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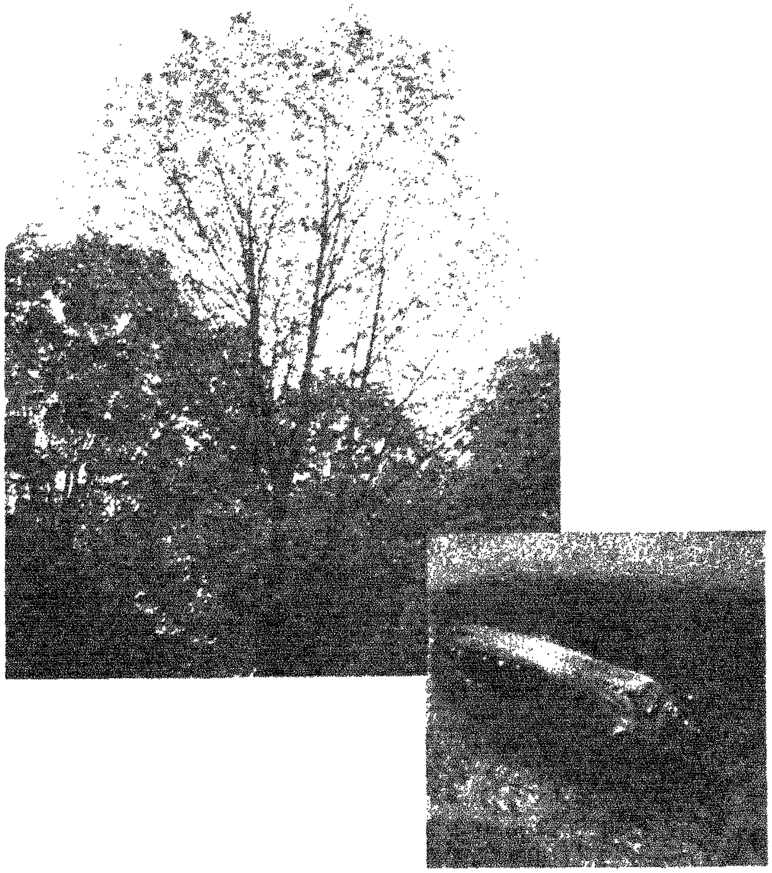
November 21-22, 1991
University Park, PA



THE 1991 CONFERENCE ON THRIPS (THYSANOPTERA): INSECT AND DISEASE CONSIDERATIONS IN SUGAR MAPLE MANAGEMENT

PROCEEDINGS

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PREFACE

Fifty-seven participants gathered at the Keller Conference Center at the Pennsylvania State University, University Park, PA, on 20-21 November 1991, for the 1991 Conference on Thrips. The theme this year was 'Insect and Disease Considerations in Sugar Maple Management.' Invited keynote speakers addressed both entomological and management components of the theme; submitted oral and poster presentations explored and expanded upon many of the facets of management of a forest resource, with particular reference to the Thysanoptera and the role they may play. Abstracts of the submitted presentations, along with full text of the keynote addresses, are included in the *Proceedings*.

Sponsors of the 1991 meeting included the School of Forest Resources and the Department of Entomology, Penn State University, and the Pennsylvania Maple Syrup Producers' Council. Sponsorship by the U.S. Forest Service, Northeastern Forest Experiment Station, has facilitated the publication of the *Proceedings*. The staff of the J.O. Keller Conference Center, Penn State, attended to the numerous details that spell success for a conference, including registration, arranging for meeting facilities, breaks, and an opportunity for informal discussion and social relaxation. The Office of the Dean of the College of Agriculture provided encouragement; Drs. A.D. Sullivan, Director, School of Forest Resources, and J.L. Frazier, Head, Department of Entomology, have consistently supported the pear thrips program at Penn State. Numerous individuals associated with pear thrips research at Penn State, especially Rob Hellested, Glenn Taylor, and Christian Sautter, attended to the many detailed needs of hosting such a conference. To all, our sincere thanks and appreciation.

Moderators facilitate the smooth presentation of contributions at any meeting, and assure that discussion flows freely and easily. Those assisting in that capacity included: Bruce L. Parker, Entomology Research Laboratory, University of Vermont; John W. Quimby, Bureau of Forestry, Pennsylvania Department of Environmental Resources; and James C. Finley, School of Forest Resources, Penn State University. They, too, are to be thanked for their efforts.

University Park, PA
March 1992

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PATTERNS OF SEXUALITY IN THYSANOPTERA

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Introduction

The purpose of this paper is to emphasize the lack of reliable information on the function and importance of sex in the biology of thrips. I produce previously unpublished data on the numbers of adult males and females in collections of many thrips species, together with observations on the systematic distribution of sexual dimorphism within the group and the possible ecological significance of unequal sex allocation in different species. Most of the data included are derived from taxonomists and their collections, although such collections are inevitably biased in various ways. A field sample, taken for taxonomic purposes, is unlikely to represent the *primary sex ratio* of a species if any difference exists between the sexes in emergence, dispersion, or aggregation behavior. Moreover, taxonomists tend to collect unusual individuals - the largest or smallest or most brightly colored - rather than a random sample of a population. Crespi (In press b) gives an extensive account of some of the problems of sex allocation in Thysanoptera, and Ananthakrishnan (1990) discusses many aspects of reproduction in these insects.

Sex Control

Thrips are haplodiploid; that is, males develop from unfertilized eggs and have half the number of chromosomes of females. Thelytoky also occurs, in which females develop from unfertilized eggs through automixis; diploid males have not been reported. Karyotype data are available for scarcely 10 of the 4500 described species of Thysanoptera (Risler & Kempter 1961), but even for these the published data are in part contradictory. Bournier (1956) suggests that the thelytokous species *Heliothrips haemorroidalis* with 21 chromosomes is possibly triploid, but it would be interesting to know the chromosome number for a bisexual population of this species such as that referred to below from southern Peru. Virgin females of *Apterothrips apteris* can produce both sexes (Strauss, Pers. comm.), and this is probably true of other species. The cytological mechanisms involved in sex determination in such thrips species are not yet understood, for example, whether or not genetic recombination is involved. Suomalainen *et al.* (1987) conclude that "Many details of the chromosomal cycle of the Thysanoptera remain obscure; more studies are needed before anything concrete can be said with certainty." Amongst Hymenoptera there is increasing evidence that several mechanisms are involved in sex determination (Luck *et al.* 1991). One remarkable mechanism demonstrated by Stouthamer *et al.* (1990) involves parthenogenetic species of *Trichogramma* that become bisexual after treatment with heat or antibiotics, suggesting that their thelytokous condition is induced by microorganisms.

Sex Ratios

Most data on sex ratios of thrips are based on field collections of adults. It is commonly inferred that such ratios are typical for a species locally or even generally. Few authors have attempted to study any possible variation in sex ratio with time within a population, and very little attempt has been made to discover the primary sex ratio of any species. Crespi (1991) has observed that, within *Elaphrothrips tuberculatus* populations, the ratio may vary from almost 1:1 to strongly female biased during the year. Olsen (1984) gives figures based on larvae of three species at a site in Norway; *Mycterothrips latus* was 23% male, *Taeniothrips picipes* was 44% male, but no males of *Thrips vulgatissimus* were found. Bournier (1956) considered that 20% of the larvae of *Taeniothrips inconsequens* taken at a site in southern France were male, although no adult males were collected at this site.

Table 1 gives the number of species for which males are not known in each of four faunal studies on Thysanoptera; this does not imply that males are unknown for such species, only that males are not known in that particular area. Male Aeolothripidae are conspicuous by their absence. This may be partly statistical in origin, since members of this family often occur in low numbers thus reducing the probability of a male being collected, although *Aeolothrips vittatus* males are quite unknown. The figure of 14 - 15% of Phlaeothripidae for which no males are recorded is curiously consistent through these four faunas, and recurs in the Californian fauna of this family (Cott 1956). The high proportion of Thripidae with males unrecorded in the faunas of Britain and New Zealand is possibly related to the high proportion of introduced species in these faunas.

Table 1. Species of Thysanoptera with males not found

Family	**Males known**	**Males unrecorded**	**Total species**	**mu/t***
BRITISH FAUNA (Mound *et al.* 1976)				
Aeolothripidae	7	6	13	46%
Thripidae	72	22	94	23%
Phlaeothripidae	30	5	35	14%
TOTALS	**109**	**33**	**142**	**23%**
ILLINOIS FAUNA (Stannard 1968)				
Aeolothripidae	4	5	9	55%
Heterothripidae	9	0	9	0%
Merothripidae	1	0	1	0%
Thripidae	73	21	94	22%
Phlaeothripidae	91	16	107	15%
TOTALS	**178**	**42**	**220**	**19%**
GERMAN FAUNA (Schliephake & Klimt 1979)				
Aeolothripidae	13	5	18	28%
Thripidae	123	24	147	16%
Phlaeothripidae	67	12	79	15%
TOTALS	**203**	**41**	**244**	**17%**
NEW ZEALAND FAUNA (Mound &Walker 1982, 1986)				
Aeolothripidae	2	1	3	33%
Merothripidae	2	0	2	0%
Thripidae	35	16	51	31%
Phlaeothripidae	58	10	68	15%
TOTALS	**97**	**27**	**124**	**22%**

*Number of species with males unrecorded divided by total number of species

Table 2 gives the numbers of the two sexes in cumulative samples of leaf-litter thrips listed in two taxonomic studies. Each of the species listed is primarily wingless, and they share the same habitat, but there is considerable variation in the numbers of males collected. Very little is known about the biology of these species, beyond the fact that they feed on fungi, and seasonal variations may be involved despite the apparent stability of the litter habitat.

Table 2. Sex ratios in some leaf litter Thysanoptera

	Males	**Females**	**% Males**
AUSTRALIA (Mound 1972)			
Baenothrips caenosus	7	39	15
Baenothrips moundi	4	45	8
NEW ZEALAND (Mound & Walker 1986)			
Baenothrips moundi	61	268	19
Carientothrips badius	53	74	42
Carientothrips loisthus	29	72	28
Emprosthiothrips bogong	53	87	38
Allothrips stannardi	24	79	23

Table 3 gives cumulative data on 21 species of thrips derived from the field notebooks of the late Guy Morison who collected in northeastern Scotland over a period of 50 years. Morison kept detailed notes of the sexes and instars of every thrips he collected, together with locality and host plants. His notebooks are preserved in the Natural History Museum, London. The data represent the essentially haphazard activities of an exceptionally able field naturalist. Morison was trying to recognize the host plants and distribution patterns of the British thrips fauna. His is a unique data set, but since it was accumulated opportunistically over a wide area and long period of time it has clear limitations.

High proportions of males were recorded for only two polyphagous species, the grass-living *Chirothrips manicatus* and the flower-living *Thrips atratus.* In contrast, no males at all were recorded for four species. This is particularly interesting for the spore-feeding, leaf-litter species *Megathrips lativentris* which is known to produce males in southern England, and also for *Taeniothrips inconsequens* of which males have been taken in central England. For most species listed in Table 3, the collections included about 20 - 30% males, notable exceptions being the leaf feeding *Mycterothrips latus,* and *Thrips brevicornis* which is specific to *Lonicera* flowers. There is no evidence of sex ratios being related to different habitats and biologies, although it is clear that in some species males are only available during restricted periods, e.g., *Thrips juniperinus* which breeds when juniper flowers are available in early summer.

Table 3. Thysanoptera Collections By Guy Morison In Britian

Species	Period	Samples	Males	Females	% Male
GRASS-LIVING THRIPIDAE					
Chiro. manicatus	1930-45	317	2161	3648	37
	[viii*	66	1343	72	95
Chiro. ruptipennis	1924-73	28	0	102	0
Balio. dispar	1928-45	122	216	711	23
Balio. kroeli	1928-65	28	41	176	19
Limo. cerealium	1927-40	275	894	2846	24
	[vii-ix*	160	880	2000	30
Limo. denticornis	1923-44	126	64	340	16
Stenchaeto. biformis	1946-65	7	40	84	32
HOST-SPECIFIC THRIPIDAE					
Myctero. latus	1945-56	340	43	801	8
Odonto. ulicis	1929-44	168	548	2041	21
	[iv-v*	110	430	1612	21
Serico. staphylinus	1927-44	155	769	2087	27
	[vii-ix*	69	413	963	30
Thrips brevicornis	1942-55	117	34	523	6
Thrips calcaratus	1941-55	115	0	1397	0
Thrips juniperinus	1924-50	72	99	621	14
	[vii*	20	94	330	22
POLYPHAGOUS THRIPIDAE					
Taen. inconsequens	1945-55	106	0	635	0
Thrips atratus	1934-40	178	1027	1421	42
	[vii*	51	691	511	58
Thrips vulgatissimus	1930-40	234	847	2141	28
	[vii*	74	427	804	34
FUNGUS-FEEDING PHLAEOTHRIPIDAE					
Mega. lativentris	1950-67	112	0	237	0
Hoplo. polysticti	1940-56	74	119	288	29
Phlaeo. annulipes	1943-56	63	70	240	22
FLOWER-LIVING PHLAEOTHRIPIDAE					
Haplo. propinquus	1932-46	99	265	656	28
PREDATORY PHLAEOTHRIPIDAE					
Hap. subtillissimus	1930-71	46	26	63	30

* Roman numeral indicates collections during specific month(s) of the year

Of particular interest is the high proportion of males in samples of the Oriental rice thrips, *Stenchaetothrips biformis,* which were taken just west of London. Several species of thrips which have become widespread around the world have done so only as unisexual populations. In North America, *Taeniothrips inconsequens* is known only from females. *Thrips tabaci* is cosmopolitan, but males are rare or absent through much of its range; only in the eastern Mediterranean where its primary host plant, *Allium,* is native have males been collected in large numbers. Similarly, although males of *Aptinothrips rufus* are sometimes common in Europe, they are rare throughout most of its distribution in the temperate parts of the world, e.g., absent from Illinois (Stannard 1968); 3 males and 682 females recorded from New Zealand (Mound & Walker 1982). *Haplothrips gowdeyi* is widespread and common in the tropics, but males are known only from parts of Africa, particularly eastern Africa including Aldabra Island. In 1976, Mound recorded only 21 males (mostly Brazilian) of *Heliothrips haemorrhoidalis* out of more than 800 specimens available in museum collections; since then a sample from southern Peru has been studied with 13 males and 28 females. In contrast, and like the Oriental rice thrips referred to above, the Cacao thrips, *Selenothrips rubrocinctus,* is apparently bisexual throughout its pantropical distribution although always with a strong female bias. Bisexuality is also found in *Thrips palmi* which has suddenly extended its range throughout the tropics in recent years, and also *Thrips orientalis* both sexes of which are now known from Trinidad (also Florida where it is found in Jasmine flowers - S. Nakahara, Pers. comm.).

All the data in these Tables, also data in Crespi (In press b) and Bullington (1978) for *Hoplothrips* species, suggest that the sex ratio of thrips species is usually female biased. Hartl & Brown (1970) indicate that a 1:1 sex ratio is favored by haplodiploidy, provided sons and daughters are of equal cost to a breeding female *and* under panmictic conditions. It is this latter proviso which is possibly the important factor for thrips. My own field collecting activities have convinced me that many species of Thysanoptera are probably not truly panmictic. Thrips biology seems typically to involve the production of localized large populations when conditions are favorable, followed by extinction and dispersal when conditions are unfavorable. Only a few highly polyphagous flower-living species seem likely to be panmictic, such as *Thrips atratus* and *Chirothrips manicatus* (see Table 3). Most other thrips species probably live as relatively isolated demes, and presumably it is this small local population size which helps drive the sex ratio to its female bias (Charnov 1982), particularly if females mate before dispersal.

Systematic Distribution of Sexual Dimorphism in Thrips

In the Merothripidae, the family which retains the largest number of primitive characteristics, males often differ from females in having the fore femora enlarged and a tubercle on the fore tibiae. Moreover, in some species in this family the males have the entire dorsal surface of the head developed into a glandular area (Moritz 1984). In the Aeolothripidae, the largest of the more primitive families, males are smaller than females and sometimes have "claspers" at the abdominal apex whose function is unknown. In one extraordinary aeolothripid, recently described from the male cones of cycads in eastern Australia (Mound 1990), the males have large stout setae on the ninth abdominal tergite which vary allometrically with body size. Similar setae are found on the ninth tergite of males in the thripid sub-family Panchaetothripinae. Males of the pantropical aeolothripid genus *Franklinothrips* are unusual in having the head shape and antennae quite different from females, and males of *Erythrothrips* species often have remarkably stout muscle insertion areas on the anterior margins of the abdominal tergites; *E. loripes* males have a unique fringe of setae on the hind tibiae. These examples of sexual dimorphism affect different structures and probably involve different behavior patterns, but in that they occur in the least advanced families of this insect Order they suggest that a tendency for sexual dimorphism was inherited from the ancestors of the Thysanoptera.

Amongst Thripidae, males are also usually smaller than females; many are short winged or apterous. In many species males have glandular areas on the abdominal sternites. Thorn-like setae on the dorsal surface of the ninth tergite are commonly found in male panchaetothripines, and the males of many unrelated thripids have various, non-homologous, projections or stout setae at the abdominal apex, e.g., *Anaphothrips, Odontothrips, Dikrothrips,* and some *Frankliniella.* The African citrus thrips, *Scirtothrips aurantii,* has a unique comb of setae on the hind femora, and the antennae of the males of leaf-feeding *Mycterothrips* species have a remarkable array of sensoria.

It is amongst the Phlaeothripidae that sexual dimorphism is most obvious. Males often have a large fore tarsal tooth, and the fore tibiae and femora may bear distinct tubercles. Other parts of the body may also bear enlarged tubercles or setae, such as on the head, pronotum, coxae, metanotum, and also dorsally or laterally on various abdominal segments; sternal glandular areas are also frequently present, particularly on the eighth sternite. This range of structures is complicated by allometric growth patterns such that the characters are most obvious in large males, and small males look like females. In contrast, the common Oriental fungus-feeding species of *Machatothrips* have distinctive secondary sexual structures primarily on females (Palmer & Mound 1978).

Strong sexual dimorphism occurs in almost all the genera of the Phlaeothripidae-Idolothripinae which feed on fungal spores; only in leaf-litter species, such as those of the genera *Allothrips* and *Zeugmatothrips,* is this phenomenon weakly developed. In the Phlaeothripidae-Phlaeothripinae sexual dimorphism is similarly obvious in many fungus-feeding species which live on dead branches, including those of the large genera *Hoplothrips, Hoplandrothrips, Phlaeothrips* and related genera. But this phenomenon, together with allometry, is not restricted to species of large body size - it also occurs in the smallest of species such as those of the genera *Sophiothrips* and *Williamsiella.* Despite this, there are many genera of fungus-feeding species in which the phenomenon is poorly developed; this is particularly true of leaf-litter species, including those of *Apelaunothrips* and all the Urothripini. Sexual dimorphism is also only weakly developed in a few members of the large flower-living genus *Haplothrips,* although it is more obvious in related genera such as *Mesothrips* whose species form galls on the leaves of trees in the Oriental region. Sexual dimorphism is developed in several gall-forming species in Australia (Crespi In press a), but is virtually absent in the large leaf-feeding genus *Liothrips* and its relatives including *Gynaikothrips,* although many of these species form leaf galls. Similarly the phenomemon seems to be absent in the predatory species of the genus *Leptothrips* and its relatives.

Sexual dimorphism thus seems to have arisen early in the evolution of Thysanoptera, and was probably inherited from the ancestors of thrips. It occurs widely throughout the Order, as does a female-biased sex ratio. Sexual inequalities such as this must have a physiological and energetic cost, and it is appropriate that we should enquire further as to their purpose.

Ecological Correlates of Sexual Inequality

Evidence for the adjustment of sex ratios by females has been produced by Crespi (1988) in one species, the idolothripine spore-feeder *Elaphrothrips tuberculatus.* In this species a female will lay male-producing eggs only if there is a high probability that the resulting progeny will have a large body size. If the environmental conditions are such that the progeny will be small, then females lay female-producing, i.e., fertilized, eggs. In this species each batch of eggs is of only one sex. Similar critical observations are needed on other thrips species, with different biologies, to determine the extent to which females control sex allocation in this group.

Considerations of the control of sex allocation by thrips species become confusing when the extent of thelytoky within the order is remembered. It may be that thelytoky has arisen by serendipity in a few widely dispersed pest species, thus enabling them to colonize new areas. But it seems more likely that occasional thelytoky is a recurrent phenomenon in this Order, and is related to the ability of many thrips species to respond to patchiness, particularly changing patchiness, in the distribution of their food resource. Species in which the food resource is relatively stable and widely available, such as *Sericothrips staphylinus* on *Ulex* leaves, may invest more of their energy in the production of males. When resources are patchy in time and space, then a female-biased sex ratio probably maintains a higher population, particularly if the option to resort to thelytoky is available when the number of females falls too low.

The physiological cost of producing giant males, with their remarkable tubercles and long setae, must be considerable, and some of the reasons underlying this energy investment by phlaeothripids have only recently become apparent. Crespi (1986, 1988, In press a) has demonstrated in several different genera that such males have an important function within the breeding system; in some species such a male may protect a particular patch of eggs to which various females contribute after mating with him (resource defense polygyny), in other species a male may protect an individual female and her eggs (post-copulatory mate guarding). Males appear to assess the body size of rivals in competitive bouts with their bodies lying parallel; they may use the abdomen to try to flick a rival over; or they may stab with the fore tarsal teeth sometimes causing death. *Idolothrips* males, which lack fore tarsal teeth but have long lateral tubercles on the abdomen, have a different competitive strategy from *Elaphrothrips* males which sometimes have very large teeth on the fore legs. Mound (1991), in discussing the variation in male structure within the genus *Actinothrips*, suggests that different fighting strategies can arise within a genus or even species, depending on the precise habitat occupied such as the size of the dead leaves on which these patterns of behavior are carried out. The females of some gall-forming phlaeothripids in Australia also fight to protect their developing galls, and some inquiline species apparently fight the gall-forming species to take over suitable galls (Crespi In press a).

There is virtually no information about male behavior and the function of male secondary sexual structures in the other families of Thysanoptera. Kirk (1985) reports an absence of aggressive behavior between males in the British flower-living species which he studied. Appanah & Chan (1981) suggest that *Megalurothrips* defend territories on the petals of tree flowers in Malaya. Terry (1990), however, has observed males of the flower-living species *Frankliniella occidentalis* swarming and fighting, and considers the possibility that larger males are more effective at jostling each other. Kirk (1985) also noted that only four *Thrips imaginis* could feed at one anther of an *Echium* flower at one time, and this suggests that competition might become important at the high population levels which this species, the Australian plague thrips, frequently reaches. Considering the wide array of armature at the abdominal apex of so many Thripidae, and also the structural modifications in males in some Aeolothripidae noted above, male competition is probably much more widespread in terebrant Thysanoptera than has yet been observed.

Studies on thrips behavior and ecology are thus making it possible to understand patterns of structural variation within the Order. In situations where the food resource is not a limiting factor, such as in leaf-litter, fungus-feeding thrips probably do not compete with each other and thus do not need to produce large males. But on dead twigs and branches, where the food resource is invading new plant tissue progressively, and presumably is optimally available only at a restricted position and for a limited time, competition is more important. Many species in this habitat seem to have a more structured breeding system, judging from their physical appearance. The breeding system is most refined in the sub-social species *Anactinothrips gustaviae* in which there is an overlap in the generations. Adults tend parties of larvae, and apparently lead them to suitable patches of lichen on a tree trunk (Kiester & Strates 1984). Nothing is known of the sexual behavior of this species, but the powerful fore legs of the males [including the so-called sound-producing organ on the fore coxae which Mound & Palmer (1984) consider might be a locking device] suggest that competitive behavior is important. Taxonomists have tended to regard the complex allometric growth patterns of Thysanoptera species as interesting aberrations. Future studies, involving collaboration between taxonomists and ethologists, are likely to demonstrate that many structures currently thought to be bizarre are essential to the biology of these insects.

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SUGAR MAPLE'S FUTURE - WILL INSECTS AND DISEASES HAVE THE UPPER HAND?

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Introduction

I accepted the invitation to address this group with no false illusions about my qualifications as an "expert" when it comes to sugar maple. Similarly, I carry no credentials that suggest I am a better candidate to forecast the future of this important species; my crystal ball is no more revealing than yours. I do believe, however, that at this juncture it might be worthwhile for those of us who have spent considerable time in northern hardwood stands to draw on our observations, research, and common sense, and to speculate on the future of sugar maple. We do not have the luxury of waiting until all of the answers are in. Landowners face problems today, and we must help these people as well as we can to make decisions that will influence the health and longevity of their stands.

I approached this meeting as an opportunity to offer a relatively unconstrained or "unrefereed" opinion of the future of sugar maple. Therefore, at the outset let me acknowledge that indeed my comments will be biased! Some of my remarks will be original, I think, but quite frankly, in addition to experience, my views have been shaped by conversations with many of you in this room and from the diverse literature on northern hardwood silviculture, forest stewardship, and landowner concerns. My objective is to share some thoughts with you and, I hope, to stimulate future dialogue.

Our ability to manage northern hardwoods will be influenced significantly by current initiatives to address forest stewardship, biological diversity, and resource sustainability. Environmental concerns, and the religious activism that frequently attends these concerns, will intensify. Not necessarily because environmental groups are more active now than they were 20 years ago, but they have honed their skills when it comes to garnering political influence and working the media and the legal system. Indeed, we have reached a point where, to make a case, protagonists often either ignore or distort facts on almost every issue.

The initial approach to environmental concerns is always characterized by polarization. As long as the parties involved insist on taking an "either/or" stance, or an "us and them" attitude, we will make little progress. Cool heads must prevail, and decisions concerning management of natural resources must be founded on good science tempered with common sense.

The general public forms its opinions according to how it *perceives* an issue. Unfortunately, these perceptions rarely are based on scientific understanding or objective assessment. This is the way of the world today, and I do not believe that the situation will change in the near future. National concerns about legitimate environmental issues, and a naive public educated largely by the popular press, will influence markedly our ability to manage forests. This is especially true for a species like sugar maple, the distribution of which encompasses the most heavily populated region of North America, and where the actions that we take to manage and protect this resource are very visible. In no other region are the integrity and traditional uses of land threatened by such a broad range of economic and environmental pressures.

The productive forest land base will continue to dwindle as human demands for land development and resources increase. This places a heavy burden on those of us who are responsible for maintaining the health and sustaining the productivity of northern hardwoods. If we want to influence future decision making, we must be imaginative and proactive. If we do not accept this challenge, decisions will be made without our input. This threat is exacerbated by the fact that the driving force in our political arena consists mainly of voters who reside in cities and urban settings. With each passing decade, these people become further removed from the source and production of natural resources.

Significance of the Maple Resource

New England and New York in 1988 manufactured approximately 890,000 gallons of maple syrup worth approximately $25,000,000 (New York Agricultural Statistics Service 1989). Additional quantities of syrup were produced in several midwestern and other northeastern states. During the same period, Canada produced more that 3.75 million gallons valued at approximately $89,000,000 (Cdn) (Bureau of Statistics of Québec 1988).

A more elusive value of sugar maple is realized through the tourist trade associated with fall foliage colors. Sugar maple crowns contribute significantly to this amenity; its economic value in many regions amounts to tens of millions of dollars annually.

The income attached to sugar maple is especially important to the economic health of many rural areas. In addition to maple syrup production and tourism, this value accrues from stumpage sales, primary processing, and secondary manufacturing. In Québec, for example, use of maple by the wood products industry is thought to contribute significantly towards stabilizing the rural population and maintaining agricultural and forestry activities. Similar values are found throughout a major portion of the geographic region that supports sugar maple. Employment opportunities and cash flow are limited in most of these rural communities, and the management and production of a diverse array of maple resources helps to ease both problems.

Sugar maple is the dominant broad-leaved tree in the northeastern United States and southeastern Canada. Its ecological position and dominance in many landscapes of the region are likely insured due to its prolific seed production, shade tolerance, and long life.

These economic and ecological realities testify to the present and future importance of sugar maple throughout our region, and argue for research and development support to address its health and management.

Threats to Maple Health and Productivity

Most of you are familiar with the key insect problems that affect sugar maple. References to outbreaks of the forest tent caterpillar, saddled prominent, fall cankerworm, and maple leafcutter, for example, are found in the earliest pest survey records.

In recent years, major concern has centered on new issues that are perceived as potential threats, especially air pollution, global warming, and, of course, pear thrips. Much speculation continues to engulf discussion about the consequences that may result from atmospheric changes, and the purpose of our gathering today is to address the pear thrips. Therefore, my remarks mainly refer to the small number of chronic or periodic insect threats that history suggests will influence sugar maple health on a relatively regular basis. My purpose is to speculate on how changes in forest development, forest management, public opinion, and the availability of pest management tools will impinge on our ability to assure that sugar maple has a healthy and productive future. A futuristic vision is essential, because good stewardship implies, among other things, a commitment to pass forests on to succeeding generations in better condition than we found them (Sample 1991).

Facts of Life that will Influence Maple Health

Several trends have helped to shape today's northern hardwood stands, and they are likely to influence their future:

1. The northern hardwood resource is highly fragmented and held mainly by private non-industrial landowners. This ownership is characterized by a widening array of management objectives, economic capabilities, and social concerns.

2. Many of these landowners are "non residents" whose interests, understanding, and values often differ markedly from those of resident landowners.

3. Selective cutting continues as the dominate means of "managing" this resource. A colleague, Ralph Nyland (1992), describes this as managing for the extraction of salable logs, not managing for growing stock *per se*. To many of you, the expression "high-grading" may be a more familiar description of the practice. This trend most likely will continue until we can create markets for poor-quality and small-diameter trees.

4. Synthetic organic insecticides rapidly are becoming unacceptable or unavailable control options in many political jurisdictions. The public clamors for more "biorational" approaches that they believe are panaceas for all pest problems.

5. As the forest base on which we depend to produce wood products declines, forest management must intensify and, accordingly, management investments and the need to protect these investments will increase.

6. The general public will continue to form their perceptions about what is happening in the forest based on information provided by the popular press.

7. Human population growth and its parallel demands for wood fiber and sundry noncommodity values will not abate. Forestry truly is caught in the middle of what at times seems like an insurmountable dilemma. Our responsibility as stewards simultaneously must address resource demands *and* environmental concerns. We do not have the option of concentrating on one need at the expense of the other.

The Future

Will forest pests gain the upper hand? Maybe! I am reluctant to offer an unqualified "NO." It is not that I lack faith in the commitment or collective wisdom of you and other colleagues who are concerned about sugar maple health. Quite the contrary. It is simply that I believe many decisions about how, or whether, to manage for a healthy northern hardwood forest will be taken out of our hands.

Let me briefly elaborate on some of the "facts of life" mentioned above. I believe that these forest conditions and social imperatives will influence the future impact of insects, diseases, and adverse atmospheric conditions on northern hardwoods in general, and sugar maple in particular.

Forest Conditions. A majority of our current maple stands were established following heavy cutting and/or fire at the turn of the century. Most of these 80 to 90 year old forests never received appropriate silvicultural treatment (thinning). Consequently, they are overstocked and of low vigor as a result of intense competition for resources. Those stands that have been exposed to the chain saw were exploited for high quality sugar maple and the more valuable and shade-intolerant species, such as black cherry, ash, and yellow birch. Additionally, in many northern hardwood stands, beech bark disease has reduced the ecological role and position of American beech. These events have resulted in less diverse stands of predominantly poor quality sugar maple, quality that is most likely reflected by the genetic as well as the physical attributes of the stand.

As sugar maple succeeded onto abandoned agricultural land during this century, it became established on a wide variety of soil conditions, especially in northern areas of its distribution. In the absence of exogenous stresses such as insect defoliation and adverse weather, it can exist on soils that vary considerably in depth, structure, and nutritional want to anticipate outbreaks and prevent significant impact on trees and stands. Early warning and evaluation facilitate the decision making process, and enhance proper choice and appropriate application of control options.

2. We must be rational about biorationals! I am sure that all of us would welcome biological and/or cultural methods to control every forest pest. I believe, however, that in the immediate future these approaches are not going to be available for maple pests, and even when available, may not be applicable in all situations. Major progress has been made with *Bacillus thuringensis* during the past decade, and I look at this microbial as an increasingly reliable and economically acceptable biological control option for many situations.

It is unlikely that development of classical biological control will materialize for the key indigenous sugar maple defoliators mentioned earlier. I think we would be wise to expand our efforts and support better to understand and capitalize on key parasitoids and predators that are already part of these life systems. As a case in point, after 15 years of monitoring changes in saddled prominent populations at 16 sites in north-central New York, I believe that the egg parasitoid *Telenomus coelodasidis* plays an important role in maintaining populations of this defoliator at innocuous levels. The parasitoid apparently responds to changes in host numbers at very low host densities. When called for, direct control measures can be applied more effectively if they are timed carefully to maximize pest mortality and impact populations of *Telenomus* as little as possible.

3. We must fight to hold on to chemical insecticides. In many instances, sugarbush operators, particularly, require a quick and effective way to save foliage. When the next forest tent caterpillar or saddled prominent outbreaks materialize, for example, a significant aspect of our rural economies could be affected. In the absence of an efficient and reliable method of direct control, the economic impact may be temporary (though in many instances losing a single year's production could significantly affect a region), or if defoliation occurs in concert with other stresses, effects can be permanent. The National Agricultural Chemicals Association in cooperation with the USDA Minor Use Task Force announced recently that the Rhône-Poulenc Company has decided not to support use of carbaryl on sugar maple used for syrup production. Apparently this action is based on the burden of extensive data requirements. Further, a recent editorial in "Pest Control", an industry magazine, indicated that a decision handed down by the Supreme Court last June, holds that the Federal Insecticide, Fungicide, and Rodenticide Act *does not* pre-empt local

government regulation of pesticide use (Russell 1991). Present interpretation of this decision is that now approximately 30,000 jurisdictions will be able to participate in pesticide regulation. From a forest management perspective, these actions are, to say the least, disturbing. The former, because I believe withdrawal of carbaryl for sugarbush use will be very detrimental to an important maple resource. The latter, because now it will be much easier for the uninformed to dictate how we manage for all maple resources. I want to indicate clearly that I am not a "poison peddler!" I simply believe that, to do our jobs as stewards of the maple resource, we must have access to the appropriate use of chemical insecticides.

4. We must make a special effort to educate landowners and the general public regarding these issues and, in general, what constitutes good stewardship. For example, people should know that, under the right circumstances, chemical control and clear cutting are valid and environmentally acceptable tools. There is no evidence that acid rain has had a major influence on maple health. Sugar maple is not in danger of becoming extinct. In many cases, we can determine the events that most likely precipitated the disease condition we call decline. Crown dieback is a response to stress and is not synonymous with decline. Deliberate forest management often is required to maintain diverse and healthy stands. And so on.

I know education commonly appears in lists of desirable actions when it comes to forest related issues. More often than not, this is easier said than done. Let me suggest that more of us make the effort to write for the popular media such as "Vermont Life", "Adirondack Life", or "Yankee Magazine", for example. These publications not only reach landowners but, more importantly, they are also read by people who live in urban settings. Recently, I have taken advantage of an offer to produce a series of articles for "The New York Forest Owner", a combination newsletter and bulletin that is published every two months by the New York Forest Owner's Association. This gives me an opportunity to communicate with a very important, albeit small, group of people who own forest land. Many states have a similar organization. In a recent issue of the "Forest Owner", Dan Weller, Chief Forester of the Bureau of Lands and Forests in the New York Department of Environmental Conservation, wrote a very good article about harvesting as a tool of forest stewardship (Weller 1991). He pointed out that a major factor which will determine the future direction of forest management is the attitudes of non-forest landowners. He emphasized how important it will be to inform people that the forest land values they want to "save" or "preserve" can best be protected by being deliberately managed.

We can not rely on others to do the telling. Somehow we must find time in our busy schedules to interact frequently and more effectively with the ultimate decision makers.

Closing

Regional meetings such as the Northeastern Forest Pest Council, the Northeastern Forest Insect Work Conference, and special sessions such as the one devoted to pear thrips this week, are essential for us to review, discuss, and debate issues. However, we must interact more with the forestry profession and the general public. Talking to ourselves is a relatively comfortable, but often dangerously reassuring, enterprise. We need to be challenged, we must listen to the concerns of others, and we should seek opportunities to share with the public our own anxieties and constraints regarding the role that forest entomologists play in forest stewardship.

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Abstracts of

ORAL PRESENTATIONS

MOLECULAR SYSTEMATICS OF THYSANOPTERA

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Sequencing of a 450 base-pair region of the mitocondrial cytochrome oxidase 1 gene for 10 thrips species in four families, and three species of Hemiptera which served as the outgroup, revealed that (1) the Phlaeothripidae are clearly the sister-group to the Terebrantia, (2) the Aeolothripidae are probably the sister-group to the Heterothripidae, (3) the Phlaeothripinae probably evolved from an Idolothripinae-like ancestor, and (4) the Thripidae form a monophyletic group. The pear thrips, *Taeniothrips inconsequens,* was used as one of the Thripidae studied, and this work shows that mitochondrial DNA sequencing could be used to analyze the population structure of this species and determine the European source of the North America populations.

FACTORS INFLUENCING PEAR THRIPS (*TAENIOTHRIPS INCONSEQUENS* (UZEL)) POPULATION SIZE IN SUGAR MAPLE

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Pear thrips, *Taeniothrips inconsequens* (Uzel), was first identified as a pest of sugar maple in Pennsylvania in 1980. The varying degrees of pear thrips damage to sugar maple since then, and the results of recent surveys, indicate that pear thrips populations undergo dramatic fluctuations in size. Preliminary results of an ongoing study to examine the population dynamics of the pear thrips in sugar maple are reported.

An intensive sampling program for pear thrips was initiated during 1990 in a sugar maple stand in central Pennsylvania to develop a life table for pear thrips. Thrips were sampled from soil, emergence traps, water traps (for flight activity), buds and leaves, and drop traps (for re-entry to the soil). The number of leaves per tree was estimated to convert thrips intensity (i.e., numbers per leaf) to thrips density (i.e., numbers per unit area).

In 1990, few adult pear thrips that emerged from the ground were found in sugar maple bud and leaf samples (< 12%), probably the result of asynchrony between thrips emergence and the timing of budburst. In leaf samples, there were 4 times as many eggs as 1st instar larvae. This reduction in 1st instar larvae may have been the result of predation. In 1991, there was high mortality (> 20%) of soil inhabiting thrips instars, possibly due to pathogens.

Other factors that may influence pear thrips population size include: thrips dispersal, the stage of bud development at the time of oviposition, the temperature during budburst, the extent of sugar maple flowering, predators, pathogens, and rainfall.

THRIPS CALCARATUS IN WISCONSIN: SEASONAL DEVELOPMENT AND HOST IMPACT

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Thrips calcaratus emergence begins in mid-April in southern Wisconsin, and early May in northern Wisconsin. There is one emergence per year, and it contains only female adults. Adults feed on the newly opening buds, and oviposit into the major veins of leaf lower surfaces. Early instar larvae emerge two weeks later, and molt to second instar larvae after an additional two weeks. Thrips larvae drop from the foliage, pass through the soil litter layer into the soil, and pupate. Most develop to adults by early July, but some remain as larvae until mid-September. Adults overwinter in the soil.

Basswood buds begin to swell in early April. Leaf formation begins in early and mid-May in southern and northern Wisconsin, respectively. There is a close association between adult *T. calcaratus* emergence and *Tilia americana* bud opening. The adult population is initially concentrated within the earliest opening buds, and then becomes more dispersed. Larvae are more closely associated with leaves. By the time 50% of the early instar larval density is reached, the average leaf has attained 2/3 of its final size.

Phenological synchrony between adult emergence and bud opening appears responsible for the extent of injury that these insects can cause. That is, feeding occurs during a particularly vulnerable plant stage. By comparison, the native basswood thrips,

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Neohydatothrips tiliae (Hood), occurs later in the season, is more closely associated with nearly mature leaves, and causes little damage.

Successive years of 33-66% defoliation by *T. calcaratus* can severely injure basswood trees. A single episode of defoliation within this range can also reduce growth, but the extent is more variable. Drought reduces basswood tolerance to thrips feeding. Severe defoliation over several years significantly increases tree dieback.

Thrips mortality in the soil during the summer can be very high (>80%). This suggests that soil natural enemies could be important regulating agents. Larval mortality during foliar feeding is relatively low. Analysis of 14 plots over 3 years suggests that heavily infested stands are more likely to undergo population declines than marginally infested stands.

Sampling and prediction of thrips populations can be augmented by using degree-day models. Statistically significant phenological relationships were obtained for all thrips stages, and for all host events. In the future, this could be refined to allow for more focused sampling efforts and subsequent prediction of peak population densities.

WITHIN-TREE DISTRIBUTION OF PEAR THRIPS, *TAENIOTHRIPS INCONSEQUENS* (UZEL), IN SUGAR MAPLE

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Within-tree distribution of pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera: Thripidae), in sugar maple, *Acer saccharum* Marsh., was determined in six trees in 1990. Trees were approximately 60 years old, 15 - 17 m in height, and were located in a 1 ha plantation of 210 trees situated near the University Park campus of Penn State University in central Pennsylvania. Five leaf buds were taken from each of four cardinal quadrants (north, east, south and west) in each of two canopy positions (inside and outside) at each of three crown height levels (upper, middle, and lower); a total of 120 buds was taken from each tree. Hand-picked bud samples, taken by tree-climbers one week after initial budburst when leaves were >2.5 cm in length and beginning to unfold, were placed immediately in sealed plastic bags and returned to the laboratory. Thrips adults and eggs from bud samples were counted in the laboratory. Thrips eggs were counted after leaves were stained with 0.2% acid fuschin in 95% ethanol and glacial acetic acid (1:1 vol/vol). Few larvae were present.

No significant difference was observed in the numbers of thrips adults or eggs on buds from outside vs. inside canopy positions. Significantly fewer thrips adults were found in west quadrants compared to north and south quadrants, and fewer adults in the east quadrant compared with the south. Significantly fewer thrips eggs were found in the west quadrant compared with the north. All other directional comparisons revealed no significant differences. Significantly more thrips eggs were found in the middle portion of the crown than in upper or lower portions, even though no significant differences in numbers of adults were identified at any of the levels.

In 1991, sticky traps were hung at 5, 10, and 15 m heights in each of six trees. Traps at 5 m were below the canopy; those at 10 and 15 m were within but near the edge of the canopy. Between 20 April, shortly after the initiation of thrips emergence from the ground but before budburst, and 30 May, by which time leaf expansion had been completed, a total of 10 samples was taken. Each sample represented 2 to 4 days of trap exposure.

Thrips were captured on all traps before budburst. More thrips were captured in higher traps throughout the trapping period. During individual sampling periods prior to budburst, differences in numbers of adults were sometimes significant by height; after budburst these differences tended to disappear. More thrips were caught on sticky traps before than after budburst.

INFECTION OF PEAR THRIPS WITH *VERTICILLIUM LECANII* - TIMING OF THE NATURAL INFECTION PROCESS AND ITS RELATION TO TEMPERATURE

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Verticillium lecanii, an entomopathogenic fungus, has been recovered from pear thrips, *Taeniothrips inconsequens,* larvae throughout the sugar maple growing regions of the northeastern USA. If the fungus is to be effectively utilized for the management of this pest, it is essential that the epizootiology of the disease is understood, and basic aspects of its biology, which relate to the infection process, investigated. Pear thrips were collected at different stages of their life cycle in order to identify when infection occurred. Adults were sampled at eclosion using emergence traps. Larvae were collected 1) in the maple foliage at two sampling dates; 2) when falling from the foliage to the forest floor, preventing the larvae from coming into contact with the soil using water pan and plastic traps; and 3) when in the soil.

No infection was detected in the adults, or the larvae collected on the foliage. Symptomatic pink larvae were recovered from the water pan traps and extracted from soil samples. *V. lecanii* strains isolated from pear thrips did not germinate or grow at <5°C. Prolonged storage at this temperature did not adversely affect spore or mycelial viability. At 10°C, slow germination and growth occurred. Soil temperatures in VT sugarbushes are generally <5°C until mid May, so it is unlikely that infection of the adults would occur with emergence in early to mid-April. Growth of the fungus would only occur by late May when mean soil and air temperatures are higher than the threshold required for growth and germination. Pear thrips infection could, therefore, only occur when the larvae were in the late stages of their development on the foliage, when air temperatures ranged between 10 and 20°C, or when entering the soil during late May when soil temperatures were >10°C.

IMPLICATION OF AN INSECT-PATHOGEN COMPLEX FOR MORTALITY OF SUGAR MAPLE SEEDLINGS

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Mortality of new sugar maple, *Acer saccharum* Marsh., seedlings in stands infested with pear thrips, *Taeniothrips inconsequens* (Uzel), occurred in 1989 and 1990 in northern Pennsylvania. Leaves became spotted and/or marginally watersoaked, then collapsed or dropped, and upper portions of stems became shriveled and necrotic. A fungus resembling those which cause anthracnose diseases of other hardwood species was observed on symptomatic seedlings. Therefore, a study was undertaken to determine the association of this fungus with symptoms, to test pathogenicity of the fungus, and to investigate the potential for interaction of the fungus and pear thrips in affected stands.

Symptoms were observed and association was determined in June in five stands (one in 1989, four in 1990). Ten samples, each consisting of five symptomatic seedlings, were collected along transects in each stand. After moist incubation, seedlings were examined for acervuli (asexual fruiting bodies) and conidia (asexual spores), and one seedling per sample was selected for fungus isolation. Acervuli and conidia of the fungus were observed from leaves of 247/250 seedlings. The fungus was isolated in all 50 attempts.

Pathogenicity was tested by inoculation of laboratory-grown seedlings. Mechanical wounding of leaves followed by inoculation with a conidial suspension resulted in collapse of leaves and seedling death. Unwounded, inoculated seedlings did not die and leaf symptoms were less frequent and less severe. Symptoms were limited to a discrete ring of necrotic tissue around the points of wounding on leaves of wounded, uninoculated seedlings and were absent on unwounded, uninoculated seedlings. The fungus was reisolated from inoculated seedlings (wounded and unwounded).

The potential for interaction of the fungus and pear thrips was evaluated by a chemical trial in four affected stands in 1990. The systemic fungicide benomyl, systemic insecticide acephate, both pesticides, or water only were applied repeatedly throughout the growing season to plots replicated three times per treatment in each stand. Each plot was surrounded by a wire cylinder and initially contained at least 15 sugar maple seedlings of the 1990 cohort, which were counted in June and September. Final seedling number divided by initial seedling number was greatest for plots treated with both fungicide and insecticide in all four stands (treatment effect significant at $p<0.05$).

The fungus, tentatively identified as a *Discula* sp., should be considered among causes of foliage symptoms and mortality of sugar maple seedlings, especially those damaged by pear thrips. Pear thrips may be the wounding agent in an insect-disease complex which could inhibit regeneration of maturing sugar maple stands. These agents, their effects, and the conditions or practices which minimize their impacts should be investigated further.

DEVELOPMENT OF AN ARTIFICIAL SELECTIVE MEDIUM FOR ISOLATION OF THE PEAR THRIPS PATHOGEN, *VERTICILLIUM LECANII* (ZIMM.) VIEGAS

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A major objective in the development of *Verticillium lecanii* (Zimm.) Viegas for the control of pear thrips, *Taeniothrips inconsequens* (Uzel), is to study its biology in a sugarbush. Development of a selective artificial growth medium which would facilitate isolation of the fungus from soil and litter samples, will provide a useful tool for these investigations. Information can then be generated on the timing of the natural infection process, where and how the fungus survives, and on seasonal variations in fungal load in the sugarbush environment. Such information is vital to the development and success of any thrips management strategy based on this fungus. The selective medium will also facilitate the recovery of the entomopathogen from infected pear thrips. A range of *V. lecanii* strains, isolated from a variety of hosts, including pear thrips, was used. The effects of various additives to a basal growth medium, on mycelial growth and spore germination, have been evaluated. The chemicals incorporated include a range of commercially used fungicides to supress the growth of non-target fungi, and antibiotics to prevent the development of bacterial contaminants. The chemicals were added to the medium ranging from 0.5 to 2000 mg per liter, and the growth or germination of the fungus measured and compared to that on a basal medium. A medium incorporating a combination of additives is being developed. Use of a range of fungal strains will provide information on differences in the tolerance of the fungi for these additives. Such differences in growth responses may also correspond to differences in pathogenicity for a particular target pest species.

A HISTORY OF THE PEAR THRIPS IN PENNSYLVANIA

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In June, 1979, damage to sugar maple was observed on about 135,000 acres of forests in north-central Pennsylvania. In May, 1980, forester Paul Lilja and others of the Pennsylvania Bureau of Forestry observed the pear thrips, *Taeniothrips inconsequens* (Uzel), on developing foliage of sugar maple at numerous locations in Potter County. That year and each spring for the following ten years Pennsylvania Bureau of Forestry personnel found pear thrips adults and larvae associated with damage to sugar maple foliage. This outbreak reached a peak in 1988 when sugar maple trees over 1,000,000 acres in northern hardwood forests were damaged. In Potter County, pear thrips was most abundant and sugar maple foliage more heavily damaged at altitudes of 2,000 feet and above. In many of these same areas maple trees have undergone extensive dieback and mortality during the last two decades.

In three instances in Tioga County, Pennsylvania, pear thrips larvae were associated with leaf-drop of black cherry foilage.

SAP CHARACTERISTICS AND CROWN CONDITION OF SUGARBUSH MAPLES TWO YEARS AFTER PEAR THRIPS ATTACK

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Spring sap sugar concentration and volume, spring budburst phenology, and summer crown condition were compared among dominant and co-dominant sugar maples *(Acer saccharum* Marsh.) that exhibited different degrees of crown damage following a 1989 attack of pear thrips *(Taeniothrips inconsequens* Uzel) in a Pennsylvania sugarbush. In the first year following attack, sap sugar concentration and volume were greater for trees with light damage compared with moderate or heavy damage. In the second year following attack, sap volume was still greater for trees with light compared with heavier degrees of damage. Sap sugar concentration in the second year was greatest for trees with heavy damage, but concentration did not differ between trees with light and moderate damage. Calculated syrup production, based on sap sugar concentration and volume, was greatest for trees with light damage and lowest for trees with heavy damage in both years. Trees with heavy damage in 1989 had earlier 1991 budburst than trees with light damage, and early budburst was associated with greater 1991 thrips infestation (number of oviposition sites per leaf). The results indicate that pear thrips damage in 1989 had a detrimental impact on sugar maple health and syrup production for two years following damage, and that heavy pear thrips damage is associated with early budburst in some years.

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SUGAR AND RED MAPLE HEALTH CONDITIONS AND THEIR RELATION TO PRODUCTION PRACTICES IN OHIO'S SUGARBUSHES

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Thirty-five sugarbushes located in ten counties were surveyed in the major maple syrup production areas of Ohio to evaluate the health status of sugar maple *(Acer saccharum* Marsh.) and red maple *(Acer rubrum* L.). The relation of sap collection systems (SCS) to tree health was also evaluated by classifying each sugarbush into one of four SCS: 1) buckets with tractor collection; 2) buckets with horse collection; 3) tubing with gravity collection; and 4) tubing with vacuum collection. In each sugarbush, five plots were established and the health of four surrounding tapped trees was evaluated using protocols developed for the North American Maple Project. Stand structure, composition, and regeneration components were estimated at each plot. Preliminary results indicate trees are healthy; over 95% of all trees have <15% crown dieback. Tapped red maples, comprising only 10% of the 700 trees evaluated, had higher crown transparency and crown dieback than sugar maples. Thrips *(Taeniothrips inconsequens* Uzel) injury was observed throughout sugarbushes in northeast Ohio, but injury was light to moderate with no significant defoliation. Crown transparency estimates indicate that the proportion of trees with dense foliage (<15% transparency) is less in sugarbushes using buckets compared to those using tubing SCS. Similarly, large (>5 cm^2) root injury incidence and severity is greater in bucket bushes compared to tubing bushes. The incidence of both small and large open wounds is positively related to the number of years a sugarbush has been tapped.

THE IMPACT OF PEAR THRIPS ON SUGAR MAPLE ON THE ALLEGHENY NATIONAL FOREST

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Thirty plot clusters were established in northern hardwood stands on the Allegheny National Forest to assess the condition of sugar maples within thinned, unthinned and clearcut with residual management types, and to determine the impact of pear thrips on the decline. Data were collected during early spring and late summer in 1990 and 1991. Several measures of crown condition, including dieback and transparency, were estimated for each tree according to the North American Maple Project (NAMP) guidelines. Defoliation was rated according to the cooperative pear thrips survey guidelines. Preliminary results indicate that the majority of sugar maples (70 and 76%, respectively) in the thinned and unthinned stands are in the lowest dieback classes, i.e., 0 to 10%. The majority of sugar maples in clear cuts (66%) are in the upper dieback classes. Dieback seems to be increasing slightly in clearcuts with residuals and thinned stands, and is unchanged in unthinned stands. At present, pear thrips may play a minor role in the decline but does not seem to be a major factor in the decline of sugar maples on the Allegheny National Forest. Continued collection of data is planned for 1992; this may help to determine the extent and possible causes for the decline of sugar maples on the Allegheny National Forest.

REGIONAL PATTERNS OF PEAR THRIPS EMERGENCE

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The severity of pear thrips damage in a given year is believed to be closely related to the timing of adult emergence from the soil and its synchrony with sugar maple budbreak. Information on emergence patterns statewide is also critical for determination of the best time for pesticide applications. For the past three years (1989-1991) we monitored adult emergence of pear thrips daily in sugarbushes in northern, central and southern regions of Vermont using 3-in (7.62 cm) diameter traps. In addition, we recorded soil and ambient temperature from 3.3 - 10.0°C at the onset of emergence. We found that emergence began as early as 2 April and as late as 15 May, but generally started in mid-April, with minimal variation among years or regions statewide. However, the average number of days from the start of emergence to peak emergence, defined as the date at which half of all the thrips in a particular site had emerged, varied greatly among years. Peak emergence was reached within 10 - 14 d, 3 - 10 d, and 7 - 17 d in 1989, 1990 and 1991, respectively. An open, snowless winter causing deep soil freezing is thought to be the reason for the relatively slow emergence in 1989. Minimal thrips damage was reported that year despite relatively high thrips populations. In contrast, deep snow cover in 1990 protected the soil from freezing, allowing thrips to emerge quickly in the spring. In some areas thrips damage was very heavy, though thrips populations were considerably less than in the previous year. These results suggest that the rate of emergence rather than the date of first emergence may be a critical factor relative to the development of damage. Further evaluation of these factors may provide tools for predicting damage before it occurs.

THE THYSANOPTERAN FAUNA OF SUGAR MAPLE IN PENNSYLVANIA

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Samples for thrips were taken from soil (1990 and 1991), emergence traps (1991), water traps (1990 and 1991), buds/leaves (1991) and drop traps (1991) in a sugar maple (*Acer saccharum* Marsh.) plantation situated close to the University Park campus of Penn State University to determine the Thysanopteran fauna associated with sugar maple. All thrips (adults and larvae) taken from samples were mounted on microscope slides for identification.

The number of pear thrips, *Taeniothrips inconsequens* (Uzel), in soil and water trap samples was much higher (by a factor of over 20 times) in 1990 compared to 1991.

In 1990 over 90% of thrips identified from soil samples (March) and water traps (March - October) were *T. inconsequens* . However, in 1991 only 16.3% of thrips identified from water traps (April - July) were *T. inconsequens*. Other thrips species commonly found in water traps in 1991 included *Oxythrips* sp., *Frankliniella stylosa* Hood, *Frankliniella tritici* Fitch, *Thrips winnemanae* Hood and *Haplothrips kurdjumovi* Karny. At least another 8 species were trapped but were less common. As over 93% of thrips in soil samples and emergence traps were *T. inconsequens* in 1991, it seems likely that many of the other species sampled flew into the sugar maple plantation.

In bud/leaf and drop trap samples, most larvae belonged to the Thripidae (99%) but between 5 and 8% of 2nd instar thripid larvae were not *T. inconsequens*. Thripid larvae taken from bud/leaf and drop trap samples and reared to adult were all *F. tritici*. Tubuliferan larvae taken from bud/leaf and drop trap samples and reared to adult were *H. kurdjumovi* and *Leptothrips mali* (Fitch). Aeolothripid larvae taken from bud/leaf and drop trap samples were probably *Aeolothrips melaleucus* Haliday because this was the only Aeolothripid adult taken in all other samples.

Over 20 species of thrips were trapped in the sugar maple plantation during 1990 and 1991, but only a few species, namely, *T. inconsequens*, *F. tritici*, *H. kurdjumovi*, *L. mali* and possibly *A. melaleucus*, appear to reproduce on the sugar maple trees.

The number of thrips species found to be associated with sugar maple in this study indicates the need for accurate thrips identification in life cycle and population dynamics research as well as for monitoring thrips populations.

We make special acknowledgement of the assistance of Dr. S. Nakahara, USDA, ARS, Beltsville, MD, with identification of many of the specimens.

EFFECTS OF TEMPERATURE DURING BUDBURST ON PEAR THRIPS DAMAGE TO SUGAR MAPLE

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Sugar maple *(Acer saccharum* Marsh.) seedlings were exposed to four treatments consisting of two temperature levels (cool, 11.9°C; warm, 18.2°C) crossed with two pear thrips *(Taeniothrips inconsequens* (Uzel)) infestation levels (40 or 0 adult thrips per seedling) during budburst and early spring growth. The temperature levels represented differences in average air temperature that often occur between years during sugar maple budburst in Pennsylvania. Compared with the warm temperature, the cool temperature extended the time required for completion of stem and leaf elongation. Thrips feeding reduced seedling height, leaf area, and dry weight at both temperatures, and reductions were greater at the cool temperature than the warm temperature. The results suggest that cool temperatures can promote pear thrips damage to sugar maple by slowing budburst and extending the duration of feeding on foliar tissues prior to leaf expansion.

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RESPONSE OF THRIPS TO CHEMICAL SCENTS

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The effects of scent (anisaldehyde) and color (yellow or black) on the capture of western flower thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), in a glasshouse were investigated in two separate trapping experiments. In the first experiment, the greatest numbers of female thrips were captured in yellow scented water traps. Female thrips were captured in significantly decreasing numbers in yellow unscented, black scented, and black unscented water traps, respectively. For male thrips there were no significant differences in trap capture in yellow scented and yellow unscented water traps, but males were captured in significantly decreasing numbers in black scented and black unscented water traps. A significant interaction occurred between scent and color for both sexes, indicating that these factors do not act independently in the capture of thrips in water traps.

In the second experiment, yellow water traps were set along two intersecting lines. A scented water trap was located at the intersection of these lines. Unscented water traps extended for 32 m at intervals of 6.4 m north and south of the center, and 30 m at intervals of 3 m east and west of the center. Numbers of thrips captured in the scented trap were greater by a factor of 13.4 than the average numbers captured per unscented trap to the east, west, and south. To the north, capture of thrips in unscented traps at increasing 6.4 m intervals was 0.4, 0.9, 4.1, 3.1, and 1.3 times the number captured in the scented trap. When compared with the average numbers of thrips caught in other unscented traps at similar distances from the scented trap, numbers in traps to the north were higher by factors of 4.5, 10.5, 23.4, 71.8, and 63.0. Increases in trap capture to the north of the scented trap may have been the result of directional airflow within the glasshouse carrying the scent to the north, or of a localized higher population of thrips in that direction.

Abstracts of

POSTER PRESENTATIONS

IMPACT OF PEAR THRIPS ON SUGAR MAPLE - OBSERVATIONS FROM THE NORTH AMERICAN SUGAR MAPLE DECLINE PROJECT (NAMP)

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Nine NAMP study sites, six in Massachusetts and three in Vermont, were moderately (30-60%) or heavily (> 60%) defoliated by pear thrips in 1988. Crown dieback and transparency ratings indicated that crown condition of 279 dominant and codominant sugar maples improved significantly one year following this single year of thrips damage, and recovery of trees to pre-defoliation condition occurred in two years. The principal effect of this damage was reduced crown transparency. Trees in active sugarbushes were more seriously damaged than trees in unmanaged northern hardwood stands.

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DEGREE-DAY MODELS FOR SLASH PINE FLOWER THRIPS IN SLASH PINE SEED ORCHARDS

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Degree-day models (DDM), based on three years' data collected from a north Florida slash pine (*Pinus elliotti* Engelm.) seed orchard, were developed for different low threshold temperatures to describe the phenology of 1) female strobilus (flower) development, and 2) different rates of attack of slash pine flower thrips [*Gnophothrips fuscus* (Morgan)] (SPFT). A biofix date of December 5 was used to start degree-day accumulation. For stage 2 flowers, the DDM with a 40°F low threshold had a coefficient of variation (CV) of 2.9. CV's for other low threshold temperatures were 8.1 at 45°F, 16.2 at 50°F, and 25.4 at 55°F, respectively. For the 50% attack rate by SPFT, the CV for 40°F was 7.0. CV's for other low threshold temperatures were 8.8 at 45°F, 9.7 at 50°F, and 11.8 at 55°F, respectively. Overall, the DDM with low threshold temperatures of 40°F appears best for predicting phenology of flower development and 50% attack rate of SPFT. The biofix date maintains agreement with Boyer's (1978) for pollen shedding of slash pine. The 40°F low threshold temperature follows Pruess' (1983) suggested standard for pest management.

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PEAR THRIPS SITUATION IN QUÉBEC, WITH PARTICULAR EMPHASIS ON THE INFESTATION OF THE OKA ARNEWS* PLOT

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The pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera: Thripidae), was first recorded in 1969 in Québec. The insect was then found infesting an apple orchard in Frelighsburg, a village located near the Vermont border. Until recent years, it was the only record of pear thrips in Québec and thus, the insect was not known to be a part of our forest insect community. However, surveys done by the Service de la Protection contre les Insectes et les Maladies of the Ministère des Forêts du Québec in 1989 and 1990 showed that pear thrips is widely distributed throughout the province, being found as far north as in the Saguenay - Lac St-Jean region. This suggests that the insect has been in Québec for a long time. Until recently, pear thrips damage, as it has often been reported, has probably been diagnosed as frost injury. However, in 1989 and 1990, no significant damage has been reported due to pear thrips attack.

Since 1988, a pear thrips infestation (light to moderate defoliation) has been recorded in our Oka ARNEWS (Acid Rain National Early Warning System; a forest health bio-monitoring program) plot. In early May, 1991, many apple producers of the Oka region sprayed chemical insecticides in their orchards to protect trees against pear thrips attacks. These orchards were all located near sugarbushes. This is the only region in Québec where pear thrips is actually a problem to some extent.

As a part of the ARNEWS network, the Oka plot has been visited twice each year since 1985 to evaluate forest health. This is a red oak (*Quercus rubra*) stand, sugar maple

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* Acid Rain National Early Warning System

representing between 30 and 40% of the trees. Pear thrips infestation is very localized, damage being observed mainly on one or two hectares of forest around the ARNEWS plot.

A marked decrease in radial growth has been observed since 1989 around the ARNEWS plot, the last three years (1989 to 1991) being those with the lowest radial growth for sugar maple around the ARNEWS plot since 1972. Estimated radial growth losses for the four years of pear thrips infestation around the ARNEWS plot (based on the five years preceding the infestation) are: 13.7%, 43.3%, 57.0% and 56.5% for 1988 to 1991, respectively.

MORTALITY OF THE 1990 COHORT OF SUGAR MAPLE SEEDLINGS IN FOUR POTTER COUNTY, PENNSYLVANIA, STANDS

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Sugar maple, *Acer saccharum* Marsh., regeneration is generally lacking in Pennsylvania's northern hardwood stands. Abundant seed production is sporadic, and rapid mortality of new seedlings has been observed. Very widespread and abundant seed production in fall 1989 prompted investigation of sugar maple seedling establishment. The objectives were to determine numbers of seedlings which emerged in spring 1990, and to quantify their survival.

New sugar maple seedlings were abundant in each of the four Potter County stands which were selected for study. Initial seedling numbers and survival were determined using square-foot plots and by examining labeled seedlings. For the first method, a plastic square-foot grid was tossed over the shoulder three times at each of ten sampling points along a transect in each stand. Each time the grid landed, living sugar maple seedlings of the 1990 cohort in that square were counted. This was done on June 1, 1990, and repeated at the same points along the same transects on September 6, 1990, and on June 4, 1991. In the vicinity of each sampling point described above, ten randomly selected seedlings were tagged on June 1, 1990, to allow periodic relocation and identification of individual seedlings. Survival was recorded on June 26, July 17, and September 6, 1990, and June 4, 1991. Damage from browsing and the subsequent condition of each seedling also were noted during 1990.

Counts in square-foot plots averaged 8.26 (359,733 per acre) on June 1, 1990, and 0.69 (30,129 per acre), a reduction of >90%, on September 6, 1990. Counts on June 4, 1991, averaged 0.06 (2,541 per acre), less than 1% of the initial number. The seven seedlings surviving in 1991 were in only two of the four stands and in only six of the 120 square plots, compared to approximately 1,000 seedlings in 113 of the 120 square plots the previous spring.

Approximately 90% of labeled seedlings were dead on September 6, 1990, and all but one were dead the following spring. Mortality most frequently occurred early in the growing season, with approximately two-thirds of seedlings dying during June. From June 1 to September 6, 1990, damage from browsing of labeled seedlings was infrequent, and that damage was not always fatal.

The rapid mortality in this 1990 cohort of sugar maple seedlings is consistent with previous reports of high mortality among sugar maple seedlings on the Allegheny Plateau. Other ongoing studies indicate the roles of insects and disease in the demise of these seedlings. Pear thrips, *Taeniothrips inconsequens* (Uzel), and an anthracnose fungus, probably acting as a complex, appear to be among the major causes of mortality. The future effects of these agents (as well as browsing) on survivors, and the conditions or practices which minimize their impact, are unknown and should be investigated.

HOW MANY LEAVES ARE THERE ON A SUGAR MAPLE TREE?

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Estimates of population intensity, such as the number of thrips per leaf, must be expressed in numbers per unit area (e.g., per m^2) before one can make valid comparisons between populations differing in time and space. In our pear thrips research we are developing life tables for this insect in sugar maple stands; therefore, we need to know the numbers of leaves or leaf clusters on sugar maple trees. We developed a simple method for counting the number of leaves on a tree that involved enclosing a single tree with bird netting in the spring and collecting leaves as they fell from the tree in the fall.

Nets were made from "Net 4" bird netting (size: 15 x 47 m; mesh size: 3.8 cm) (National Netting Inc., Norcross, GA). Nets were folded over onto themselves lengthwise and the sides sewn together to form a long tubular bag, open at one end, approximately 23 m long and 15 m wide. Nets were then rolled up from the open end in a fashion similar to a condom and placed in a large cardboard box.

Five sugar maple trees were selected for net enclosure in 1990. Professional tree climbers pulled the branches of each tree toward the tree center and tied them in place so that the tree crown width was considerably reduced. A net was carried to the top of the tree, removed from the box, placed on top of the canopy, and unrolled to the ground. The branches were untied so that the tree resumed its normal shape. The bottom of the net was tied to the tree bole close to ground level to enclose the tree completely.

HOST PLANT ASSOCIATIONS OF PEAR THRIPS

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Records of host plants of pear thrips (*Taeniothrips inconsequens* (Uzel)) (Thysanoptera: Thripidae) were collated from literature published prior to June 1991. Samples of buds, leaves and/or flowers were taken from plant species associated with northern hardwood forests in Pennsylvania during 1990 and 1991. Thrips adults and larvae were removed from the plant material and pear thrips identified. These plants were placed in one of the following pear thrips-host categories: (1) breeding host, (2) probable breeding host , (3) feeding host, or (4) incidental host.

Our host plant list indicates that pear thrips has been recorded from at least 110 plant species from a wide range of plant families and genera. Pear thrips has been reported breeding on at least 20 plant species, mostly deciduous fruit or forest tree species belonging to the Rosaceae or the Aceraceae. Forest tree species identified as pear thrips breeding hosts include: *Acer macrophyllum* Pursh (broad-leaved maple), *A. saccharum* Marsh. (sugar maple), *A. negundo* L. (box-elder), *A. pensylvanicum* L. (striped maple), *A. platanoides* L. (Norway maple), *A.rubrum* L. (red maple), *Fagus grandifolia* Ehrh. (American beech), *Quercus rubra* L. (red oak), and *Fraxinus americana* L. (white ash). No breeding hosts were identified from Europe. Pear thrips has been reported as an occasional pest of deciduous fruit trees in Europe; it has been recorded regularly on *Acer* species since 1895 in Europe and North America.

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