pinus halepensis Mill.	Aleppo pine
Pinus hartwegii Lindl.	Hartweg pine
Pinus jeffreyi Grev. & Balf.	Jeffrey pine
Pinus lambertiana Dougl.	sugar pine
Pinus lawsonii Roezl.	Lawson pine
Pinus leiophylla var. *chihuahuana* (Engelm.) Shaw	Chihuahua pine
Pinus lumholtzii Rob. & Fern	Lumholtz pine
Pinus michoacana Martinez	Michoacan pine
Pinus montezumae Lamb.	Montezuma pine
Pinus mugo Turra	mugo or Swiss mountain pine
Pinus muricata D. Don	bishop pine
Pinus nigra Arnold	Austrian pine
Pinus occidentalis Swartz	Western Indian pine
Pinus oocarpa Schiede	wheelbarrow torchwood pine
Pinus palustris Mill.	longleaf pine
Pinus patula Schl. & Cham.	jelecote pine
Pinus pinaster Ait.	maritime pine
Pinus pinceana Gord.	Pince pinyon (pine)
Pinus pinea L.	planted pine
Pinus ponderosa Dougl. ex Laws.	ponderosa pine
Pinus ponderosa var. *arizonica* (Engelm.) Shaw	Arizona pine
Pinus pseudostrobus Lindl.	false Weimouth pine
Pinus pungens Lamb.	Table Mountain pine
Pinus radiata D. Don	Monterey pine
Pinus resinosa Ait.	red pine
Pinus rigida Mill.	pitch pine
Pinus rudis Endl.	rudis pine
Pinus sabiniana Dougl.	Digger pine
Pinus serotina Michx.	pond pine
Pinus strobus L.	eastern white pine
Pinus sylvestris L.	Scotch (Scots) pine
Pinus taeda L.	loblolly pine
Pinus teocote Schl. & Cham.	Aztec pine
Pinus thunbergii Parl.	Japanese black pine
Pinus virginiana Mill.	Virginia pine
Populus L.	cottonwood or aspen
Populus deltoides Bartr.	eastern cottonwood
Populus tremuloides Michx.	trembling aspen
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Pyrola L.	wintergreen
Pyrola asarifolia Michx.	large or pink wintergreen
Pyrola dentata Sm.	Nootka wintergreen
Pyrola elliptica Nutt.	shinleaf
Pyrola grandiflora Radius	arctic wintergreen
Pyrola minor L.	lesser wintergreen
Pyrola picta Sm.	painted pyrola
Pyrola rotundifolia L.	Muguet de Bois
Pyrola secunda L.	one-sided wintergreen
Pyrola virens Schweigg.	greenish-flowered wintergreen
Quercus L.	oak
Quercus alba L.	white oak
Quercus arizonica Sarg.	Arizona white oak
Quercus bicolor Willd.	swamp white oak

Scientific name	Common name
Quercus chapmanii Sarg.	Chapman oak
Quercus chrysolepis Liebm.	canyon live oak
Quercus dunnii Kellogg	Dunn oak
Quercus emoryi Torr.	Emory oak
Quercus grisea Liebm.	gray oak
Quercus hypoleucoides A. Camus	silverleaf oak
Quercus ilicifolia Wangenh.	bear oak
Quercus incana Bartr.	bluejack oak
Quercus laevis Walt.	turkey oak
Quercus laurifolia Michx.	laurel oak
Quercus macrocarpa Michx.	bur oak
Quercus myrtifolia Willd.	myrtle oak
Quercus nigra L.	water oak
Quercus oblongifolia Torr.	Mexican blue oak
Quercus phellos L.	willow oak
Quercus prinus L.	chestnut oak
Quercus rugosa Nee	netleaf oak
Quercus stellata Wangenh.	post oak
Quercus virginiana Mill. var. *virginiana*	live oak (typical)
Quercus virginiana var. *geminata* (Small) Sarg.	sand live oak
Rubus L.	raspberry
Tsuga (Endl.) Carr.	hemlock
Tsuga canadensis (L.) Carr.	eastern hemlock
Tsuga heterophylla (Raf.) Sarg.	western hemlock
Tsuga mertensiana (Bong.) Carr.	mountain hemlock

List of Cone and Seed Disease Hosts by Common Name

(40,44,74,106,107,108,118,130,152,161,188)

Common name	Scientific name
Arctic wintergreen	*Pyrola grandiflora* Radius
Arizona pine	*Pinus ponderosa* var. *arizonica* (Engelm.) Shaw
Arizona white oak	*Quercus arizonica* Sarg.
Aspen	*Populus* L.
Aleppo pine	*Pinus halepensis* Mill.
Apache pine	*Pinus engelmannii* Carr.
Austrian pine	*Pinus nigra* Arnold
Aztec pine	*Pinus teocote* Schl. & Cham.
Balsam fir	*Abies balsamea* (L.) Mill.
Bear oak	*Quercus ilicifolia* Wangenh.
Bishop pine	*Pinus muricata* D. Don
Black spruce	*Picea mariana* (Mill.) B.S.P.
Bluejack oak	*Quercus incana* Bartr.
Blue spruce	*Picea pungens* Engelm.
Bur oak	*Quercus macrocarpa* Michx.
Canary Island pine	*Pinus canariensis* Smith
Canyon live oak	*Quercus chrysolepis* Liebm.
Chapman oak	*Quercus chapmanii* Sarg.
Chestnut oak	*Quercus prinus* L.
Chihuahua pine	*Pinus leiophylla* var. *chihuahuana* (Engelm.) Shaw
Cooper pine	*Pinus cooperi* Blanco
Cottonwood	*Populus* L.
Coulter pine	*Pinus coulteri* D. Don
Digger pine	*Pinus sabiniana* Dougl.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Dunn oak	*Quercus dunnii* Kellogg
Durango pine	*Pinus durangensis* Martinez
Eastern cottonwood	*Populus deltoides* Bartr.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Eastern white pine	*Pinus strobus* L.
Emory oak	*Quercus emoryi* Torr.
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
European black pine	see Austrian pine
False Weimouth pine	*Pinus pseudostrobus* Lindl.
Fir	*Abies* Mill.
Fireweed	*Epilobium* L.
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Gray oak	*Quercus grisea* Liebm.
Greenish-flowered wintergreen	*Pyrola virens* Schweigg.
Gregg pine	*Pinus greggii* Engelm.

Common name	Scientific name
Hartweg pine	*Pinus hartwegii* Lindl.
Hemlock	*Tsuga* (Endl.) Carr.
Incense-cedar	*Libocedrus decurrens* Torr.
Jack pine	*Pinus banksiana* Lamb.
Japanese black pine	*Pinus thunbergii* Parl.
Japanese larch	*Larix kaempferi* (Lamb.) Carr.
Japanese red pine	*Pinus densiflora* Sieb. & Zucc.
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.
Jelecote pine	*Pinus patula* Schl. & Cham.
Knobcone pine	*Pinus attenuata* Lemm.
Kuro-matsu	see Japanese black pine
Larch	*Larix* Mill.
Large wintergreen	*Pyrola asarifolia* Michx.
Laurel oak	*Quercus laurifolia* Michx.
Lawson pine	*Pinus lawsonii* Roezl.
Lesser wintergreen	*Pyrola minor* L.
Live oak (typical)	*Quercus virginiana* Mill. var. *virginiana*
Loblolly pine	*Pinus taeda* L.
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Longleaf pine	*Pinus palustris* Mill.
Lumholtz pine	*Pinus lumholtzii* Rob. & Fern.
Maritime pine	*Pinus pinaster* Ait.
Mexican blue oak	*Quercus oblongifolia* Torr.
Mexican pinyon (pine)	*Pinus cembroides* Zucc.
Mexican white pine	*Pinus ayacahuite* Ehrenb.
Michoacan pine	*Pinus michoacana* Martinez
Monterey pine	*Pinus radiata* D. Don
Montezuma pine	*Pinus montezumae* Lamb.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Mugo pine	*Pinus mugo* Turra
Muguet de Bois	*Pyrola rotundifolia* L.
Myrtle oak	*Quercus myrtifolia* Willd.
Netleaf oak	*Quercus rugosa* Nee
Nootka wintergreen	*Pyrola dentata* Sm.
Norway spruce	*Picea abies* (L.) Karst.
Oak	*Quercus* L.
One-sided wintergreen	*Pyrola secunda* L.
Pacific silver fir	*Abies amabilis* (Dougl.) Forbes
Painted pyrola	*Pyrola picta* Sm.
Pince pinyon (pine)	*Pinus pinceana* Gord.
Pine	*Pinus* L.
Pink wintergreen	see large wintergreen
Pitch pine	*Pinus rigida* Mill.
Planted pine	*Pinus pinea* L.
Pond pine	*Pinus serotina* Michx.
Ponderosa pine	*Pinus ponderosa* Dougl. ex. Laws.
Post oak	*Quercus stellata* Wangenh.
Raspberry	*Rubus* L.
Red pine	*Pinus resinosa* Ait.
Red spruce	*Picea rubens* Sarg.
Rudis pine	*Pinus rudis* Endl.
Sand live oak	*Quercus virginiana* var. *geminanata* (Small) Sarg.
Sand pine	*Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg.

Common name	Scientific name
Scotch (Scots) pine	*Pinus sylvestris* L.
Shinleaf	*Pyrola elliptica* Nutt.
Shore pine	*Pinus contorta* Dougl. ex Loud. var. *contorta*
Shortleaf pine	*Pinus echinata* Mill.
Silverleaf oak	*Quercus hypoleucoides* A. Camus
Single-delight	*Moneses uniflora* (L.) Gray
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Slash pine	*Pinus elliottii* Engelm. var. *elliottii*
South Florida slash pine	*Pinus elliottii* var. *densa* Little & Dorman
Spruce	*Picea* A. Dietr.
Spruce pine	*Pinus glabra* Walt.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Sugar pine	*Pinus lambertiana* Dougl.
Swamp white oak	*Quercus bicolor* Willd.
Swiss mountain pine	see mugo pine
Table Mountain pine	*Pinus pungens* Lamb.
Tamarack	*Larix laricina* (Du Roi) K. Koch
Trembling aspen	*Populus tremuloides* Michx.
Turkey oak	*Quercus laevis* Walt.
Virginia pine	*Pinus virginiana* Mill.
Water oak	*Quercus nigra* L.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western Indian pine	*Pinus occidentalis* Swartz
Wheelbarrow torchwood pine	*Pinus oocarpa* Schiede
Whitebark pine	*Pinus albicaulis* Engelm.
White fir	*Abies concolor* (Gord. & Glend.) Lindl ex. Hildebr.
White spruce	*Picea glauca* (Moench) Voss
White oak	*Quercus alba* L.
Willow oak	*Quercus phellos* L.
Wintergreen	*Pyrola* L.

Literature Cited[1]

1. Anderson, G.W. 1965. The distribution of eastern and western gall rusts in the Lake States. Plant Dis. Rept. 49: 527-528.
2. Anderson, R.L., E. Belcher and T. Miller. 1980. Occurrence of internal seed fungi in slash pine seed produced in seed orchards. Southeast. Area, State and Priv. For., U.S. Dep. Agric. For. Serv. Atlanta, GA. Rep. 81-1-4.
3. Anderson, G.W. and D.W. French. 1965. Western gall rust in the Lake States. Forest Sci. 11: 139-141.
4. Arthur, J.C. 1934. Manual of the Rusts in the United States and Canada. Purdue Research Foundation, Lafayette, IN. 438 p.
5. Arthur, J.C. and F.D. Kern. 1906. North American species of *Peridermium*. Bull. Torr. Bot. Club 33: 403-438.
6. Artman, J.D. 1973. Eastern white pine — A new host for *Fusarium lateritium* f. *pini*. Plant Dis. Rept. 57: 182-184.
7. Baker, B.H. and T.H. Laurent. 1974. Forest insect and disease conditions in Alaska, 1973. U.S. Dep. Agric. For. Serv., Alaska Region, Div. Timber Mngt., 11 p.
8. Baranyay, J.A. and G.R. Stevenson. 1964. Mortality caused by *Armillaria* root rot, *Peridermium* rusts, and other destructive agents in lodgepole pine regeneration. Forest Chron. 40: 350-361.
9. Baranyay, J.A. and N.G. Bauman. 1972. Distribution maps of the common tree diseases in British Columbia. Can. Dep. Env. For. Serv., Information Rept., BC-X-71., Pacific For. Res. Centre, Victoria, BC. 80 p.
10. Barnard, E.L. and G.M. Blakeslee. 1980. Pitch canker of slash pine seedlings: A new disease in forest tree nurseries. Plant Dis. Rept. 64: 695-696.
11. Barnett, P.E. and E. Thor. 1979. Effects of site and inheritance on *Fusarium* incidence in Virginia pine. pp. 159-161. Proc., Symposium for the management of Pines of the Interior South, Knoxville, TN. U.S. Dep. Agric. For. Serv. State and Priv. For. Southeast. Area, Tech. Publ. SA-TP2.
12. Barrows-Broaddus, J. and L.D. Dwinell. 1979. Variation in virulence of diverse sources of *Fusarium moniliforme* var. *subglutinans* on Virginia and loblolly pine. [Abstr.] Phytopathology 69: 525.
13. Barrows-Broaddus, J. and L.D. Dwinell. 1983. Histopathology of *Fusarium moniliforme* var. *subglutinans* in four species of southern pines. Phytopathology 73: 882-889.
14. Barrows-Broaddus, J. and L.D. Dwinell. 1984. Variation in susceptibility to the pitch canker fungus among half-sib and full-sib families of Virginia pine. Phytopathology 74: 438-444.
15. Barrows-Broaddus, J. and L.D. Dwinell. 1985. Branch dieback and cone and seed infection caused by *Fusarium moniliforme* var. *subglutinans* in a loblolly pine seed orchard in South Carolina. Phytopathology 75: 1104-1108.
16. Barrows-Broaddus, J., S.D. Teeslink and T.J. Kerr. 1983. Characterization of *Arthrobacter* strains isolated from the pine environment that inhibit *Fusarium moniliforme* var. *subglutinans*, the causal agent of pine pitch canker. Can. J. Microbiol. 29: 1382-1389.
17. Bergdahl, D.R. and D.W. French. 1975. *Endocronartium harknessii* on *Pinus mugo* in Minnesota. Plant Dis. Rept. 59: 433-434.
18. Berry, C.R. and G.H. Hepting. 1959. Pitch canker of southern pines. U.S. Dep. Agric. For. Serv., For. Pest Leafl. 35. 4 p.
19. Bethune, J.E. and G.H. Hepting. 1963. Pitch canker damage to south Florida slash pine. J. Forestry 61: 517-519, 522.
20. Blakeslee, G.M., R.D. Dorset and S.W. Oak. 1979. Inoculum dispersal of the pine pitch canker fungus, *Fusarium moniliforme* var. *subglutinans*. [Abstr.] Phytopathology 69: 1022.
21. Blakeslee, G.M., and L.D. Dwinell, and R.L. Anderson. 1980. Pitch canker of southern pines, identification and management considerations. U.S. Dep. Agric. For. Serv., State and Private For., Southeastern Area, For. Rep. SA-FR11. 15 p.
22. Blakeslee, G.M., S.H. Kratka, R.A. Schmidt, and C.S. Moses. 1978. Sporodochia of the pitch canker fungus (*Fusarium moniliforme* var. *subglutinans)* as found in diseased slash pine in Florida. Plant Dis. Rept. 62: 656-657.

[1] Literature search completed late 1985.

23. Blakeslee, G.M., T. Miller and E.L. Barnard. 1981. Pitch canker in forest tree nurseries. U.S. Dep. Agric. For. Serv. For. Bull. SA-FB/P 22. 1 p.
24. Blakeslee, G.M. and S.W. Oak. 1979. Significant mortality associated with pitch canker infection of slash pine in Florida. Plant Dis. Rept. 63: 1023-1025.
25. Blakeslee, G.M., S.W. Oak, W. Gregory and C.S. Moses. 1978. Natural association of *Fusarium moniliforme* var. *subglutinans* with *Pissodes nemorensis.* [Abstr.] Phytopathol. News 12: 208.
26. Blakeslee, G.M., S.W. Oak and S.H. Kratka. 1980. Shoot dieback of planted sand pine caused by *Fusarium moniliforme* var. *subglutinans.* Plant Disease 64: 703-704.
27. Bloomberg, W.J. 1966. The occurrence of endophytic fungi in Douglas-fir seedlings and seeds. Can. J. Botany 44: 413-420.
28. Boyce, J.S. 1943. Host relationships and distribution of conifer rusts in the United States and Canada. Trans. Conn. Acad. Arts and Sci. 35: 329-482.
29. Boyce, J.S. 1957. The fungus causing western gall rust and Woodgate rust of pines. Forest Sci. 3: 225-234.
30. Bramlett, D.L., E.W. Belcher, G.L. Debarr, G.D. Hertel, R.P. Karfalt, C.W. Lantz, T. Miller, K.D. Ware and H.O. Yates, III, 1977. Cone analysis of southern pines. General Tech. Rep. SE-13., U.S. Dep. Agric., For. Serv. Southeast. For. Exp. Stn., Asheville, NC, and Southeast. Area, State and Priv. For., Atlanta, GA. 28 p.
31. Bramlett, D. L. Inventory-monitoring system for southern pine seed orchards. *In* Proc. Cone and seed insects Working Party Conference. Ed. H. O. Yates, III, Southeastern For. Exp. Sta., Asheville, NC, 1984, pp. 102-111.
32. Bramlett, D. L. and J. F. Godbee, Jr. Inventory monitoring system for southern pine seed orchards. Georgia For. Res. Pap. 28., GA. For. Comm., Macon, GA, 1982, 18 p.
33. Brown, H.D. and P.W. Orr. 1978. Forest insect and disease conditions in the United States, 1976. U.S. Dep. Agric. For. Serv., For. Insect Dis. Mngt., Washington, DC. 40 p.
34. Byler, J.W. and W.D. Platt. 1972. Cone infection by *Peridermium harknessii.* Can. J. Botany 50: 1429-1430.
35. Byler, J.W., F.W. Cobb, Jr. and J.P. Parmeter, Jr. 1972. Effects of secondary fungi on the epidemiology of western gall rust. Can. J. Botany 50: 1061-1066.
36. Canada, Department of Environment. 1950-1982. Annual Reports, Forest Insect and Disease Survey, Can. For. Serv., Queen's Printer, Ottawa, ON.
37. Canada, Department of the Environment, Forestry Service. 1982. Historical list of softwood cone diseases by source, disease, region, and grid. Can. Dep. Env. For. Serv., For. Insect Disease Surv. Rep. S132AR90., Ottawa, ON. 99 p.
38. Carlson, L.W. 1969. Western gall rust on jack pine nursery stock in Manitoba. Plant Dis. Rept. 53: 100.
39. Cash, E.K. 1953. A checklist of Alaskan fungi. Plant Dis. Rept. Suppl. 219. 70 p.
40. Clark, L.J. 1973. Wild Flowers of British Columbia. Gray's Publishing Ltd., Sidney, BC. 591 p.
41. Commonwealth Mycological Institute. 1977. *Cronartium conigenum* Hedgc. & Hunt. Distribution Maps of Plant Diseases, No. 519, Edition 1.
42. Conners, I.L. 1967. An annotated index of plant diseases in Canada and fungi recorded on plants in Alaska, Canada and Greenland. Can. Dep. Agric. Res. Br. Publ. 1251. 381 p.
43. Cooley, S. 1982. Cone and seed disease. U.S. Dep. Agric. For. Serv., Region 6 Tree Seed Pap. 4/82. 17 p.
44. Critchfield, W.B. and E.L. Little, Jr. 1966. Geographic distribution of the pines of the world. U.S. Dep. Agric. For. Serv., Misc. Publ. 991. 97 p.
45. Cummins, G.B. 1943. Annotated check list and host index of the rusts of Guatemala. Plant Dis. Rept. Suppl. 142. pp. 79-131.
46. Curtis, D.J. and C.W. Swanson. 1972. Forest insect and disease conditions in Alaska during 1971. U.S. Dep. Agric. For. Serv., Alaska Region, Div. Timber Mngt., 18 p.
47. Curtis, D.J. and D.W. Johnson. 1975. Forest pest conditions in the Pacific Northwest, 1974. U.S. Dep. Agric. For. Serv., Pac. Northwest Region, State and Priv. For., Insect and Dis. Control, 29 p.
48. Dahms, W.G. 1965. Rust cankers — a threat to central Oregon lodgepole pine? U.S. Dep. Agric. For. Serv., Res. Note PNW-20, Pacific Northwest For. Range. Exp. St., Portland, OR. 3 p.
49. Dooling, O.J. and J.E. Dewey. 1973. Forest insect and disease conditions in the Northern Region, 1972. U.S. Dep. Agric. For. Serv., North. Region, Div. State and Priv. For., Rep. 73-1., Missoula, MT. 21 p.
50. Dwinell, L.D. 1976. A dieback of loblolly pine in seed orchards. [Abstr.]. Proc. Am. Phytopath. Soc. 3: 335.
51. Dwinell, L.D. 1978. Susceptibility of southern pines to infection by *Fusarium moniliforme* var. *subglutinans.* Plant Dis. Rept. 62: 108-111.
52. Dwinell, L.D. and J.B. Barrows. 1978. Recovery of

the pine pitch canker fungus from pine plantation and seed orchard soil. [Abstr.] Phytopathol. News 12: 207.

53. Dwinell, L.D. and J. Barrows-Broaddus. 1981. Pitch canker in seed orchards. Pages 234-240 in: Proc. Sixteenth South. For. Tree Improv. Conf., Virginia Polytechnic Inst., Blacksburg, VA.
54. Dwinell, L.D. and W.R. Phelps. 1977. Pitch canker of slash pine in Florida. J. Forestry 75: 488-489.
55. Dwinell, L.D., P.L. Ryan and E.G. Kuhlman. 1977. Pitch canker of loblolly pine in seed orchards. pp. 130-137 *in*: Proc. Fourteenth South. For. Tree Improv. Conf. Univ. of Florida, Gainesville, FL.
56. Ebel, B.H. 1983. Personal communication. U.S. Dep. Agric. For. Serv., Southeast. For. Exp. Stn., Olustee, FL.
57. Elliott, M.E. and R. Cauchon. 1976. *Sclerotinia kerneri.* Fungi Canadenses, Nat. Mycol. Herb. Biosyst. Res. Inst., Agric. Canada, Ottawa, ON. No. 90. 2 p.
58. Epners, Z. 1964. A new psychrophilic fungus causing germination failure of conifer seeds. Can. J. Botany 42: 1589-1604.
59. Etheridge, D.E. 1968. Preliminary observations on the pathology of *Pinus caribaea* Morelet in British Honduras. Commonw. For. Rev. 47: 72-80.
60. Fatzinger, C. W., G. D. Hertel, E. P. Merkel, W.D. Pepper and R.S. Cameron. Identification and sequential occurrence of mortality factors affecting seed yields of southern pine seed orchards. U.S. Dept. of Agriculture For. Serv. Res. Pap. SE-216., 1980; Southeastern For. Exp. Sta., Asheville, NC, 43 p.
61. Fatzinger, C. W. Monitoring pest-caused losses of cones and seed in southern pine seed orchards, *In* proc. Cone and seed insects Working Party Conference. Ed. H. O. Yates, III, Southeastern For. Exp. Sta., Asheville, NC., 1984, pp. 122-127 p.
62. Fogal, W.H. 1979. Bionomic sketches of insects and fungal pests of cones and seeds of forest trees in Canada east of the Rockies. Can. For. Serv., Petawawa For. Exp. Stn., Chalk River, ON., Inform. Rep. PS-X-72. 17 p.
63. Fraedrich, B.R. and W. Witcher. 1982. Influence of fertilization on pitch canker development on three southern pine species. Plant Disease 66: 938-940.
64. Funk, A. 1972. *Sirococcus* shoot-blight of western hemlock in British Columbia and Alaska. Plant Dis. Rept. 56: 645-647.
65. Funk, A. 1981. Parasitic microfungi of western trees. Canada Department of the Environment, For. Serv., Information Rept., BC-X-222., Pacific For. Res. Centre, Victoria, BC. 189 p.
66. Gilbertson, R.L. and J. McHenry. 1969. Check list and host index for Arizona rust fungi. Univ. Ariz. Agric. Exp. Stn., Tech. Bull. 186. 40 p.
67. Ginns, J. 1975. *Caloscypha fulgens.* Fungi Canadenses, Nat. Mycol. Herb. Biosyst. Res. Inst., Agric. Canada, Ottawa, ON. No. 66. 2 p.
68. Goyer, R.A. and L.H. Nachod. 1976. Loblolly pine conelet, cone, and seed losses to insects and other factors in a Louisiana seed orchard. Forest Sci. 22: 386-391.
69. Graham, J.H. and R.G. Linderman. 1983. Pathogenic seedborne *Fusarium oxysporum* from Douglas-fir. Plant Disease 67: 323-325.
70. Graham, V.O. 1944. Mushrooms of the Great Lakes Region. Chicago Acad. Sci., Spec. Publ. 5., Chicago, IL. 390 p.
71. Graves, A.H. 1914. Notes on diseases of trees in the southern Appalachians. III. Phytopathology 4: 63-72.
72. Gross, H. 1983. Personal communication. Canada Department of the Environment, For. Serv., For. Insect Dis. Surv., Great Lakes For. Res. Centre, Sault Ste. Marie, ON.
73. Hamel, D.R. and O.J. Dooling. 1975. Forest insect and disease conditions in the Northern Region, 1974. U.S. Dep. Agric. For. Serv., North. Reg. State and Priv. For. Rep. 75-1., Missoula, MT. 26 p.
74. Harrison, S.G. and E.A. Dallimore. 1966. A Handbook of Coniferae and Ginkoaceae. Edward Arnold (Publishers) Ltd. London. 729 p.
75. Hart, J.H., D.G. Mosher and R. Ajewole. 1978. Occurrence of *Endocronartium harknessii* and *Cronartium quercuum* on Scots and Jack pine in Michigan's lower peninsula. Plant Dis. Rept. 62: 779-782.
76. Harvey, R.D., Jr. 1980. Mortality from *Caloscypha fulgens* and other fungi on spruce seed in Oregon and Washington. Plant Disease 64: 223-224.
77. Hedgcock, G.G. and G.G. Hahn. 1922. Two important pine cone rusts and their new cronartial stages. I. *Cronartium strobilinum.* Phytopathology 12: 109-116.
78. Hedgcock, G.G. and N.R. Hunt. 1922. Two important pine cone rusts and their new cronartial stages. II. *Cronartium conigenum.* Phytopathology 12: 116-122.
79. Hedgcock, G.G. and P.V. Siggers. 1949. A comparison of the pine-oak rusts. U.S. Dep. Agric. For. Serv., Tech. Bull. 978. 30 p.
80. Hepting, G.H. 1958. Southern cone rust. U.S. Dep. Agric. For. Serv., For. Pest Leafl. 27. 4 p.

81. Hepting, G.H. 1961. *Pinus radiata* susceptible to pitch canker. Plant Dis. Rept. 45: 889-890.

82. Hepting, G.H. 1971. Diseases of forest and shade trees of the United States. U.S. Dep. Agric. For. Serv., Agric. Handb. 386. 658 p.

83. Hepting, G.H. and E.R. Roth. 1946. Pitch canker, a new disease of some southern pines. J. Forestry 44: 742-744.

84. Hepting, G.H. and E.R. Roth. 1953. Host relations and spreads of the pine pitch canker disease. [Abstr.] Phytopathology 43: 475.

85. Hepting, G.H. and F.R. Matthews. 1970. Southern cone rust. U.S. Dep. Agric. For. Serv., For. Pest Leafl. 27. 4 p.

86. Hiratsuka, Y. and J.M. Powell. 1976. Pine stem rusts of Canada. Canada Department of the Environment, For. Serv., For. Tech. Rep. 4., Ottawa, ON. 83 p.

87. Hofacker, T.H. and R.C. Loomis. 1982. Forest insect and disease conditions in the United States, 1981. U.S. Dep. Agric. For. Serv., For. Pest Mngt., Washington, DC. 51 p.

88. Hofacker, T.H. and R.C. Loomis. 1983. Forest insect and disease conditions in the United States, 1982. U.S. Dep. Agric., For. Serv., For. Pest Mngt., Washington, DC. 51 p.

89. Holsten, E.H., R.A. Werner and T.H. Laurent. 1980. Insects and diseases of Alaskan forests. U.S. Dep. Agric. For. Serv., Alaska Region Rep. 75. 187 p.

90. Hosie, R.C. 1979. Native Trees of Canada, 8th ed. Fitzhenry & Whiteside Ltd., Don Mills, ON. 380 p.

91. Hulten, E. 1971. The Circumpolar Plants. II. Dicotyledons. Kunzl. Svenska Vetenskapsakadmiens Handl. 13: 1. Almqvist and Wiksell, Stockholm. 463 p.

92. Hunt, R.S. 1969. *Pinus sabiniana* and *Pinus muricata* as hosts for *Diplodia pinea* in California. Plant Dis. Rept. 53: 675-677.

93. Illingworth, K. 1973. Variation in the susceptibility of lodgepole pine provenances to *Sirococcus* shoot blight. Can. J. For. Res. 3: 585-589.

94. Jewell, F.F. 1957. Preventing cone rust on slash pine by pollination techniques used in breeding programs. [Abstr.]. Phytopathology 47: 241-242.

95. Kelley, W.D. 1982. Pine hosts of the pitch canker fungus (*Fusarium moniliforme* var. *subglutinans*) in Alabama seed orchards. [Abstr.] Phytopathology 72: 170.

96. Kelley, W.D. and J.C. Williams. 1982. Incidence of pitch cankers among clones of loblolly pine in seed orchards. Plant Disease 66: 1171-1173.

97. Kimmey, J.W. and J.A. Stevenson. 1957. A forest disease survey of Alaska. Plant Dis. Rept. Suppl. 247. pp. 87-98.

98. Kraus, Sch. H. and W. Witcher. 1977. Survey of pine pitch canker in South Carolina. Plant Dis. Rept. 61: 976-978.

99. Krebill, R.G. 1970. Autoecious gall rusts of pines in southern Michigan and New York. Plant Dis. Rept. 54: 853-855.

100. Kuhlman, E.G. and S. Cade. 1985. Pitch canker disease of loblolly and pond pines in North Carolina plantations. Plant Disease 69: 175-176.

101. Kuhlman, E.G., S.D. Dianis and T.K. Smith. 1982. Epidemiology of pitch canker disease in a loblolly pine seed orchard in North Carolina. Phytopathology 72: 1212-1216.

102. Kuhlman, E.G., L.D. Dwinell, P.E. Nelson and C. Booth. 1978. Characterization of the *Fusarium* causing pitch canker of southern pines. Mycologia 70: 1131-1143.

103. Larsen, H.J., Jr. and W.C. Denison. 1978. A checklist of the operculate cup-fungi (Pezizales) of North America west of the Great Plains. Mycotaxon 7: 68-90.

104. Lavallee, A. and G. Bard. 1973. Observations sur deux rouilles-tumeurs du pin gris (*Pinus banksiana*). Can. J. For. Res. 3: 251-255.

105. Leaphart, C.D. 1955. Preliminary observations on a current outbreak of western gall rust (*Cronartium coleosporioides*). Plant Dis. Rept. 39: 314-315.

106. Little, E.L., Jr. 1971. Atlas of United States trees. Volume 1. Conifers and important hardwoods. U.S. Dep. Agric. For. Serv., Misc. Publ. 1146. 9 p., plus maps.

107. Little, E.L., Jr. 1976. Atlas of United States trees. Volume 3. Minor western hardwoods. U.S. Dep. Agric. For. Serv., Misc. Publ. 1314. 13 p., plus maps.

108. Little E.L., Jr. 1976. Atlas of United States trees. Volume 4. Minor eastern hardwoods. U.S. Dep. Agric. For. Serv., Misc. Publ. 1342. 17 p., plus maps.

109. Longenecker, J., B.R. Kistler and W. Merrill. 1975. Major conifer disease occurrences and new records for Pennsylvania. Plant Dis. Rept. 59: 702-704.

110. Loomis, R.C. and T.H. Hofacker. 1981. Forest insect and disease conditions in the United States, 1980. U.S. Dep. Agric. For. Serv., For. Pest Mngt., Washington, DC. 36 p.

111. Lowe, D.P. 1977. Checklist and host index of bacteria, fungi, and mistletoe of British Columbia. Canada Department of the Environment, For. Serv., BC-X-32., Pacific For. Res. Centre, Victoria, BC. 542 p.

112. McCain, J.W. and J.F. Hennen. 1980. Sugarcane rust and other new rust diseases from El Salva-

dor. Plant Disease 64: 1120.

113. McGrath, W.T. and R.F. Patton. 1969. The range of western gall rust in Wisconsin. Plant Dis. Rept. 53: 357-359.

114. McPherson, J.A., E.K. Morgenstern and B.S.P. Wang. 1982. Seed production in grafted clonal orchards at Longlac, Ontario. For. Chron. 58: 31-34.

115. Magasi, L.P. 1975. First record of *Sirococcus* shoot blight on red pine in Nova Scotia. Plant Dis. Rept. 59: 623-624.

116. Magasi, L.P., S.A. Manley and R.E. Wall. 1975. *Sirococcus strobilinus*, a new disease of spruce seedlings in Maritime nurseries. Plant Dis. Rept. 59: 664.

117. Maloy, O.C. and F.R. Matthews. 1960. Southern cone rust: Distribution and control. Plant Dis. Rept. 44: 36-39.

118. Martinez, M. 1948. Los pinos Mexicanos. Ediciones Botas, Ed. 2. Mexico. 361 p.

119. Matthews, F.R. 1962. Pitch canker tip-moth damage association on slash pine seedlings. J. Forestry. 60: 825-826.

120. Matthews, F.R. 1964. Some aspects of the biology and control of southern cone rust. J. Forestry 62: 881-884.

121. Matthews, F.R. 1967. Southern cone rust *Cronartium strobilinum* (Arth.) Hedgc. and Hahn. pp. 225-227 *in*: Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico. Can. Dep. For. and Rural Devel., For. Serv. Publ. 1180. 248 p.

122. Matthews, F.R. and O.C. Maloy. 1960. What to do about cone rust. For. Farmer 19: 8, 14-15.

123. Meinecke, E.P. 1916. *Peridermium harknessii* and *Cronartium quercuum*. Phytopathology 6: 225-240.

124. Merkel, E.P. 1958. *Dioryctria* cone moth attack as related to cone rust of slash pine in north Florida. J. Forestry. 56: 651.

125. Merrill, W. 1972. Occurrence of *Endocronartium harknessii* in Pennsylvania. Plant Dis. Rept. 56: 1058.

126. Merrill, W. and B.R. Kistler. 1976. Phenology and control of *Endocronartium harknessii* in Pennsylvania. Phytopathology 66: 1246-1248.

127. Miller, O.K., Jr. 1972. Mushrooms of North America. E.P. Dutton and Co., Inc. New York, N.Y. 360 p.

128. Miller, T. and D.L. Bramlett. 1978. Damage to reproductive structures of slash pine by two seedborne pathogens: *Diplodia gossypina* and *Fusarium moniliforme* var. *subglutinans*. pp. 347-355 *in*: Proc: A symposium on flowering and Seed Development in Trees: a Symposium (F. Bonner, ed.). U.S. Dep. Agric. Southern For. Exp. Stn., 380 p.

129. Miller, T. and D.L. Bramlett. 1978. Fungi associated with damage to strobili, cones, and seed of slash and loblolly pines. [Abstr.] Phytopathol. News 12: 207.

130. Mirov, N.T. 1967. The Genus *Pinus*. The Ronald Press Co. New York. 602 p.

131. Myren, D.T. and H.L. Gross. 1977. Distribution of organisms causing important forest tree diseases in Ontario. Can. For. Serv., Great Lakes For. Res. Centre, Rep. 0-X-262. 136 p.

132. Nelson, D.L. and R.G. Krebill. 1982. Occurrence and effect of *Chrysomyxa pirolata* cone rust on *Picea pungens* in Utah. Great Basin Nat. 42: 262-272.

133. Nienstaedt, H. 1957. Silvical characteristics of white spruce (*Picea glauca*). U.S. Dep. Agric. For. Serv., Lake State For. Exp. Stn., Station Pap. 55., St. Paul, MN. 23 p.

134. O'Brien, J.T. 1973. *Sirococcus* shoot blight on red pine. Plant Dis. Rept. 57: 246-247.

135. Offord, H.R. 1964. Diseases of Monterey pine in native stands of California and in plantations of western North America. U.S. Dep. Agric. For. Serv., Res. Pap. PSW-14., Pac. Southwest For. Range Exp. Stn., Berkeley, CA. 37 p.

136. Old, K.M. 1981. Western gall rust, a serious disease of *Pinus radiata* in California. Aust. For. 44: 178-184.

137. Orr, P.W. and H.D. Brown. 1978. Forest insect and disease conditions in the United States, 1977. U.S. Dep. Agric. For. Serv., For. Insect Dis. Mngt., Washington, DC. 88 p.

138. Orr, P.W. and H.D. Brown. 1980. Forest insect and disease conditions in the United States, 1978. U.S. Dep. Agric. For. Serv., For. Insect Dis. Mngt., Washington, DC. GTR-WO-19. 83 p.

139. Paden, J.W., J.R. Sutherland and T.A.D. Woods. 1978. *Caloscypha fulgens* (Ascomycetidae, Pezizales): the perfect state of the conifer seed pathogen *Geniculodendron pyriforme* (Deuteromycotina, Hyphomycetes). Can. J. Botany 56: 2375-2379.

140. Peterson, G.W. and R.S. Smith, Jr. 1975. Forest nursery diseases in the United States. U.S. Dep. Agric. For. Serv., Agric. Handb. 470. 125 p.

141. Peterson, R.S. 1960. Western gall rust on hard pines. U.S. Dep. Agric. For. Serv., For. Pest Leafl. 50. 8 p.

142. Peterson, R.S. 1961. Notes on western rust fungi. I. *Chrysomyxa*. Mycologia 53: 427-431.

143. Peterson, R.S. 1962. Notes on western rust fungi. III. *Cronartium*. Mycologia 54: 678-684.

144. Peterson, R.S. 1967. The *Peridermium* species on pine stems. Bull. Torr. Bot. Club. 94: 511-542.

145. Peterson, R.S. 1971. Wave years of infection by western gall rust on pine. Plant Dis. Rept. 55: 163-167

146. Peterson. R.S. and R. Salinas Quinard. 1967. *Cronartium conigenum*: Distribucion y efectos en los pinos. [*C. conigenum*: Distribution and effects on pine trees.] Bol. tec. Inst. Nac. Invest. Forest Mex. 19: 1-11.

147. Phelps, W.R. and C.W. Chellman. 1976. Evaluation of "pitch canker" in Florida slash pine plantations and seed orchards, 1976. U.S. Dep. Agric. For. Serv., State and Priv. For., Southeast. Area, 22 p.

148. Powell, J.M. and Y. Hiratsuka. 1973. Serious damage caused by stalactiforme blister rust and western gall rust to a lodgepole pine plantation in central Alberta. Can. Plant Dis. Surv. 53: 67-71.

149. Rhoads, A.S., G.G. Hedgcock, E. Bethel and C. Hartley. 1918. Host relationships of the North American rusts, other than Gymnosporangiums which attack conifers. Phytopathology 8: 309-352.

150. Rogers, J.D. and J.M. Bonman. 1978. A white variant of *Caloscypha fulgens* from northern Idaho. Mycologia 70: 1286-1287.

151. Rowan, S.J. 1982. Tip dieback in southern pine nurseries. Plant Disease 66: 258-259.

152. Salinas Quinard, R. 1983. Personal communication. Inst. Nac. de Invest. Forestales, Mexico.

153. Salt, G.A. 1971. Conifer seedling pathology. Extr. from Rep. For. Res. For. Comm., London. 1971: 131-132.

154. Salt, G.A. 1974. Etiology and morphology of *Geniculodendron pyriforme* gen. et. sp. nov., a pathogen of conifer seeds. Trans. Br. Mycol. Soc. 63: 339-351.

155. Savile, D.B.O. 1950. North American species of *Chrysomyxa*. Can. J. Res. (Section C) 28: 318-330.

156. Savile, D.B.O. 1955. *Chrysomyxa* in North America — additions and corrections. Can. J. Botany 33: 487-496.

157. Schieber, E. 1967. Pine cone rust in the highlands of Guatemala. Plant Dis. Rept. 51: 44-46.

158. Schmidt, R.A. and E.M. Underhill. 1974. Incidence and impact of pitch canker in slash pine plantations in Florida. Plant Dis. Rept. 58: 451-454.

159. Schmidt, R.A., R.C. Wilkinson, C.S. Moses and F.S. Broerman. 1976. Drought and weevils associated with severe incidence of pitch canker in Volusia County, Florida. Inst. Food and Agric. Sci., Univ. of Florida, Progress Rep. 76-2. 4 p.

160. Schwandt, J.W. 1981. *Sirococcus* tip blight in North Idaho nurseries. Idaho Dep. Lands, For. Insect Dis. Control, Rep. 81-7., Cour d'Alene, ID. 14 p.

161. Scoggan, H.J. 1979. The Flora of Canada. Nat. Mus. Can., Nat. Mus. Nat. Sci., Publ. in Botany, No. 7.

162. Seaver, F.J. 1913. The genus *Pseudoplectania*. Mycologia 5: 299-302.

163. Seaver, F.J. 1928. The North American Cup-fungi (Operculates). Published by the author. New York, NY. 284 p.

164. Seaver, F.J. 1942. The North American Cup-fungi (Operculates). Supplemented ed. Published by the author., New York, NY. 377 p.

165. Shahin, E.A. and L.E. Claflin. 1978. The occurrence and distribution of *Sirococcus* shoot blight of spruce in Kansas. Plant Dis. Rept. 62: 648-650.

166. Shaw, C.G. 1973. Host fungus index for the Pacific Northwest. I and II. Wash. Agric. Exp. Stn., Wash. State Univ., Bull. 765 and 766.

167. Shea, K.R. and J.H. Rediske. 1964. *Schizophyllum commune* Fr. isolated from stored Douglas-fir cones. Plant Dis. Rept. 48: 234.

168. Singh, P. 1981. Inland spruce cone rust of black spruce in Newfoundland and Labrador. Can. Plant Dis. Surv. 61: 43-47.

169. Skelly, J.M. 1976. Western gall rust found in Virginia. Plant Dis. Rept. 60: 222-223.

170. Smith, H.V. and A.H. Smith. 1973. How to Know the Non-gilled Fleshy Fungi. Wm. C. Brown Company Publishers, Dubuque, IA. 402 p.

171. Smith, R.S., Jr. 1973. *Sirococcus* tip dieback of *Pinus* spp. in California forest nurseries. Plant Dis. Rept. 57: 69-73.

172. Smith, R.S., Jr. 1975a. *Sirococcus* tip blight. pp. 45-46 *in*: Forest nursery diseases in the United States (G.W. Peterson and R.S. Smith, Jr., eds.). U.S. Dep. of Agric., For. Serv. Agric. Handb. 470. 125 p.

173. Smith, R.S., Jr. 1975b. Western gall rust. pp. 56-58 *in*: Forest nursery diseases in the United States (G.W. Peterson and R.S. Smith, Jr., eds.). U.S. Dep. Agric., For. Serv., Agric. Handb. 470. 125 p.

174. Smith, R.S., Jr., A.H. McCain, M. Srago, R.F. Krohn and D. Perry. 1972. Control of *Sirococcus* tip blight of Jeffrey pine seedlings, Plant Dis. Rept. 56: 241-242.

175. Spaulding, P. 1961. Foreign diseases of forest trees of the world. U.S. Dep. Agric. For. Serv., Agric. Handb. 197. 361 p.

176. Stegall, W.A. 1966. Fruiting of *Fusarium lateritium pini* on naturally infected pine pitch cankers. Plant Dis. Rept. 50: 476-477.

177. Sullivan, T.P., J.R. Sutherland, T.A.D. Woods

and D.S. Sullivan. 1984. Dissemination of the conifer seed fungus *Caloscypha fulgens* by small mammals. Can. J. For. Res. 14: 134-137.

178. Sutherland, J.R. 1979. The pathogenic fungus *Caloscypha fulgens* in stored conifer seeds in British Columbia and relation of its incidence to ground and squirrel-cache collected cones. Can. J. For. Res. 9: 129-132.
179. Sutherland, J.R. 1981. Effects of Inland spruce cone rust, *Chrysomyxa pirolata* Wint., on seed yield, weight, and germination. Can. For. Serv., Res. Notes 1(2): 8-9.
180. Sutherland, J.R. 1981. Time, temperature, and moisture effects on incidence of seed infected by *Caloscypha fulgens* in Sitka spruce cones. Can. J. For. Res. 11: 727-730.
181. Sutherland, J.R. and E. Van Eerden. 1980. Diseases and insect pests in British Columbia forest nurseries. B.C. Min. For./Can. For. Serv., Jt. Rep. 12., Victoria, BC. 55 p.
182. Sutherland, J.R., W. Lock and S.H. Farris. 1981. *Sirococcus* blight: a seed-borne disease of container-grown spruce seedlings in coastal British Columbia forest nurseries. Can. J. Botany 59: 559-562.
183. Sutherland, J.R., W. Lock and L.E. Benson. 1982. Diseases and insects and their management in container nurseries. pp. 215-223 *in*: Proc. Canadian Containerized Seedling Symposium, September 14-16, 1981, Toronto, Ontario (J.B. Scarratt, C. Glerum, and C.A. Plexman, eds.). Can. For. Serv., Great Lakes For. Res. Centre, COJFRC symposium proceedings; 0-P-10. 460 p.
184. Toko, H.V. and K.H. Knauer. 1977. Forest insect and disease conditions in the United States, 1975. U.S. Dep. Agric. For. Serv., Div. For. Insect Dis. Mngt., Washington, DC. 60 p.
185. Toko, H.V. and J.J. Rogers. 1977. Forest insect and disease conditions in the United States, 1974. U.S. Dep. Agric. For. Serv., Div. For. Insect Dis. Mngt., Washington, DC. 55 p.
186. Trelease, W. 1969. The American Oaks. Plant Monograph Reprints, Vol. 4 (J. Cramer and H.K. Swan, eds.). Lehre, Cramer. New York. 255 p.
187. Tylutki, E.E. 1979. Mushrooms of Idaho and the Pacific Northwest. Discomycetes. University of Idaho, Moscow, ID.
188. U.S. Department of Agriculture, Agricultural Research Service. 1960. Index of plant diseases in the United States. U.S. Dep. Agric., Agric. Res. Serv., Agric. Handb. 165. 531 p.
189. U.S. Department of Agriculture, Forest Service. 1979. Forest insect and disease conditions in Alaska in 1978. U.S. Dep. Agric. For. Serv., Alaska Region, Div. State and Priv. For., Rep. No. 62. 35 p.
190. U.S. Department of Agriculture, Forest Service. 1980. Forest insect and disease conditions in Alaska in 1979. U.S. Dep. Agric. For. Serv., Alaska Region, Div. State and Priv. For., Rep. No. 115. 17 p.
191. U.S. Department of Agriculture, Forest Service. 1981. Forest insect and disease conditions in Alaska in 1980. U.S. Dep. Agric. For. Serv., Alaska Region, Div. State and Priv. For., Rep. No. 146., Anchorage, AK. 17 p.
192. Van Sickle, G.A. and W.R. Newell. 1968. Occurrence of *Peridermium harknessii* of the *Cronartium coleosporioides* complex confirmed in the Maritime Provinces. Plant Dis. Rept. 52: 455-458.
193. Wall, R.E. and L.P. Magasi. 1976. Environmental factors affecting *Sirococcus* shoot blight of black spruce. Can. J. For. Res. 6: 448-452.
194. Walla, J.A. and R.W. Stack. 1979. Western gall rust in North Dakota. Plant Dis. Rept. 63: 432-433.
195. Weir, J.R. 1915. Observations on the pathology of the jack pine. U.S. Dep. Agric., Bull. 212. 10 p.
196. Wicker, E.F., T.H. Laurent and S. Israelson. 1978. *Sirococcus* shoot blight damage to western hemlock regeneration at Thomas Bay, Alaska. U.S. Dep. Agric. For. Serv., Res. Pap. INT-198., Intermountain For. Range Exp. Stn., Ogden UT. 11 p.
197. Wicklow-Howard, M.C. and J. Skujins. 1980. Infection of Engelmann spruce seed by *Geniculodendron pyriforme* in western North America. Mycologia 72: 406-410.
198. Wilkinson, R.C., E.M. Underhill, J.R. McGraw, W.L. Pritchett and R.A. Schmidt. 1977. Pitch canker incidence and fertilizer-insecticide treatment. Inst. Food and Agric. Sci., Univ. of Florida, Gainesville, FL, Progress Rep. 77-1. 4 p.
199. Williams, R.E., C.E. Carlson and O.J. Dooling. 1972. Forest disease conditions in the Northern Region, 1971. U.S. Dep. Agric. For. Serv., North. Region, Div. State and Priv. For., Rep. 72-2., Missoula, MT. 14 p.
200. Woods, T.A.D., S.H. Farris and J.R. Sutherland. 1982. Penetration of Sitka spruce seeds by the pathogenic fungus *Caloscypha fulgens*. Can. J. Botany 60: 544-548.
201. York, H.H. 1926. A *Peridermium* new to the northeastern United States. Science 64: 500-501.
202. Zasada, J.C. and R.A. Gregory. 1969. Regeneration of white spruce with reference to interior Alaska: A literature review. U.S. Dep. Agric.

For. Serv., Res. Pap. PNW-79., Pac. Northwest For. Range Exp. Stn., Inst. North. For., Juneau, AK. 37 p.

203. Ziller, W.G. 1954. Studies of western tree rusts. I. A new cone rust on Sitka spruce. Can. J. Botany 32: 432-439.

204. Ziller, W.G. 1964. Life cycles of tree rusts and their significance to forestry. Can. For. Serv., Pacific For. Res. Centre, Victoria, B.C. Misc. 87. 12 p.

205. Ziller, W.G. 1967. Western gall rust. *Peridermium harknessi* J.P. Moore. pp. 53-54 *in*: Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico. Can. Dep. For. & Rural Dev., For. Serv. Publ. 1180. 248 p.

206. Ziller, W.G. 1974. The tree rusts of western Canada. Canada Department of the Environment, For. Serv., Publ. 1329., Ottawa, ON. 272 p.