This is to certify that the
thesis entitled

FUSARIUM AND THE ASPARAGUS MINER
(*OPHIOMYIA SIMPLEX* L.) IN MICHIGAN

presented by

Julianna K. Tuell

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Plant Pathology

Mary K. Hausbeck
Major Professor's Signature

5/8/03
Date

FUSARIUM AND THE ASPARAGUS MINER (*OPHIOMYIA SIMPLEX* L.) IN MICHIGAN

By

Julianna K. Tuell

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Plant Pathology

2003

ABSTRACT

FUSARIUM AND THE ASPARAGUS MINER (*OPHIOMYIA SIMPLEX* L.) IN MICHIGAN

By

Julianna K. Tuell

Fusarium crown and root rot, (*Fusarium oxysporum* f. sp. *asparagi*, *F. proliferatum*) has been implicated in the decline problems in production areas of asparagus. Pathogenic strains of both *Fusarium* spp. have been associated with the asparagus miner (*Ophiomyia simplex*). Commercial fields were monitored in 2001 and 2002 for miner activity via weekly trapping for adults, monitoring of above ground stem damage, and end of season puparia counts. Puparia and mined tissue were plated to detect the presence of *Fusarium* spp. A bivoltine trend was seen across different-aged fields with the highest numbers of adult flies trapped in early to mid-August. Mining damage was greatest in the 1 year old fields early in the season and *Fusarium* was seen sporulating on up to 30% of mined stems in those fields. There was no significant difference among the fields as to the number of puparia per stem (3-4). However, most of the pupae emerged during the season in the 1 year old fields, while in older fields, which went into fern later in the season due to harvesting, more pupae were intact for overwintering. Pupae from above ground mines had 15% *F. proliferatum* and 3% *F. oxysporum*, while pupae from below ground mines had 11% and 17% respectively. Stem tissue from above ground mines had 44% *F. proliferatum* and 4% *F. oxysporum*. It is not known how significant sporulation of *Fusarium* on above ground mines is to the overall spread of pathogen inoculum, but it appears that young fields are more vulnerable to mining damage and prolonged exposure to infection by *Fusarium*.

DEDICATION

To my mother, Laura, and grandmother, Evelyn,
whose love of gardening and the natural world set me on this path;
To my father, Gary, who first believed in me;
And to my husband and partner, Matthew,
whose love and support sustains me.

ACKNOWLEDGEMENTS

With any major undertaking, there are many who contribute to its success. For patiently taking down data while I scooted on my rear through asparagus fields looking for mining damage, my thanks goes to Elizabeth Webster Dorman, Amanda Gevens, Sarah Lebeis, Nicole Werner, and Jeffrey Woodworth. Jeff, Elizabeth and Nicole also lent their ears and advice whenever I needed to try out new ideas. Stevie Malone helped extract puparia and Sarah Lebeis helped examine plates of *Fusarium*. Sheila Linderman helped with graphing programs and editing. Brian Cortright helped with locating grower-cooperators and equipment. Bill Quackenbush applied insecticides in the trial that unfortunately only made it to the appendix. And Beth Bishop gave advice about trapping methods and insect biology.

The majority of my appreciation, however, must go to my advisor, Mary K. Hausbeck, without whom this thesis would never have been possible. It was her conviction in my abilities as a scientist that gave me the opportunity and the confidence to pursue an advanced degree in biological science. Thank you!

Julianna Tuell

May 8, 2003

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

LITERATURE REVIEW

ASPARAGUS

Asparagus officinalis L. is a member of the Liliaceae family, and is thought to have evolved in Asia and/or eastern regions of the Mediterranean seacoast (3). Although records of cultivation methods date from 161 BC, most extant records originate in the 15th century. The first asparagus for sale in a public market is recorded in 1680 at the Central London Market in England (56).

Asparagus is a perennial crop that under ideal conditions can have a production lifespan of 20 years or more. Seeds are planted in nursery fields with well-drained soil and grown until the following spring, when the young crowns are transplanted into production fields. A young stand is allowed to grow for one to two years, also known as the "non-bearing" or crown establishment stage of production, before harvesting begins (27), although some commercial growers will harvest once in the first year of a production field with the idea that it will promote more intense shoot growth.

Spears emerge in early spring and are harvested when they are between 30-40 cm long either by being snapped off at the base by hand or mechanically harvested every one to five days for two to eight weeks depending on weather and maturity of the stand. Harvested spears are cooled quickly before shipping to a processor or fresh market packer (2). After the last harvest, a production field enters "layby," when fields are prepared for the fern stage of growth, often with an application of herbicide to control weeds throughout the rest of the season. Essential to a good yield the following year, healthy ferns produce carbohydrates through photosynthesis that are translocated and stored in the crown and roots for the next season's growth (36).

Michigan produces 13.6% of the total asparagus grown in the United States and ranks third in asparagus production nationally behind California and Washington. In terms of production acreage, asparagus is the fourth most important vegetable crop grown in Michigan behind potatoes, cucumbers and snap beans, and in 2001 approximately 290,000 cwt was produced at a value of $12.5 million (41). Although 75% of the over 15,500 acres of asparagus production in Michigan is devoted to processing, fresh market production has been increasing gradually to its current level of 25% up from 15% in 1998 (41). Over the last two decades, planting of open-pollinated varieties such as Mary Washington has steadily decreased as planting of all-male hybrids has increased. Over 60% of asparagus acreage is currently planted with 'Jersey Giant,' an all male hybrid (42).

FUSARIUM CROWN AND ROOT ROT

Fusarium species are ubiquitous in soil, are distributed worldwide and have been isolated from vegetative and reproductive plant tissues of plant species from diverse habitats (9). While most *Fusarium* spp. are harmless or even beneficial endophytes, some are serious pathogens that may produce mycotoxins in agricultural crops, and others have been known to cause disease in animals and humans (9, 11). Strains of *F. moniliforme* are serious pathogens of Gramineae causing diseases of sugarcane, rice and other important cereal crops around the world (9). Formae speciales of *F. oxysporum*, the most economically important member of the genus *Fusarium*, cause many serious wilts in a variety of plant species such as bananas, sweet potatoes and date palms (9).

Since it was first described in Massachusetts in 1908, *Fusarium* crown and root rot has been implicated as the primary cause of asparagus decline (23). Cohen and Heald (13) first confirmed through pathogenicity tests that *F. oxysporum* was causing mature stalks to yellow and die prematurely and young shoots to wilt on asparagus in Washington. Grogan and Kimble (31) went on to implicate *F. oxysporum* f. sp. *asparagi* (FOA) in decline and replant problems in California. Johnston et al. (39) isolated pathogenic strains of FOA and *F. moniliforme* from declining fields in New Jersey, calling FOA a wilt and root rot and *F. moniliforme* a stem and crown rot. Hartung et al. (34) isolated FOA and *F. moniliforme* from all Michigan asparagus production fields in which they sampled, even finding low densities of both in fields never planted to asparagus. While FOA can be found in association with most *Fusarium* infections on asparagus, other members of the *Fusarium* crown and root rot complex can differ between continents. In the United States, *Fusarium* crown and root rot generally consists of *Fusarium oxysporum* Schl.:Fr. f. sp. *asparagi* S.I. Cohen & Heald, *F. proliferatum* (T. Matsushima) Nirenberg (teleomorph *Gibberella fujikuroi* (Sawada) Ito G) and *F. subglutinans* (13, 14, 39), while in the Netherlands, *F. culmorum* is associated with the disease and *F. proliferatum* and *F. subglutinans* are not found (7).

Fusarium is a form genus in the Hyphomycetes (subdivision Deuteromycotina) that is known to produce macroconidia, microconidia and chlamydospores (9). Macroconidia are fusiform, usually have distinct foot-shaped cells and are formed in sporodochia (9). *Fusarium proliferatum* and *F. subglutinans*, neither of which produce chlamydospores (11), were previously classified under *F. moniliforme* but have been taxonomically separated (52). *Fusarium proliferatum* can be differentiated from *F.*

moniliforme by its production of microconidia on polyphialides in shorter chains or sometimes in falseheads (11).

Fusarium oxysporum f. sp. *asparagi* persists in soil as chlamydospores and on infected symptomless plant tissue of asparagus (36). The fungus is usually associated with vascular wilts, but may also be responsible for cortical decay (36). *Fusarium proliferatum* does not produce chlamydospores and is usually associated with crop residues, although it may also be isolated from soil (11, 36). *Fusarium proliferatum* can be found sporulating near the soil line on asparagus stems with conidia aerially dispersed by rain splashing or wind (51).

Symptoms of *Fusarium* infection include damping-off of seedlings in crown nurseries, poor stand establishment in young asparagus fields, and a slow decline in productivity of mature fields (36). Weak, spindly spears in the spring may be followed by yellowing of the ferns in midsummer, progressing basipetally toward the crown, causing the stalk to senesce prematurely (36). Advance stages of the disease may include a complete destruction of feeder roots, collapse of storage roots, and crown discoloration and rot (36).

Both *F. oxysporum* f. sp. *asparagi* (FOA) and *F. proliferatum* can be isolated from asparagus seeds (30, 37). Manning et al. (48) noted that infection began at the point of seed attachment and readily isolated FOA and *F. moniliforme* from 1 year-old plants with apparently healthy crowns as well as from flowers and berries. Both *Fusaria* can be isolated readily from mines produced by larvae of *Ophiomyia simplex* (Loew) (asparagus miner), and from larvae, pupae, and empty puparia (28). Both Davis (17) and Damicone et al. (15) have found strains of *F. moniliforme* pathogenic on both corn and asparagus.

ASPARAGUS DECLINE SYNDROME

During the 1950s to 1960s, asparagus decline was responsible for the near complete demise of the asparagus industry in many northeastern states and continues to be the major limiting factor in other asparagus-producing areas of the world (23). Asparagus decline is defined as the gradual decrease in size and number of spears such that a planting becomes unprofitable to maintain (40). Although *Fusarium* crown and root rot is considered to be the primary agent associated with asparagus decline, other diseases, insect pests, weeds, and certain cultural practices may contribute to asparagus decline when they compete with, wound or weaken the asparagus, exacerbating *Fusarium* infections (14, 23). Strategies for suppressing Fusarium crown and root rot have focused on management of factors that contribute stress to the stand (23).

Evans and Stephens (1989) found that *Fusarium* disease severity was markedly increased in asparagus seedlings infected with viral agents (AV I and AV II) compared to uninfected seedlings. They concluded that viral infection leads to an increased leakage of nutrients including carbohydrates and amino acids, which attract secondary pathogens, as well as reduce the ability of roots to synthesize lignin barriers against infection (24). Virus indexing of seed lots has become an important part of producing quality asparagus planting stock.

Severe infections of foliar diseases such as rust (*Puccinia asparagi* De Candolle) and purple spot (*Stemphylium vesicarium* Wallr. (teleomorph *Pleospora herbarum* (Pers.:Fr.) Rabenh)), cause premature senescence of asparagus foliage that may reduce carbohydrate storage in the crown, resulting in lower yields in subsequent seasons (38,

40, 50). Ironically, it was the no-till system implemented by most growers in the early 1980s to reduce erosion and damage to crowns and roots for the prevention of *Fusarium* infection that preceded the rise in foliar pathogen incidence. Debris left on the soil surface serve as overwintering sources of inoculum for both asparagus rust and the purple spot pathogen (46).

Allelopathic compounds from asparagus plant residues left in old production fields have been blamed for poor or delayed seed germination (32, 62), and predisposition to and increase of crown and root rot due to a synergistic effect (32, 33). However, Blok and Bollen found that while these compounds do inhibit new asparagus growth, contributing to a stressful environment for young stands, they do not seem to increase *Fusarium* disease incidence directly (8).

Damicone and Manning found that planting F_1 hybrid asparagus in preplant fumigated soil, along with the management of the asparagus miner (*Ophiomyia simplex* L.), significantly reduced *Fusarium* stem and crown rot (14). These results suggested that increases in *Fusarium* stem and crown rot associated with certain management practices that contribute to poor yields and plant survival is stress-related (14). Shelton and Lacy found that extended harvest one year significantly impacted yield the following two years suggesting that shorter harvest duration would benefit overall stand vigor (57). These stress factors along with other environmental stresses exacerbate and accelerate asparagus decline, playing important roles in the development of latent Fusarium infections (23).

MANAGEMENT OF ASPARAGUS DECLINE

Research in the areas of genetic resistance, use of virus-free seed and cultural practices have led to limited management of Fusarium crown and root rot. Resistance screening for FOA and *F. moniliforme* has had very little impact on F_1 hybrid production, as so far only ornamental asparagus species (*A. densiflorus* 'Sprengeri' and 'Myersii') have shown significant resistance (35, 58, 59). However, all-male hybrids are more vigorous, produce higher yields, and produce fewer volunteer seedlings than open-pollinated varieties (21). Using hybrid cultivars along with virus-indexing techniques to ensure virus-free stock have increased the quality of the initial plant stock (23).

Cultural strategies to suppress Fusarium crown and root rot include planting in fields not previously used for asparagus production, maintaining soil pH at 6.8 (63), taking care not to over-harvest the stand (57) and effective weed and insect control in the first 2 years of production field establishment (14, 45, 63). Knaflewski and Sadowski looked at the health of asparagus seedlings grown under various levels of irrigation, fertilization and spacing (44). Irrigation and plant density had no significant effect on root rot occurrence, however seedlings fertilized with 150-750 Kg/ha NPK were less infected by FOA and *Rhizoctonia solani*, another soil-borne pathogen, than those that were unfertilized (44).

A no-till system adopted by most Michigan growers to lessen erosion and protect crowns and roots from injury was recommended by Putnam and Lacy (53). However, this has exacerbated foliar disease problems by allowing infested plant debris to overwinter on the soil surface (46). Considering the defoliation that can result from foliar

diseases left unchecked, scouting for foliar diseases combined with fungicide applications and the implementation of the TOM-CAST disease forecasting system for purple spot, have in most years virtually eliminated foliar disease outbreaks (50).

Mixed results have been obtained using fungicide treatments with direct intent against *Fusarium*. Seed treatments, while they can effectively decontaminate seed, have done little to improve emergence, survival or reduction in infection of pathogenic *Fusaria* in one-year-old seedlings (43, 45). Manning and Vardaro observed a reduction in Fusarium decline symptoms and larger, more vigorous plants after using soil fumigation and preplant crown soaks (benomyl or captafol) in asparagus newly planted into *Fusarium* infested soil of Massachusetts (49). However, Lacy (45) observed that fumigation of infested soils resulted in significantly higher yields in one plot, but not in another, and that preplant fungicide dips did not significantly improve survival or increase production over untreated plants.

Once primarily used to suppress weeds, salting asparagus beds occurred until the 1940s when synthetic herbicides took their place. Coincidentally, with this cultural change came an increase in the number of reports implicating Fusarium crown and root rot in asparagus decline. Applying NaCl (common rock salt) to declining asparagus fields has been shown to suppress the effects of *Fusarium* crown and root rot (22). However, in a study conducted by Reid et al., there was little or no effect on apparently healthy fields with applications of NaCl (54). It also has not been determined what kind of long term effects continuous applications of salt might have on soil structure (23, 54).

Some success in laboratory and greenhouse experiments has been observed in the use of non-pathogenic strains of *F. oxysporum* to limit disease, however field trials have

not been successful (16, 18, 55, 61). Davis (18) found that using non-pathogenic strains of *F. oxysporum* to infest tomato, flax, carnation, cabbage and watermelon seedlings, reduced disease incidence when each was inoculated with its corresponding pathogenic strain. Damicone and Manning observed that avirulent strains of *F. oxysporum* appeared to protect asparagus seedlings from crown and root rot and *F. solani* (16). Tu et al. found that a non-pathogenic isolate of *F. oxysporum* reduced the severity of pathogenic strains in pot tests, but not in the field (61). However, in the same field study they found that organic amendments (1% (w/w) rice bran and 2% (w/w) "SH-mixture") alone and in combination with non-pathogenic strains of *F. oxysporum*, increased stand vigor and yield significantly (61). With the addition of 10% benlate WP at a rate of 1/2000 (w/w) to the organic amendments, further improvements to stand health and yield were noted (61).

ASPARAGUS MINER

Among the insects commonly found on asparagus throughout the commercial asparagus growing regions of the United States is the asparagus miner, *Ophiomyia simplex* (4, 12, 20, 26). During the fern stage, adult asparagus miners oviposit eggs near the soil line on asparagus stems, from which larvae hatch, mine and pupate under the epidermis. Larvae are small (approx. 5 mm) and mining is confined to the parenchymous tissues of the cortex between the pericycle and the epidermis, leaving vascular tissue within the pericycle unaffected. Damage by asparagus miner has been considered alternately significant (4, 12, 13, 26) and insignificant (20). However, it is currently thought that feeding by the asparagus miner larvae, resulting in extensive stem mining

damage, can lead to increased stem rot by *Fusarium*. Gilbertson et al. found that *Fusarium* inoculum increased dramatically when the fungus sporulated on dead and dying epidermal and cortical tissue damaged by larval feeding (28). Pathogenic strains of both *F. oxysporum* f. sp. *asparagi* and *F. moniliforme* have been associated with all life stages of the asparagus miner, suggesting that infected pupae serve as an additional overwintering source of inoculum in Massachusetts (14, 28).

Commercial growers in Michigan who regularly scout for asparagus beetles and cutworms, the two major insect pests of asparagus, have paid little attention to the asparagus miner (J. Bakker, personal communication). However, in the summer of 2000, extensive mining damage was noticed in several newly established commercial asparagus fields in Michigan (M. K. Hausbeck, personal communication).

Bionomics and population dynamics of the asparagus miner have been examined by Fink (26), Barnes (4), and more recently by Ferro and Gilbertson (25). *Ophiomyia simplex* is bivoltine, producing two generations per season. Overwintered adults emerge around mid-May, mate and oviposite to produce first generation adults, which emerge in mid- to late June, but may be delayed by up to a month in commercially harvested fields due to the lack of available stems for oviposition (25). One author has suggested that first generation adults aestivate throughout July and most of August, during which time second generation adults emerge (25). It is the offspring of the second generation that overwinter as pupae (25).

Early work by Barnes discussed three different parasitic wasps that were found attacking the asparagus miner in England: *Dacnusa bathyzona* Marsh. (Braconidae); *Sphegigaster* sp. (Pteromalidae); and *Pleurotropis epigonus* Walk. (Eulophidae) (4). *D.*

bathyzona was found to overwinter in the pupae of the asparagus miner (4). However, similar studies have not been conducted in the U.S. to determine natural enemies of the asparagus miner.

Chemical control strategies for *O. simplex* have largely been ignored by asparagus growers, starting with recommendations made by Fink (26), Drake and Harris (19) of using tobacco derivative sprays in the 1930s. More recently, diazinon insecticide applications have been shown to successfully reduce mining damage as well as Fusarium disease incidence (14, 25). Lampert et al. (47) proposed a mathematical model to predict fly populations for the following year based on the number of pupae found in a sample of stems. No determination has been made as to when it would be best to apply control measures.

Using meteorological data compiled over time combined with observations of a particular organism's life cycle, a phenology model predicts developmental stages for that organism (29). Organisms such as plants and invertebrates, which cannot internally regulate temperature, rely on ambient heat in their development from one stage to another. Because of yearly variations in weather, measuring the amount of heat accumulated over time provides a physiological time scale that is biologically more accurate than calendar days. Physiological time scales are measured in accumulated degree-days (a.k.a. growing degree days), which can be calculated using formulas that vary in their complexity (1, 5).

Phenology models of insect pests have been used primarily to better time control measures such as insecticide applications, often reducing pest management costs while improving control. As monitoring becomes an increasingly important component of

intensive IPM programs, phenology models are being used in some systems to help schedule these activities for better accuracy and reduction in monitoring costs.

One example of the successful use of a phenology-based model is in the control of the codling moth, (*Laspeyresia pomonella*) (Lepidoptera: Tortricidae), a serious pest of apples and pears (6, 10). In Washington state, Beers and Brunner validated the use of a model known as PETE using lower and upper thresholds of 50° and 88°F respectively, calculating degree days beginning the day of biofix (when the first male moth is captured in a pheromone trap). Insecticide sprays for the first generation were applied 250 degree-days after biofix, corresponding to a predicted 3% egg hatch. A second spray application was made according to the residual effect of the spray used (21 days later). An insecticide application for the second generation was applied 1260 degree-days (at 7% egg hatch) after biofix followed by a second spray, again according to the residual effect of the spray. In areas where biofix could not be determined, "full bloom" of the apple variety 'Delicious' was used instead. Degree-days were calculated using a sine-wave technique developed by Baskerville and Emin (5). The results of using PETE in the control of codling moth compared to traditional calendar sprays were significant. The phenology model was never more than two days different from the observed first entry of larvae into fruit and in 5 out of 9 years it was 100% accurate (6)

Phenology models have been validated for over 100 species of insect pests and compiled on the University of California Integrated Pest Management Database. Although it has not been validated in Michigan, a phenology model already exists for the asparagus beetle, *Crioceris asparagi* in eastern Ontario (60). A phenology model to predict the development of asparagus miner would benefit commercial growers through

better timing of insecticide applications to control this pest that exacerbates *Fusarium* crown and root rot in asparagus.

LITERATURE CITED

1. Allen, J. C. 1976. A modified sine wave method for calculating degree-days. Environmental Entomology. 5:388-396.
2. Anonymous 1999. National Asparagus Festival: Asparagus Facts and Information. New Era, MI, The Walk About Group, Inc.
3. Bailey, L. H., and Bailey, E. Z. 1976. Hortus Third: A Concise Dictionary of Plants Cultivated in the United States and Canada. Macmillan Publishing, New York.
4. Barnes, H. F. 1937. The asparagus miner, *Melanagromyza simplex* (H. Loew). Ann. Appl. Biol. 24:574-588.
5. Baskerville, G. L., and Emin, P. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50:514-517.
6. Beers, E. H., and Brunner, J. F. 1992. Implementation of the codling moth phenology model on apples in Washington State, USA. Acta Phytopathologica et Entomologica Hungarica. 27:97-102.
7. Blok, W. J., and Bollen, G. J. 1995. Fungi on roots and stem bases of asparagus in the Netherlands: Species and pathogenicity. Eur. J. Plant Pathol. 101:15-24.
8. Blok, W. J., and Bollen, G. J. 1996. Interactions of asparagus root tissue with soil microorganisms as a factor in early decline of asparagus. Plant Pathology. 45:809-822.
9. Booth, C. 1971. The Genus Fusarium. Commonwealth Mycological Institute, Key, Surrey, England.

10. Brunner, J. F., Hoyt, S. C., and Wright, M. A. 1982. Codling moth control - a new tool for timing sprays on pests of apples and pears in Washington. Wash. State. Univ. Coop. Ext. Serv. Pullman, Wash. Ext. Bull. 1072:4.

11. Burgess, L. W., Summerell, B. A., Bullock, S., Gott, K. P., and Backhouse, D. 1994. Laboratory Manual for Fusarium Research. Fusarium Research Laboratory, Department of Crop Sciences, University of Sydney, and Royal Botanic Gardens, Sydney, New South Wales.

12. Chittendon, F. H. 1907. The asparagus miner. U.S. Dep. Agric. Bur. Entomol. Bul. No. 66: 10.

13. Cohen, S. I., and Heald, F. D. 1941. A wilt and root rot of asparagus caused by *Fusarium oxysporum* Schlecht. Plant Disease Rep. 25:503-509.

14. Damicone, J. P., and Manning, W. J. 1987. Influence of management practices on severity of stem and crown rot, incidence of asparagus miner, and yield of asparagus grown from transplants. Plant Disease. 71:81-84.

15. Damicone, J. P., Vineis, P. D., and Manning, W. J. 1988. Cross-pathogenicity of *Fusarium moniliforme* isolates from corn and asparagus. Plant Disease. 72:774-777.

16. Damicone, J. P., and Manning, W. J. 1982. Avirulent strains of *Fusarium oxysporum* protect asparagus seedlings from crown rot. Canadian Journal of Plant Pathology. 4:143-146.

17. Davis, D. 1966. Cross-infection in *Fusarium* wilt diseases. Phytopathology. 56:825-828.

18. Davis, D. 1967. Cross-protection in *Fusarium* wilt diseases. Phytopathology. 57:311-314.

19. Drake, C. J., and Harris, H. M. 1932. Asparagus insects in Iowa. Iowa Experimental Station. 12.

20. Eichmann, R. D. 1943. Asparagus miner really not a pest. Journal of Economic Entomology. 36:849-852.

21. Ellison, J. H., and Kinelski, J. J. 1985. 'Jersey Giant,' an all male asparagus hybrid. Hort-Science. 20:1141.

22. Elmer, W. H. 1992. Suppression of *Fusarium* crown and root rot of asparagus with sodium chloride. Phytopathology. 82:97-104.

23. Elmer, W. H., Johnson, D. A., and Mink, G. I. 1996. Epidemiology and management of the diseases causal to asparagus decline. Plant Disease. 80:117-125.

24. Evans, T. A., and Stephens, C. T. 1989. Increased susceptibility to *Fusarium* crown and root rot in virus-infected asparagus. Phytopathology. 79:253-258.

25. Ferro, D. N., and Gilbertson, R. L. 1982. Bionomics and population dynamics of the asparagus miner, *Ophiomyia simplex* (Loew), in western Massachusetts. Environmental Entomology. 11:639-644.

26. Fink, D. E. 1913. The asparagus miner and the twelve-spotted beetle. New York (Cornell) Agricultural Experiment Station Bulletin. 331:410-435.

27. Foster, R. 1999. Midwest Vegetable Production Guide for Commercial Growers. Purdue University Cooperative Extension Service. 139.

28. Gilbertson, R. L., Manning, W. J., and Ferro, D. N. 1981. Relationship of the asparagus miner fly to *Fusarium* stem rot of asparagus and inoculum increase by *Fusarium*. Phytopathology. 71:218-219.

29. Glendenning, R. 1943. Phenology: the most natural of sciences. Canadian Field-Naturalist. 57:75-78.

30. Graham, K. M. 1955. Seedling blight, a fusarial disease of asparagus. Can. J. Bot. 33:374-400.

31. Grogan, R. G., and Kimble, K. A. 1959. The association of *Fusarium* wilt with the asparagus decline and replant problem in California. Phytopathology. 49:122-125.

32. Hartung, A. C., and Stephens, C. T. 1983. Effects of alleopathic substances produced by asparagus on the incidence and severity of asparagus decline due to *Fusarium* crown rot. J. Chem. Ecol. 9:1163-1174.

33. Hartung, A. C., Putnam, A. R. and Stephens, C. T. 1989. Inhibitory activity of asparagus root tissue and extracts on asparagus seedlings. J. Amer. Soc. Hort. Sci. 114:144-148.

34. Hartung, A. C., Stephens, C. T., and Elmer, W. H. 1990. Survey of *Fusarium* populations in Michigan's asparagus fields. Acta Horticulturae. 271:395-401.

35. He, C., Hsiang, T., and Wolyn, D. J. 2001. Activation of defense responses to *Fusarium* infection in *Asparagus densiflorus*. European Journal of Plant Pathology. 107:473-483.

36. Howard, R. J., Garland, J. A., and Seaman, W. L., ed. 1994. Diseases and pests of vegetable crops in Canada. The Canadian Phytopathological Society and the Entomological Society of Canada,

37. Inglis, D. A. 1980. Contamination of asparagus seed by *Fusarium oxysporum* f. sp. *asparagi* and *Fusarium moniliforme*. Plant Disease. 64:74-76.

38. Johnson, D. A., and Lunden, J. D. 1992. Effect of rust on yield of susceptible and resistant asparagus cultivars. Plant Disease. 76:84-86.

39. Johnston, S. A., Springer, J. K., and Lewis, G. D. 1979. *Fusarium moniliforme* as a cause of stem and crown rot of asparagus and its association with asparagus decline. Phytopathology. 69:778-780.

40. Kahn, R. P., Anderson, H. W., Hepler, P. R., and Linn, M. B. 1952. An investigation of asparagus rust in Illinois, its causal agent and its control. Illinois Agric. Exp. Stn.

41. Kleweno, D. D., and Matthews, V. 2002. Michigan Agricultural Statistics 2001-2002. Michigan Agricultural Statistics Service, MDA, USDA.

42. Kleweno, D. D. a. M., V. 2002. Michigan Rotational Survey: Vegetable Inventory 2001-2002. Michigan Agricultural Statistics Service, MDA, USDA.

43. Knaflewski, M., and Sadowski, Cz. 1990. Effect of chemical treatment of seeds on the healthiness of asparagus seeds and crowns. Acta-Horticuture. 271:383-387.

44. Knaflewski, M., and Sadowski, Cz. 1990. Influence of irrigation, fertilization and spacing on the healthiness of asparagus seedlings. Acta Horticulturae. 271:269-271.

45. Lacy, M. L. 1979. Effects of chemicals on stand establishment and yields of asparagus. Plant Disease Reporter. 63:612-616.

46. Lacy, M. L. 1982. Purple spot: a new disease of young asparagus spears caused by *Stemphylium vesicarium*. Plant Disease. 66:1198-1200.

47. Lampert, E. P., Cress, D. C., and Haynes, D. L. 1984. Temporal and spatial changes in abundance of the asparagus miner, *Ophiomyia simplex* (Loew) (Diptera: Agromyzidae), in Michigan. Environmental Entomology. 13:733-736.

48. Manning, W. J., Damicone, J. P., and Gilbertson, R. L. 1985. Asparagus root and crown rot: sources of inoculum for *Fusarium oxysporum* and *Fusarium moniliforme*. 6th International Aparagus Symposium. University of Guelph, Ontario, Canada.

49. Manning, W. J., and Vardaro, P. M. 1977. Soil fumigation and preplant fungicide crown soaks: effects on plant growth and *Fusarium* incidence in newly planted asparagus. Plant Disease Reporter. 61:355-357.

50. Meyer, M. P., Hausbeck, M. K., and Podolsky, R. 2000. Optimal fungicide management of purple spot of asparagus and impact on yield. Plant Disease. 84:525-530.

51. Nelson, P. E., Toussoun, T. A., and Cook, R. J., ed. 1981. Fusarium: Diseases, Biology, and Taxonomy. The Pennsylvania State University Press, University Park and London.

52. Nelson, P. E., Toussoun, T. A., and Marasas, W. F. O. 1983. Fusarium Species: An Illustrated Manual for Identification. The Pennsylvania State University Press,

53. Putnam, A. R., and Lacy, M. L. 1977. Asparagus management with no-tillage. MI State Univ. Agric. Exp. Stn.

54. Reid, T. C., Hausbeck, M. K., and Kizilkaya, K. 2001. Effects of sodium chloride on commercial asparagus and of alternative forms of chloride salt on Fusarium crown and root rot. Plant Disease. 85:1271-1275.

55. Reid, T. C., Hausbeck, M. K., and Kizilkaya, K. 2002. Use of fungicides and biological controls in the suppression of Fusarium crown and root rot of asparagus under greenhouse and growth chamber conditions. Plant Disease. 86:493-498.

56. Schofield, M. 1946. Asparagus, past and present. Food Manufacture. 21:443-445.

57. Shelton, D. R., and Lacy, M. L. 1980. Effect of harvest duration and yield depletion of storage carbohydrate in asparagus roots. J. Am. Soc. Hortic. Sci. 105:332-335.

58. Stephens, C. T., and Elmer, W. H. 1988. An in vitro assay to evaluate sources of resistance in *Asparagus* spp. to *Fusarium* crown and root rot. Plant Disease. 72:334-337.

59. Stephens, C. T., De Vries, R. M. and Sink, K. C. 1989. Evaluation of *Asparagus* species for resistance to *Fusarium oxysporum* f. sp. *asparagi* and *F. moniliforme*. HortScience. 24:365-368.

60. Taylor, R. G., and Harcourt, D. G. 1978. Effects of temperature on developmental rate of the immature stages of *Crioceris asparagi* (Coleoptera: Chrysomelidae). Can. Ent. 110:57-62.

61. Tu, C. C., Cheng, Y. H. and Cheng, A. S. 1990. Recent advance in biological control of *Fusarium* wilt of asparagus in Taiwan. Acta Horticulturae. 271:353-362.

62. Yang, H. 1982. Autotoxicity of *Asparagus officinalis*. Am. Soc. Hortic. Sci. 107:860-862.

63. Zandstra, B. H., Kelly, J. F., Hausbeck, M., Grafius, E. J. and Price, H. C. 1992. Commercial Vegetable Recommendations: Asparagus. Michigan State University.

CHARACTERIZATION OF *OPHIOMYIA SIMPLEX* ACTIVITY INDICATED BY SEASONAL ADULT POPULATIONS, MINING DAMAGE, AND OVERWINTERING PUPAE IN COMMERCIAL ASPARAGUS FIELDS AND ITS ASSOCIATION WITH FUSARIUM CROWN AND ROOT ROT

ABSTRACT

Fusarium crown and root rot, (*Fusarium oxysporum* f. sp. *asparagi*, *F. proliferatum*) has been implicated in the decline problems in production areas of asparagus. Pathogenic strains of both *Fusarium* spp. have been associated with *Ophiomyia simplex* (asparagus miner). Commercial fields were monitored in 2001 and 2002 for miner activity via weekly trapping for adults, monitoring of above ground stem damage, and end of season puparia counts. Puparia and mined tissue were plated to detect the presence of *Fusarium* spp. A bivoltine trend was seen across different-aged fields with the highest numbers of adult flies trapped in early to mid-August. Mining damage was greatest in the 1 year old fields early in the season and *Fusarium* was seen sporulating on up to 30% of the mined stems in those fields. There was no significant difference among the fields as to the number of puparia per stem (3-4). However, most of the pupae emerged during the season in the 1 year old fields, while in older fields, which went into fern later in the season due to harvesting, more pupae were intact for overwintering. Pupae from above ground mines had 15% *F. proliferatum* and 3% *F. oxysporum*, while pupae from below ground mines had 11% and 17% respectively. Stem tissue from above ground mines had 44% *F. proliferatum* and 4% *F. oxysporum*. It is not known how significant sporulation of *Fusarium* on above ground mines is to the overall spread of pathogen inoculum, but it appears that young fields are more vulnerable to mining damage and prolonged exposure to infection by *Fusarium*.

INTRODUCTION

Michigan produced approximately 290,000 cwt of asparagus at a value of $12.5 million in 2001 (21). In terms of production acreage, asparagus is the fourth most important vegetable crop grown in Michigan behind potatoes, cucumbers and snap beans, making Michigan third in asparagus production in the United States (21). Since it was first described in 1908, Fusarium crown and root rot has been implicated in decline and replant problems in production areas of asparagus throughout the United States (5, 17, 18, 20). This disease consists of a complex of *Fusarium* species, which in Michigan includes *Fusarium oxysporum* Schl.:Fr. f. sp. *asparagi* S.I. Cohen & Heald and *F. proliferatum* (T. Matsushima) Nirenberg (teleomorph *Gibberella fujikuroi* (Sawada) Ito G). Both species have been isolated from asparagus seeds (16, 19), from 1 year-old plants with asymptomatic crowns as well as from flowers and berries (23).

Over the past few years, concern about extensive mining damage caused by *Ophiomyia simplex* L. in newly established commercial asparagus fields in Michigan has been growing, where problems with Fusarium have also been noted (M. K. Hausbeck, personal communication). *Ophiomyia simplex* (asparagus miner) is among the insects commonly found throughout the commercial asparagus growing regions of the United States (2, 4, 9, 13). During the fern stage, adult asparagus miners oviposite eggs near the soil line on asparagus stems, from which larvae hatch, mine and pupate under the epidermis. Larvae are small (approx. 5 mm) and mining is confined to the parenchymous tissues of the cortex between the pericycle and the epidermis, leaving vascular tissue within the pericycle unaffected. Damage by asparagus miner has been considered alternately significant (2, 4, 5, 13) and insignificant (9). However, it is currently thought

that feeding by the asparagus miner larvae, resulting in extensive stem mining damage, can lead to increased stem rot by Fusarium (7, 14).

Our primary objective was to determine whether *Fusarium* spp. are associated with the asparagus miner among commercial asparagus fields in Michigan and to observe the relationship between the biology of the miner and asparagus stand maturity. Correlating air and soil temperature with asparagus miner populations was also of interest.

MATERIALS AND METHODS

Monitoring for adult asparagus miners. Commercial asparagus fields (3 in 2001; 10 in 2002) in four Michigan counties, along with a single research field in Oceana County (see Table 1), were monitored for adult *O. simplex* populations in 2001 and 2002. Ferro and Suchak found that 30cm wooden stakes painted with yellow paint and tanglefoot were effective for trapping *O. simplex* (11). Twenty years after that study, commercially available yellow sticky insect traps are regularly used for scouting and trapping for a variety of insects in greenhouse and field applications. In keeping with our goal that the methods used in this research could be practically applied by growers in the future, we used commercially available Yellow Stiky Strips™ (3 by 5 inch) insect traps (Olson Products, P.O. Box 1043, Medina, Ohio 44258) instead of the stake traps.

Early in this study (2001), we noticed that as soon as the asparagus fern reached its maximum height (up to 2m), the number of flies caught in ground level traps dropped dramatically, yet the flies were still seen active in the fern. This prompted us to add

Table 1. Locations and descriptions of asparagus fields observed in 2001 and 2002.

Sites monitored	Location (County)	Year(s) observed[a]	Field history[b]	Cultivar[c]	Age of plot (years)	Plot size (acres)[d]
CASS	Cass	2001-02	?	'Jersey Giant'	5	15
KOK1	Oceana	2002	?	'Jersey Knight' and 'Jersey Gem'	1	20
KOK2	Oceana	2002	?	'Jersey Giant'	5	40
OOM2	Oceana	2001-02	virgin	'Jersey Giant'	4	40
RKO1[e]	Oceana	2001-02	replant	'Jersey Supreme'	1	30
RKO3	Oceana	2001-02	?	'Franklim'	13	30
SEL1	Oceana	2002	virgin	'Jersey Giant'	1	40
SEL2	Oceana	2002	virgin	'Jersey Giant'	4	40
SEL3	Oceana	2002	virgin	'KB Viking'	12	40
SHA3	Oceana	2002	?	'Syn456'	14	10
VANB[f]	VanBuren	2002	?	'Jersey Giant'	4	40

[a] With RKO1 as the only exception (mining damage was not monitored in 2001), all the Oceana county sites were monitored for both *O. simplex* adult populations and above ground mining damage in the years indicated. Only *O. simplex* populations were monitored in CASS and VANB.

[b] "Replant" refers to a field previously planted to asparagus, "virgin" refers to a field never before planted to asparagus.

[c] The cultivar listed is the main cultivar planted in the area where traps were placed.

[d] This refers to the acres of asparagus that surrounded the observational area that were usually of varying ages and cultivars.

[e] This was the single research plot used in the study that was surrounded by commercial fields on three sides within a 30 acre area.

[f] This field was irrigated overhead throughout the season, an unusual practice in Michigan.

canopy height traps to try to document the activity of *O. simplex* after the asparagus was in fern. Traps held by wire loop holders were either duct-taped to 30cm wooden stakes (for ground level traps in 2001), inserted directly into the ground (for ground level traps in 2002) or inserted into the top of 19 mm galvanized rigid steel conduit at a finished height of 1.5 m within the canopy (in both 2001 and 2002).

In 2001, a single trap was placed at the edge of each of the three commercial fields while asparagus was harvested to track when *O. simplex* adults first emerged beginning in late April. At the same time, traps were set out within the single research plot (RKO1) that was not harvested. Once harvest was complete and each commercial field went to fern, traps were set out within the fields and changed every 7-10 days between 24 May until 4 October 2001. Ground level traps in RKO1 and CASS were placed 10m apart, three per row, with rows 10m apart, for a total of 9 ground traps. Additionally, CASS had 9 canopy height traps paired with the ground level traps. RKO3 and OOM2 were originally part of a project described in Appendix A in which pairs of traps (one each of ground level and canopy height) were placed in the center of fifteen $225m^2$ blocks separated by 2.25m buffers. The five untreated blocks in 2001 have been used to draw comparisons with the 2002 season.

In 2002, 9 ground level traps were placed 10 m apart within 3 different rows for a total of 9 traps per field. Traps were in place prior to and during harvest. Four canopy height traps were added as soon as each field went to fern and placed in different rows within the $36m^2$ area of the ground traps. No canopy height traps were used in RKO1 because of poor stand vigor (average height of fern was less than a meter high). Traps were collected every 7-10 days beginning 30 April until the beginning of October 2002.

Weather data collection. Specware™ leaf wetness and air temperature sensors (Spectrum Technologies, Inc.) were placed at the edge of asparagus production fields being monitored for *O. simplex* populations, beginning in early April and extending through the season. In 2001, two sensors were placed in Oceana county, and one in Cass county. In 2002, sensors were placed in five locations in Oceana County and one location in southwest Michigan. Temperature data were downloaded using a laptop computer every one to two weeks throughout the season using Specware 5 software (Spectrum Technologies, Inc.). Air and soil temperature data recorded by Michigan Agricultural Weather Network (MAWN) were also used. Data from the sensors were transferred into Microsoft Excel to make simple degree-day calculations (base 50F) starting 1 January in 2001 and 2002. The following equation was used to calculate simple degree-days, the results of which were added together to accumulate degree-days over the field season:

$$DD50 = (dailyMAX + dailyMIN)/2 - 50$$

Accumulated growing degrees-days from MAWN were calculated directly by the website using the numerical integration method that uses hourly minimum and maximum temperature in its calculations.

Monitoring for mining incidence and severity. Except for RKO1 in 2001, all of the fields in Oceana County were also monitored for progressive above ground mining damage. As asparagus went to fern in each field, stems (125 in 2001; 60 in 2002) within the trapping areas were marked with string tags at intervals of approximately 30 cm. Marked stems were examined every 7-10 days for mining incidence and severity. Severity was determined by noting what proportion of the stem within 5 cm of the soil

line was girdled by mining. Additionally, the height of the tallest mine was measured and an estimate made as to the number of mines per stem. At the end of the season, all of the marked stems were collected and brought back to the lab for examination. Puparia were extracted and collected from the mined stems, circumference girdled (%) and height of the tallest mine measured. The number of mines per stem was inferred from the number of pupae collected from each stem. In 2002, the collected pupae were crushed to determine whether adults had emerged or whether they remained intact for overwintering.

***Fusarium* isolations from puparia and stem tissue.** A total of 414 puparia, collected from 375 mined stems in fields examined in 2001 (half were from OOM2 and half were from RKO3) and from 60 stems collected in 2002 (from KOK1), were surface sterilized using 10% bleach for 5 minutes and rinsed in sterile distilled water before being plated on water agar or carnation leaf agar. One third of the pupae were taken from mines above ground and treated as a separate group in 2001. Stem tissue from 55 aboveground mines with intact epidermis was surface sterilized with 10% bleach, excised and plated on water agar. After 7 to 10 days, plates were examined for the presence and subsequent identification of *Fusarium*.

Pathogenicity tests. Asparagus seed of cultivar 'Mary Washington' were surface sterilized in a mixture of 5g of benomyl and 100ml of acetone by spinning on a magnetic stir plate for 24 hrs according to the methods described by Damicone et al. (6). The seeds were then drained and rinsed three times with sterile distilled water after which the seeds were placed on the magnetic stir plate for another hour in a 10% chlorine bleach solution. The seeds were rinsed again with sterile distilled water, allowed to dry in a laminar flow

hood on sterile paper towel, then placed on water agar plates and kept in the dark until germination.

After germination, uniformly sprouted seeds were placed in sterile test tubes containing Hoagland's Solution amended with water agar (15g/L) and allowed to grow into seedlings for two weeks. Mycelial plugs (5mm) of a representative number (10%) of the *Fusarium* isolates gleaned from puparia and asparagus stem tissue in 2001 and 2002, were placed at the base of the two-week-old seedlings and allowed to grow for 28 days. Pathogenicity was determined by assessing disease severity based on the percentage of the root system that exhibited lesions or had collapsed, and dead plants were considered to be 100% infected (25). Each isolate was tested twice using three reps each time, and then pathogenicity was averaged over the two tests.

RESULTS

Monitoring *O. simplex* adult populations. In both 2001 and 2002, *O. simplex* adults were initially trapped approximately 4 to 5 weeks after the first asparagus began to emerge, (Figures 4-9). Comparisons between years or locations regarding accumulated degree days (base 50; numerical integration) and initial sightings of *O. simplex* did not reveal a distinct pattern (Figures 4-9). We found that while the ground level traps caught few flies after asparagus was in fern (Figure 16), the canopy height traps enabled us to see a major increase in fly activity in August in most of the fields (Figures 1, 2 and 3). Two distinct population peaks or generations of *O. simplex* were observed in both 2001 and 2002 (Figure 1). These peaks generally occurred from early June to early July and then again from late July to late August (Figure 1). In 2001, populations of adults were

higher in Oceana compared with a single field (CASS) in Cass County (Figure 2), though in one week 171 flies were observed on one trap placed near a volunteer fern in CASS while the adjacent field was being harvested. With the addition of a second field (VANB) in 2002, the average population of the two fields in southwest Michigan was comparable to numbers in fields of similar age in Oceana County (Figure 3). Although the number of *O. simplex* adults trapped in Oceana County in 2002 appeared to be highly variable between fields, the differences were not significant between fields ($p = 0.6147$, using AUDPC analyzed with a mixed model analysis of variance using Proc Mixed of SAS).

Mining incidence and severity. In 2001, the incidence of asparagus stems with mining above ground was greater earlier in the season in the 3-year-old field (OOM2) than in the 12-year-old field (RKO3) (Figure 10). However, by the end of the season both fields had more than 90% of the observed stems exhibiting mining (Figure 10). The severity of mining damage observed above ground remained greater in the 3-year-old field (OOM2) throughout the season with over 80% of the stem circumference girdled compared with 30% in the 12-year-old field (RKO3) (Figure 10).

Through August of 2002, a similar trend was seen between the younger fields and the older fields with mining incidence and severity greater in the 1-year-old fields than in the older fields (4-5 and >10 year-old) (Figures 11). In September, the percentage of stems with mining increased in fields of all ages (Figure 11). However, the biggest increase in mining incidence (>30%) was observed in the older fields (Figure 11). A similar trend in mining severity was also observed (Figure 11).

Fusarium was observed sporulating out of the mined areas of the stems under observation at least once in each field during 2002 (Figure 12) (Table 2). In KOK1, where above ground mining occurred earliest (Figures 13 and 14), sporulation was observed every week except the first week in which observations were made (Table 2).

Puparia location and condition. Although the total number of puparia collected from stems in 2002 was not significantly different among the fields (Table 3), there were significantly more intact versus non-intact (emerged) puparia in the 1-year-old fields compared to the older fields combined (Figure 15) ($t_{1611} = 6.09$, $p < 0.0001$, using contrasts that looked at the difference in the number of intact and non-intact puparia in the youngest fields compared with the average of the two older fields). In the 1-year-old fields, more pupae had emerged during the 2002 season than would have over-wintered when compared to the older fields (Figure 15).

Isolations of *Fusarium* spp. from puparia and stem tissue. *Fusarium proliferatum* was isolated from 15% of the pupae collected from above ground mines, and from 11% of the pupae from below ground (Table 4). In addition, *F. proliferatum* was isolated from 44% of the above ground mined stem tissue (Table 4). *Fusarium oxysporum* was isolated from 3% of the pupae collected from above ground mines, and from 17% of the pupae from below ground (Table 4). Four percent of the above ground mined stem tissue harbored *F. oxysporum* (Table 4). Other *Fusarium* spp. were also infrequently isolated from pupae and stems (Table 4). Seventy-five percent of isolates tested (both *F. oxysporum* and *F. proliferatum*) were determined to be pathogenic.

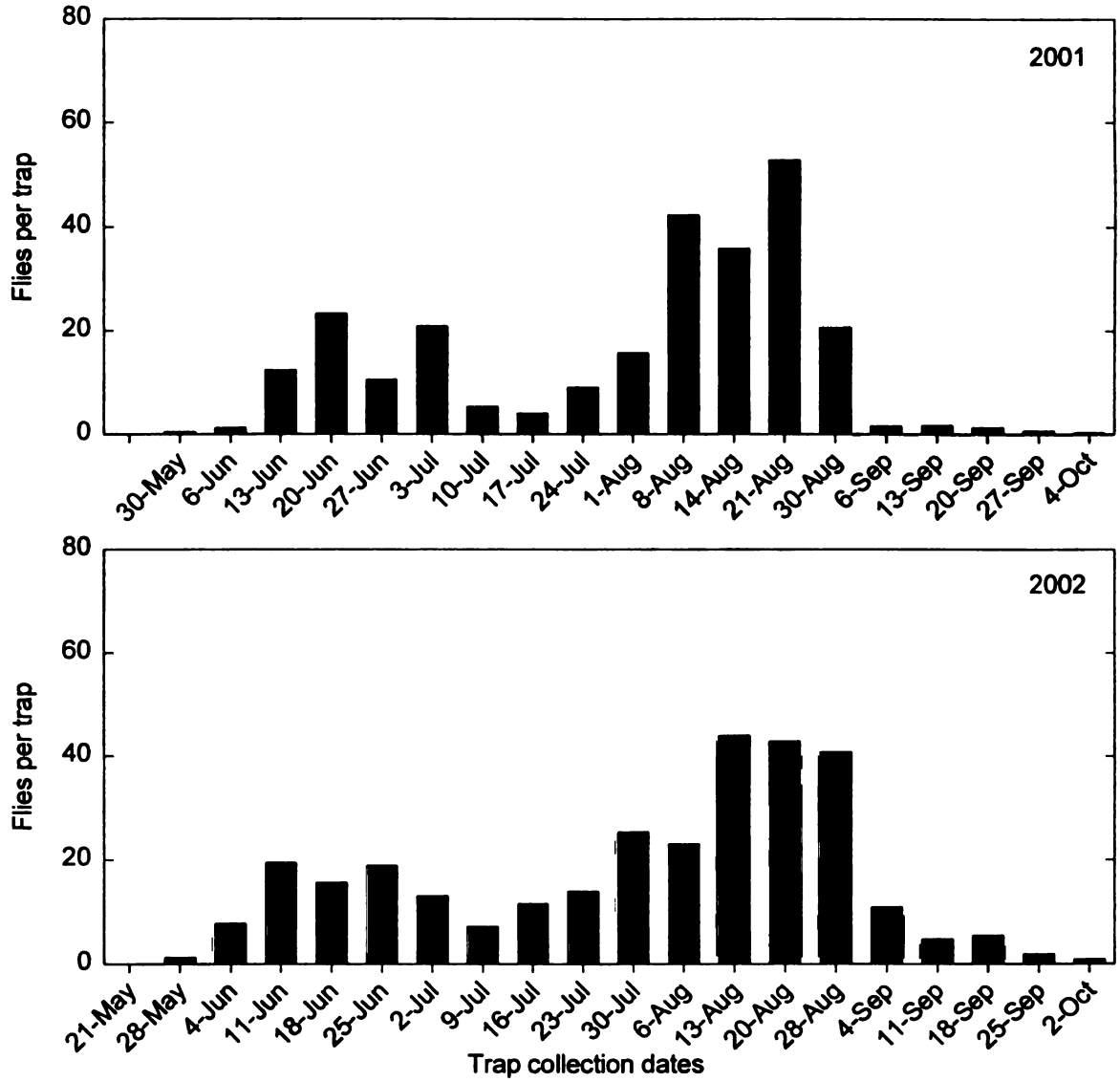


Figure 1. Average number of *O. simplex* adults trapped in Oceana County, Michigan in 2001 and 2002.

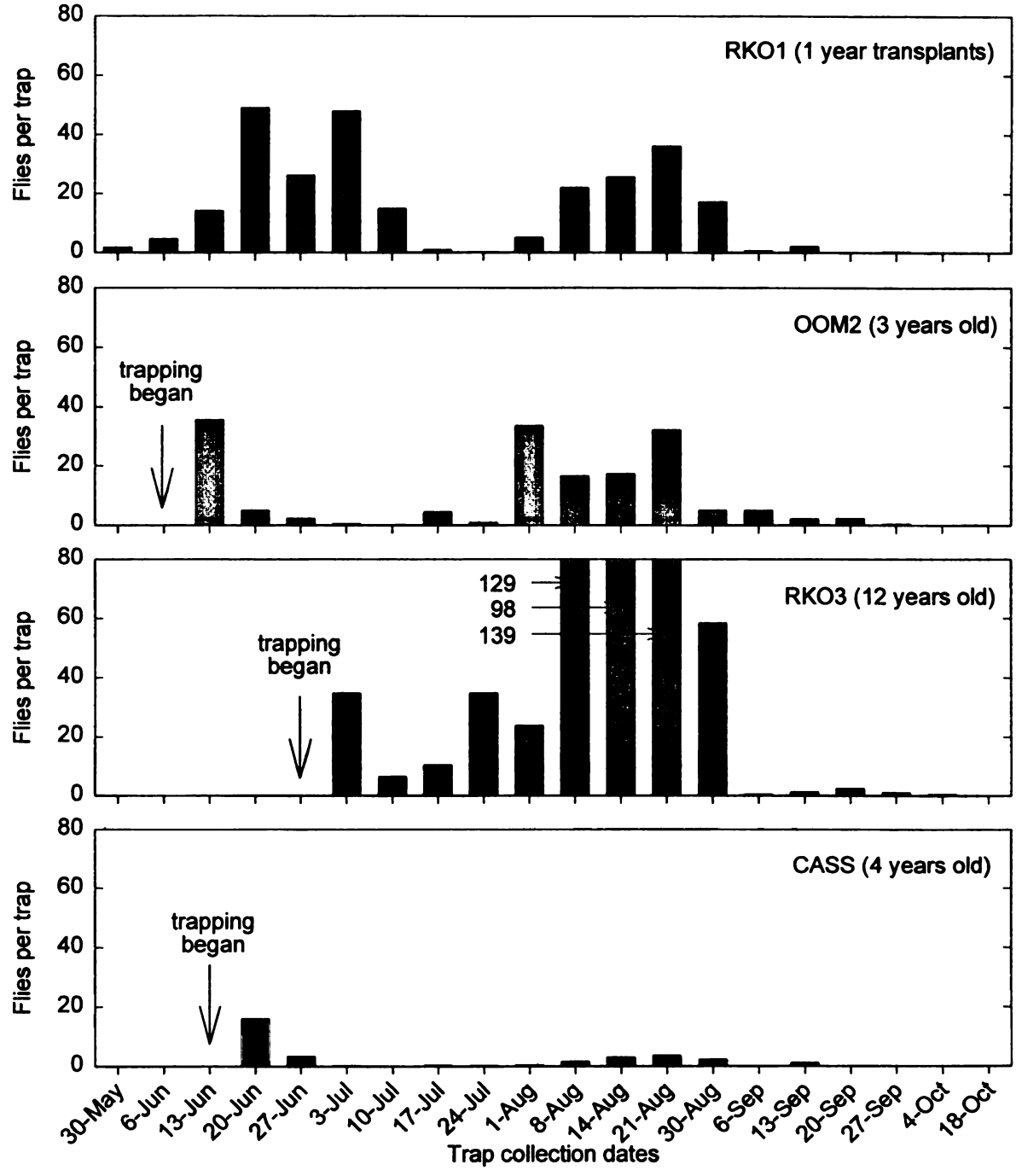


Figure 2. *Ophiomyia simplex* adults trapped in 2001 in fields located in Oceana (RKO1, OOM2, and RKO3) and Cass (CASS) Counties in Michigan.

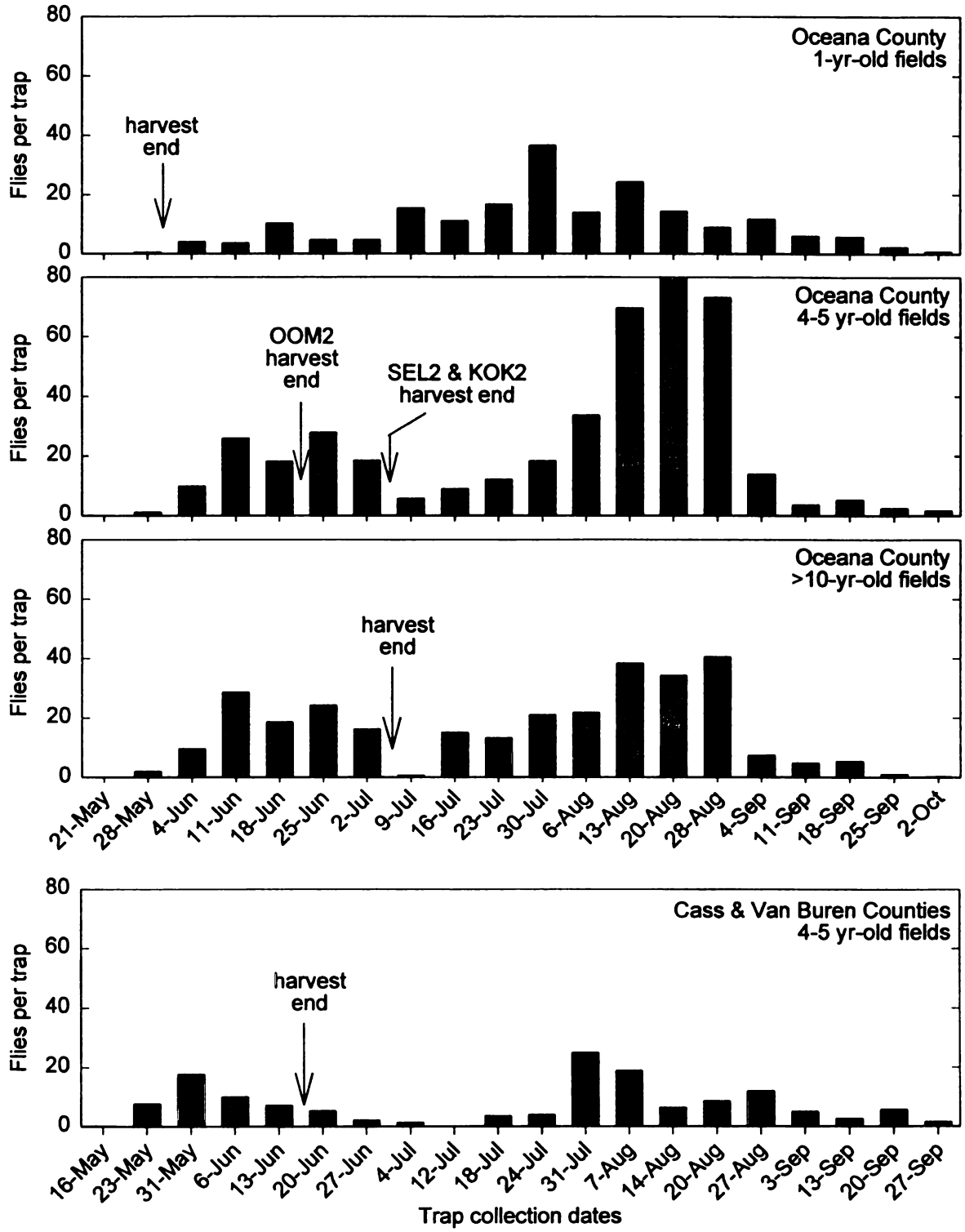


Figure 3. Average number of *O. simplex* adults trapped in Michigan fields divided by age and location in 2002. Each of the top three graphs represents the average of three fields in Oceana or Mason Counties, while the bottom graph represents the average of two fields in Cass and Van Buren Counties

Figure 4. Accumulated degree-days (base 50; numerical integration) compared with *O. simplex* adults trapped (bars) and mining incidence (line and scatter) in fields in Oceana County, Michigan in 2001.

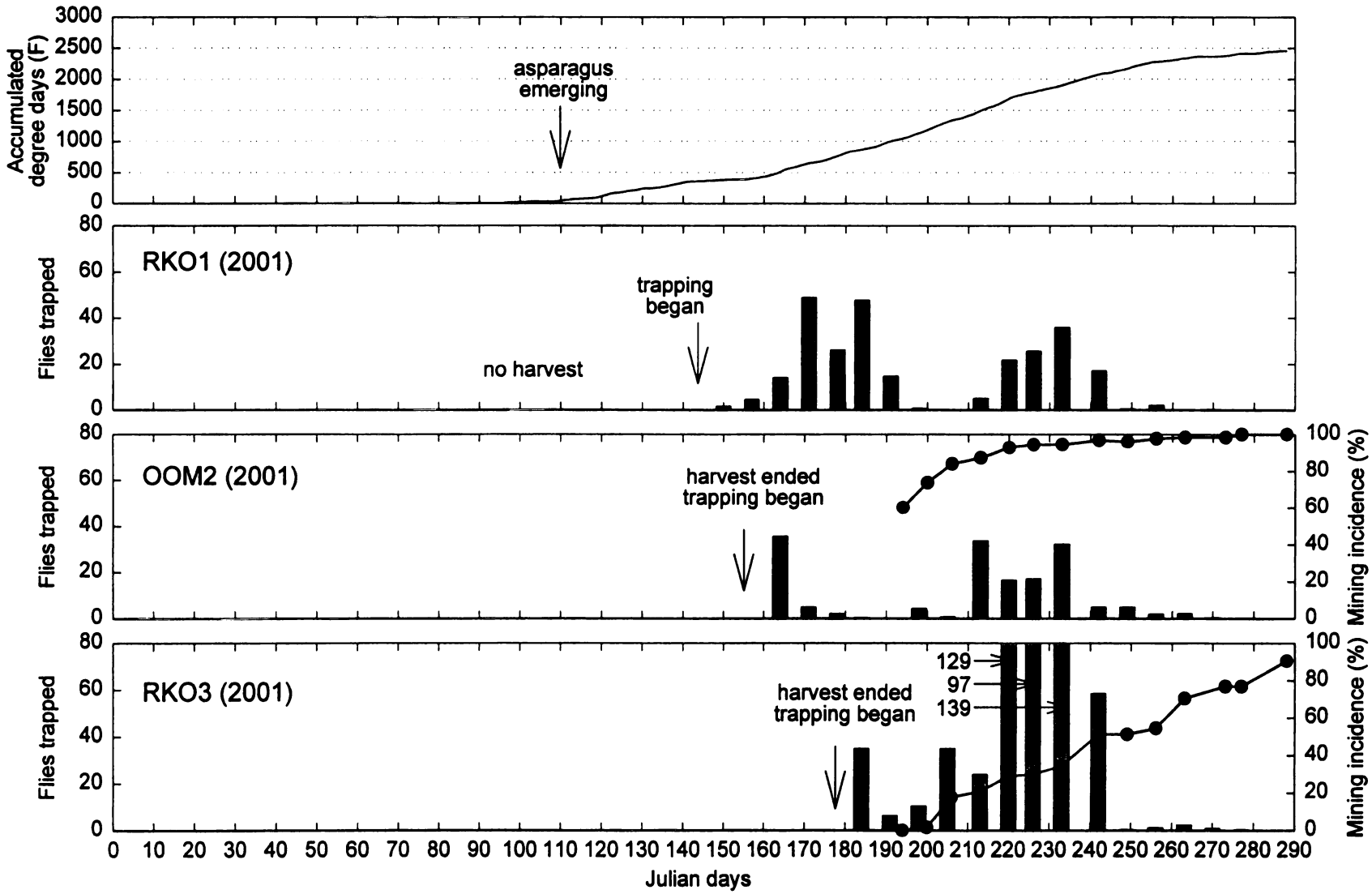

Accumulated degree days (F)
3000
2500
2000
1500
1000
500
0
asparagus emerging
Flies trapped
80
60
40
20
0
RKO1 (2001)
trapping began
no harvest
OOM2 (2001)
harvest ended trapping began
Mining incidence (%)
100
80
60
40
20
0
RKO3 (2001)
harvest ended trapping began
129
97
139
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Julian days

Figure 5. Accumulated degree-days (base 50; numerical integration) compared with *O. simplex* adults trapped (bars) in a field in Cass County, Michigan in 2001.

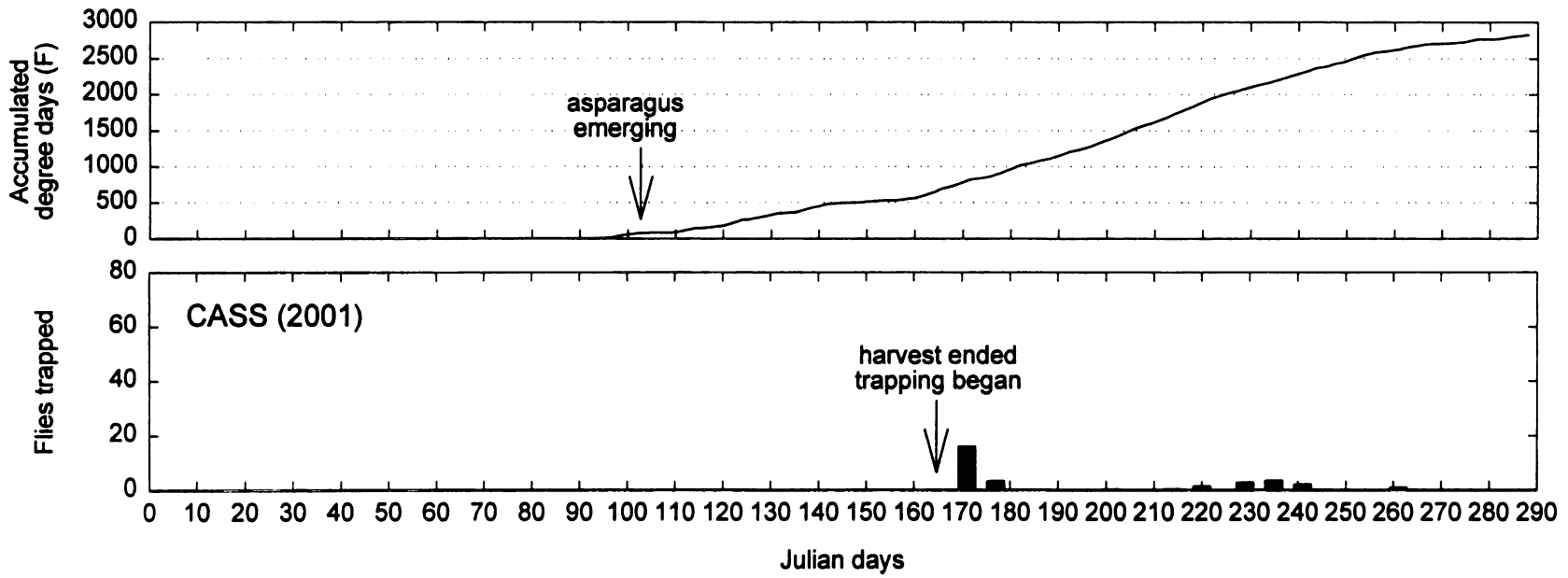

Accumulated degree days (F)
3000
2500
2000
1500
1000
500
0
asparagus emerging
Flies trapped
80
60
40
20
0
CASS (2001)
harvest ended trapping began
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Julian days

Figure 6. Accumulated degree-days (base 50; numerical integration) compared with *O. simplex* adults trapped (bars) and mining incidence (line and scatter) in 1-year-old fields in Oceana County, Michigan in 2002.

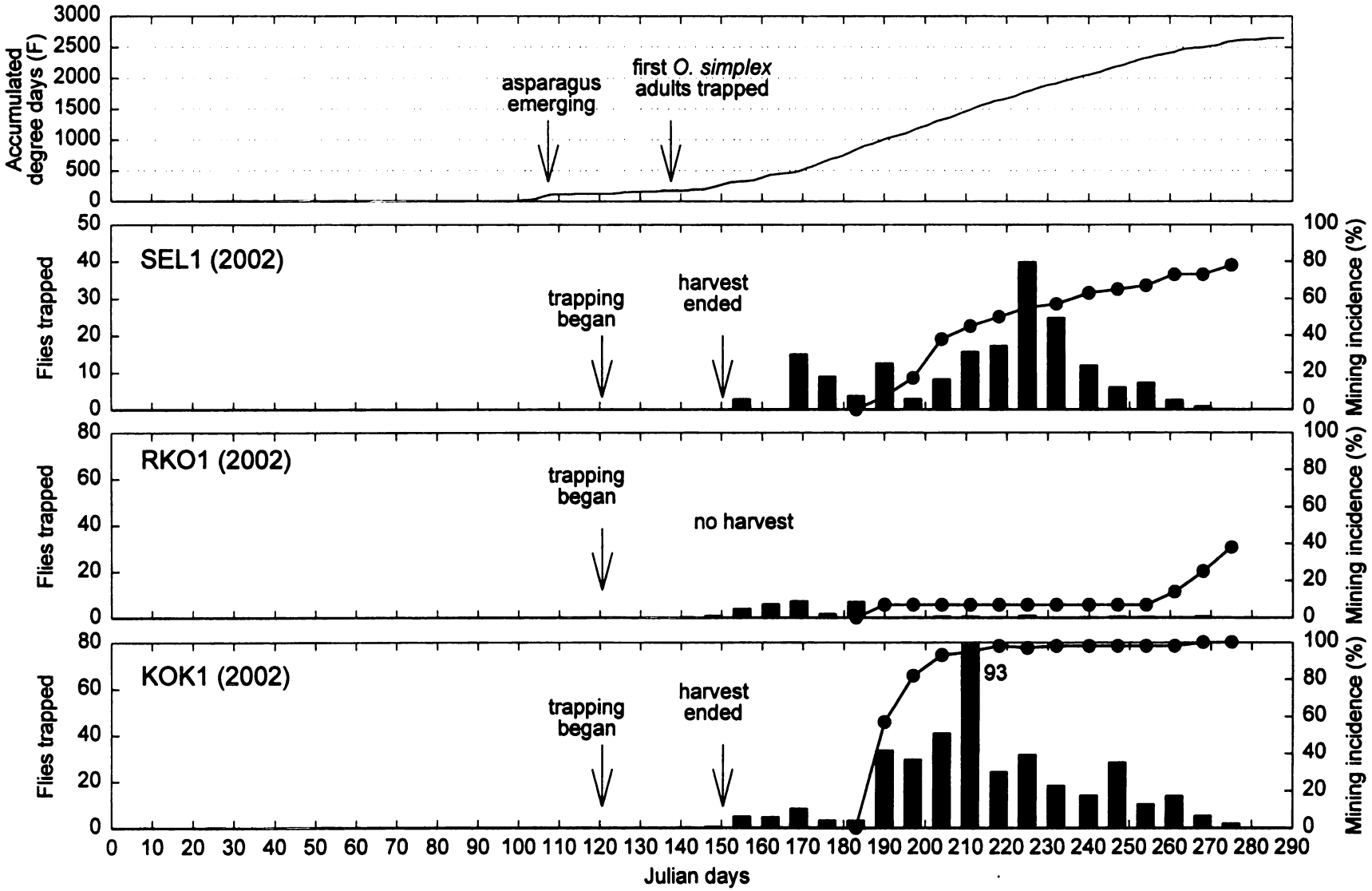

Accumulated degree days (F)
3000
2500
2000
1500
1000
500
0
asparagus emerging
first O. simplex adults trapped
SEL1 (2002)
trapping began
harvest ended
Flies trapped
Mining incidence (%)
RKO1 (2002)
trapping began
no harvest
KOK1 (2002)
trapping began
harvest ended
93
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Julian days

Figure 7. Accumulated degree-days (base 50; numerical integration) compared with *O. simplex* adults trapped (bars) and mining incidence (line and scatter) in 4 to 5-year-old fields in Oceana County, Michigan in 2002.

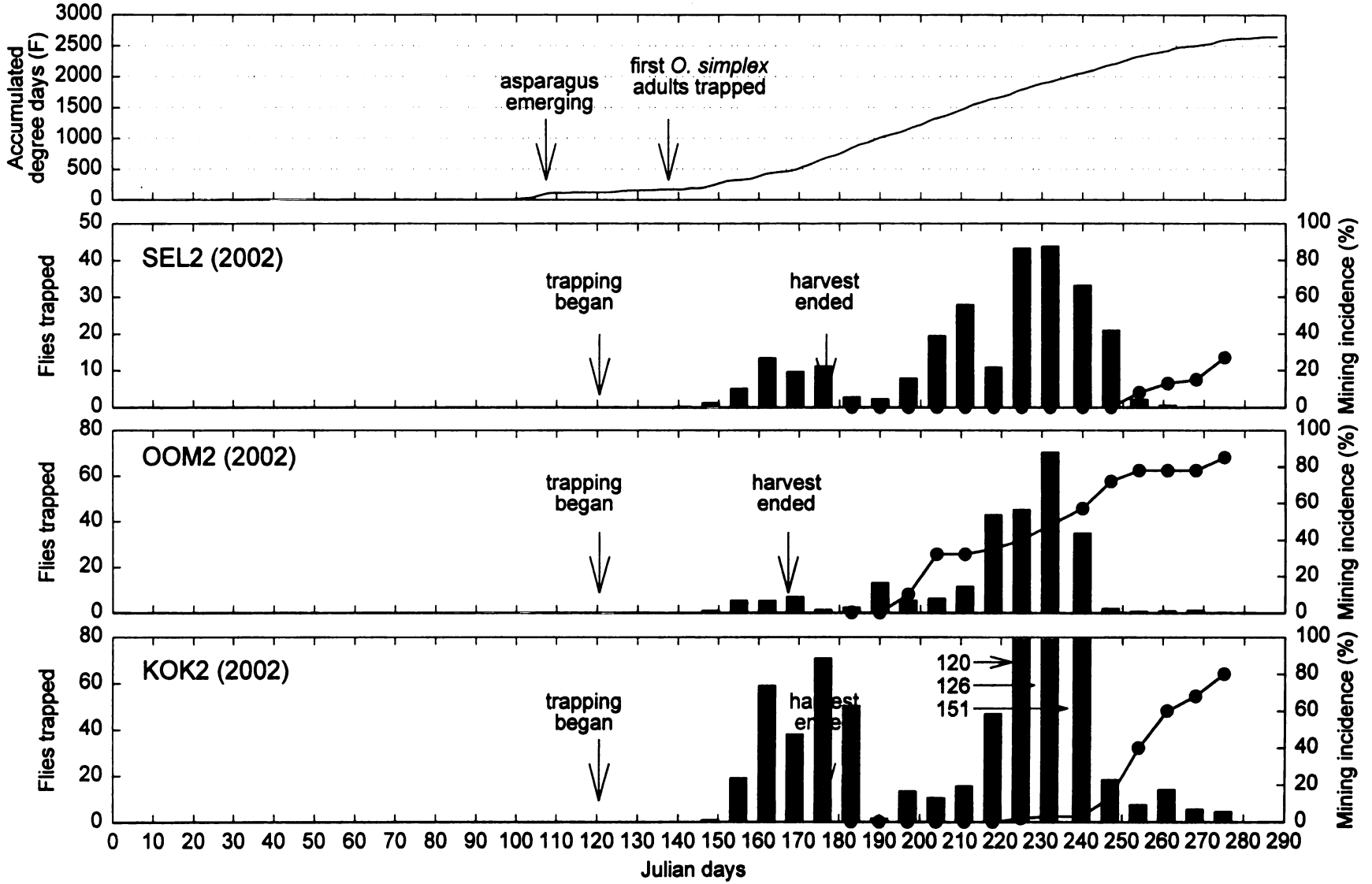

Accumulated degree days (F)
asparagus emerging
first O. simplex adults trapped
SEL2 (2002)
OOM2 (2002)
KOK2 (2002)
trapping began
harvest ended
Flies trapped
Mining incidence (%)
120
126
151
Julian days

Figure 8. Accumulated degree-days (base 50; numerical integration) compared with *O. simplex* adults trapped (bars) and mining incidence (line and scatter) in >10-year-old fields in Oceana County, Michigan in 2002.

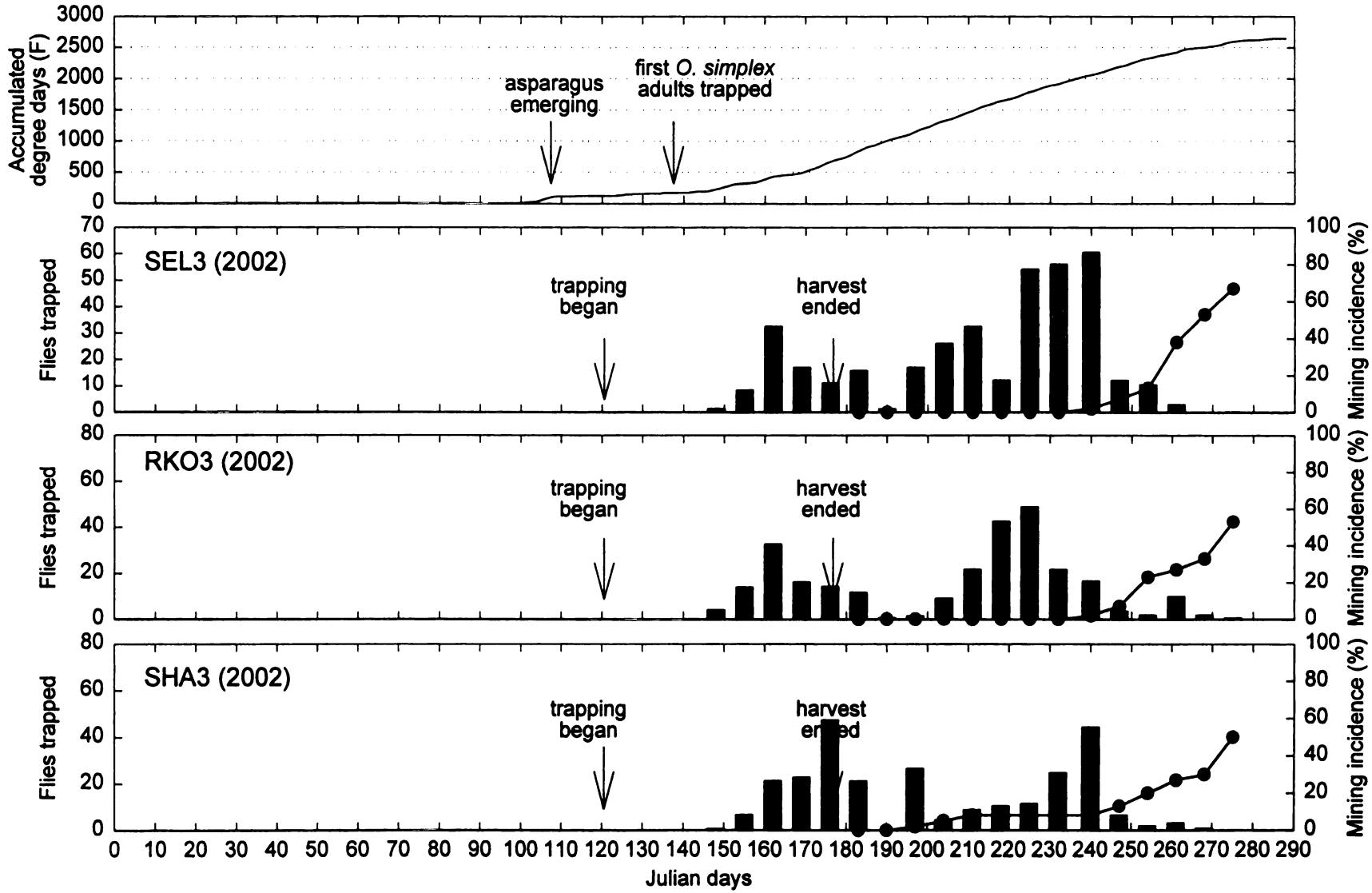
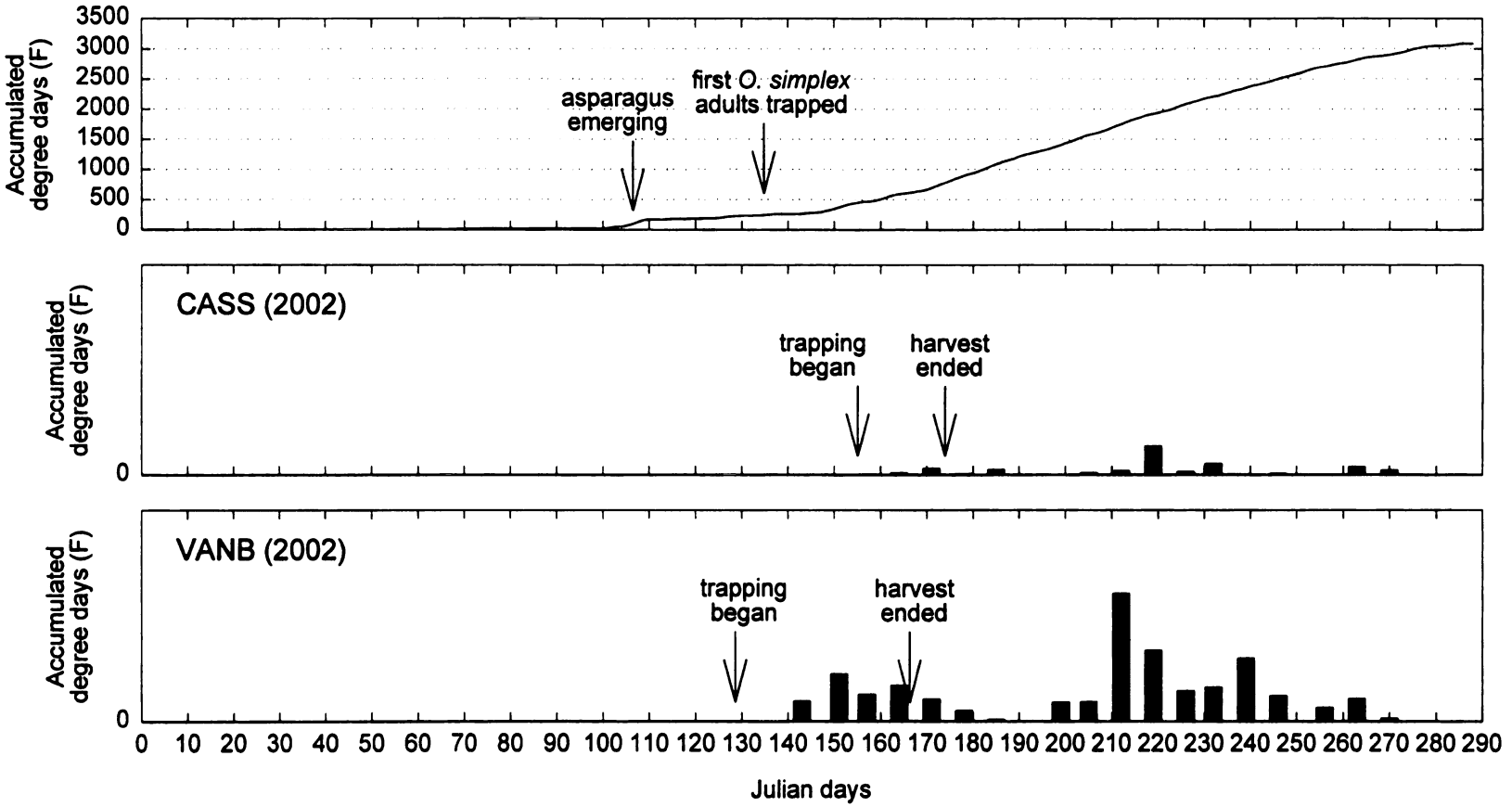

Accumulated degree days (F)
asparagus emerging
first O. simplex adults trapped
SEL3 (2002)
RKO3 (2002)
SHA3 (2002)
trapping began
harvest ended
Flies trapped
Mining incidence (%)
Julian days

Figure 9. Accumulated degree-days (base 50; numerical integration) compared with *O. simplex* adults trapped (bars) in two fields in Cass and Van Buren Counties in Michigan in 2002.


Accumulated degree days (F)
3500
3000
2500
2000
1500
1000
500
0
asparagus emerging
first O. simplex adults trapped
CASS (2002)
trapping began
harvest ended
VANB (2002)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Julian days

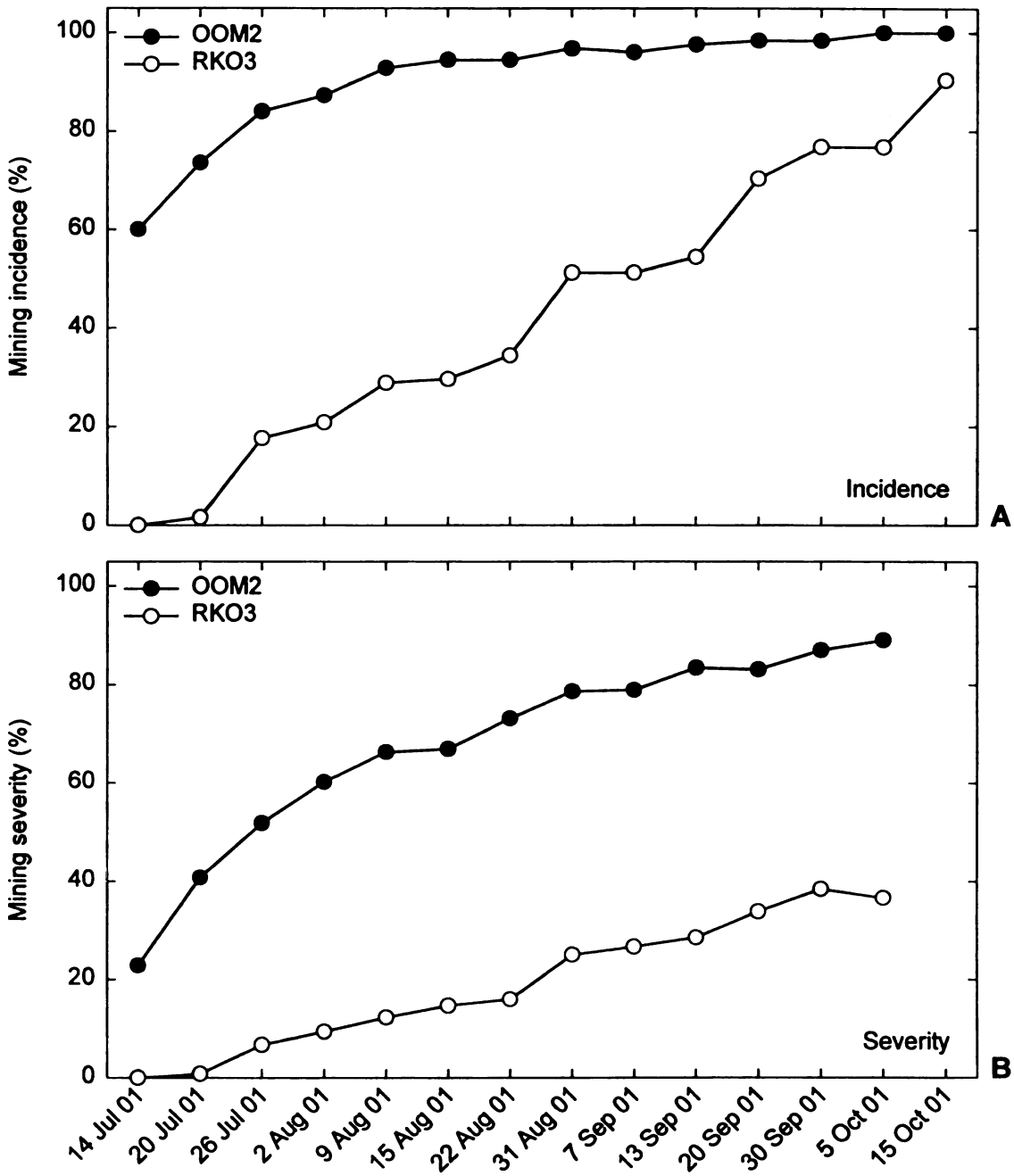


Figure 10. Percent of asparagus stems (n = 125 per field) that were mined above ground (A) and mining severity represented by the percent of stems girdled within 5cm of the soil line due to mining damage (B) in Oceana County, Michigan during 2001. OOM2 was a 3-year-old field and RKO3 was a 12-year-old field.

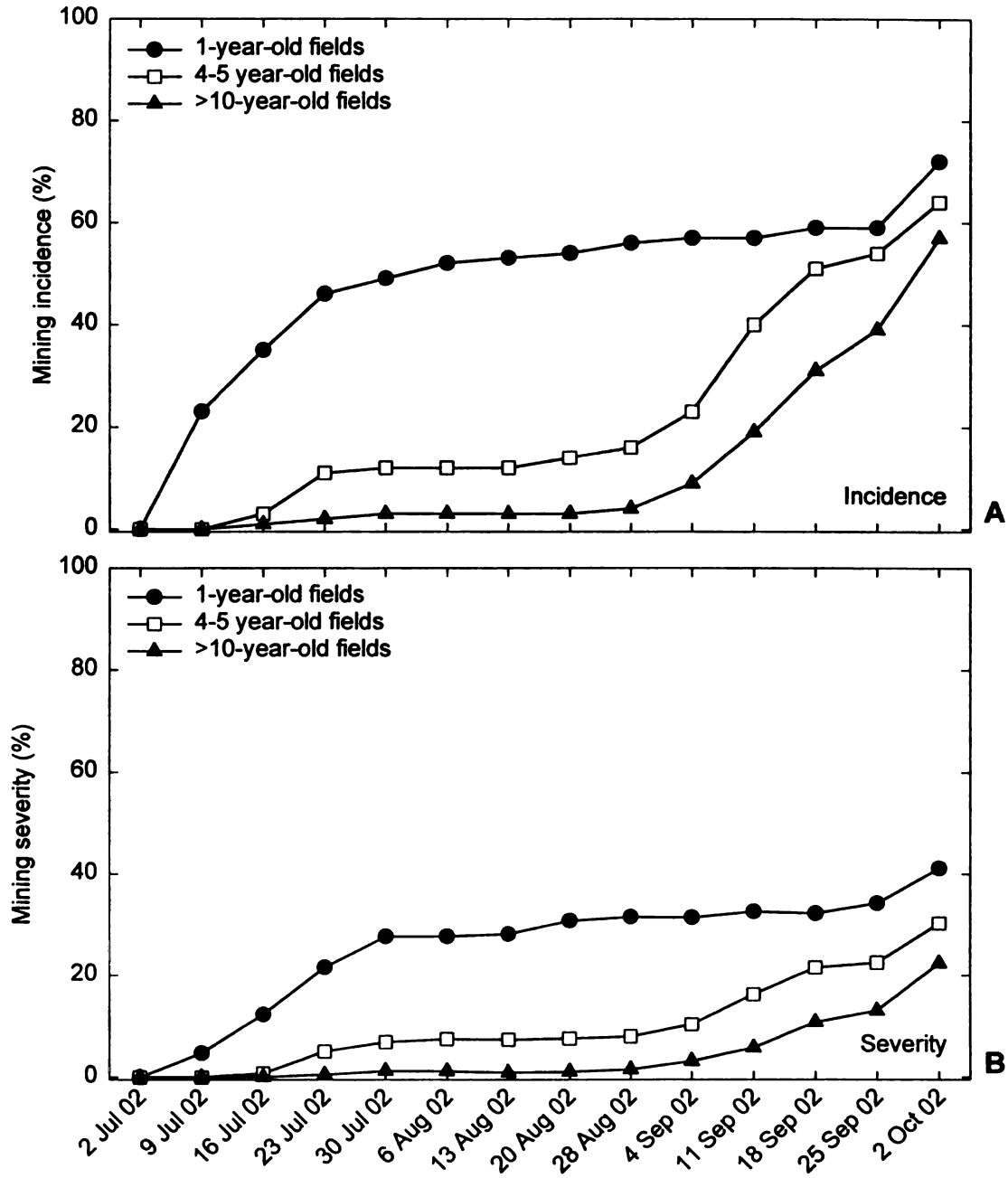


Figure 11. Percent of asparagus stems (n = 60 per field) that were mined above ground (A) and mining severity represented by the percent of stems girdled within 5cm of the soil line due to mining damage (B) in Oceana County, Michigan during 2002. Numbers represent the average of three fields that were monitored in each of the following categories; 1-year-old fields, 4 to 5 year-old fields, and >10-year-old fields.

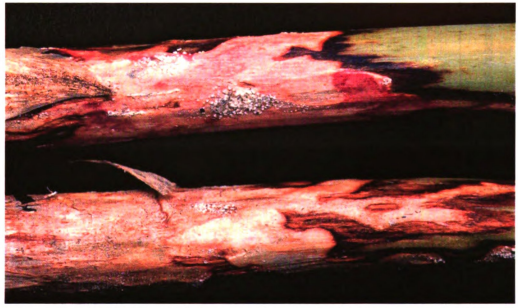


Figure 12. Fusarium sporulating out of coalescing lesions on mined asparagus stems in 2002. This image is presented in color.

Table 2. Percentage of stems out of 60 on which *Fusarium* was observed sporulating in 2002.

Obs. Dates[a]	Age of asparagus field								
	1-year-old			4-5 year-old			>10 year-old		
	KOK1 (%)	RKO1 (%)	SEL1 (%)	KOK2 (%)	OOM2 (%)	SEL2 (%)	SHA3 (%)	RKO3 (%)	SEL3 (%)
2-Jul	0	0	0	0	0	0	0	0	0
9	2	0	0	0	0	0	0	0	0
16	2	0	0	0	0	0	0	0	0
23	2	0	0	0	0	0	0	0	0
30	28	2	8	0	17	2	0	0	0
6-Aug	22	0	3	0	8	0	0	0	0
13	12	0	0	0	0	0	0	0	0
20	15	0	2	0	0	0	0	0	0
28	37	0	2	0	0	0	0	0	0
4-Sep	35	0	2	0	2	0	0	0	0
11	32	0	0	2	2	0	0	3	0
18	27	0	3	2	12	0	2	2	2
25	26	0	3	15	20	0	2	0	12

[a] Observation dates match the dates on which traps were collected and mining damage was assessed.

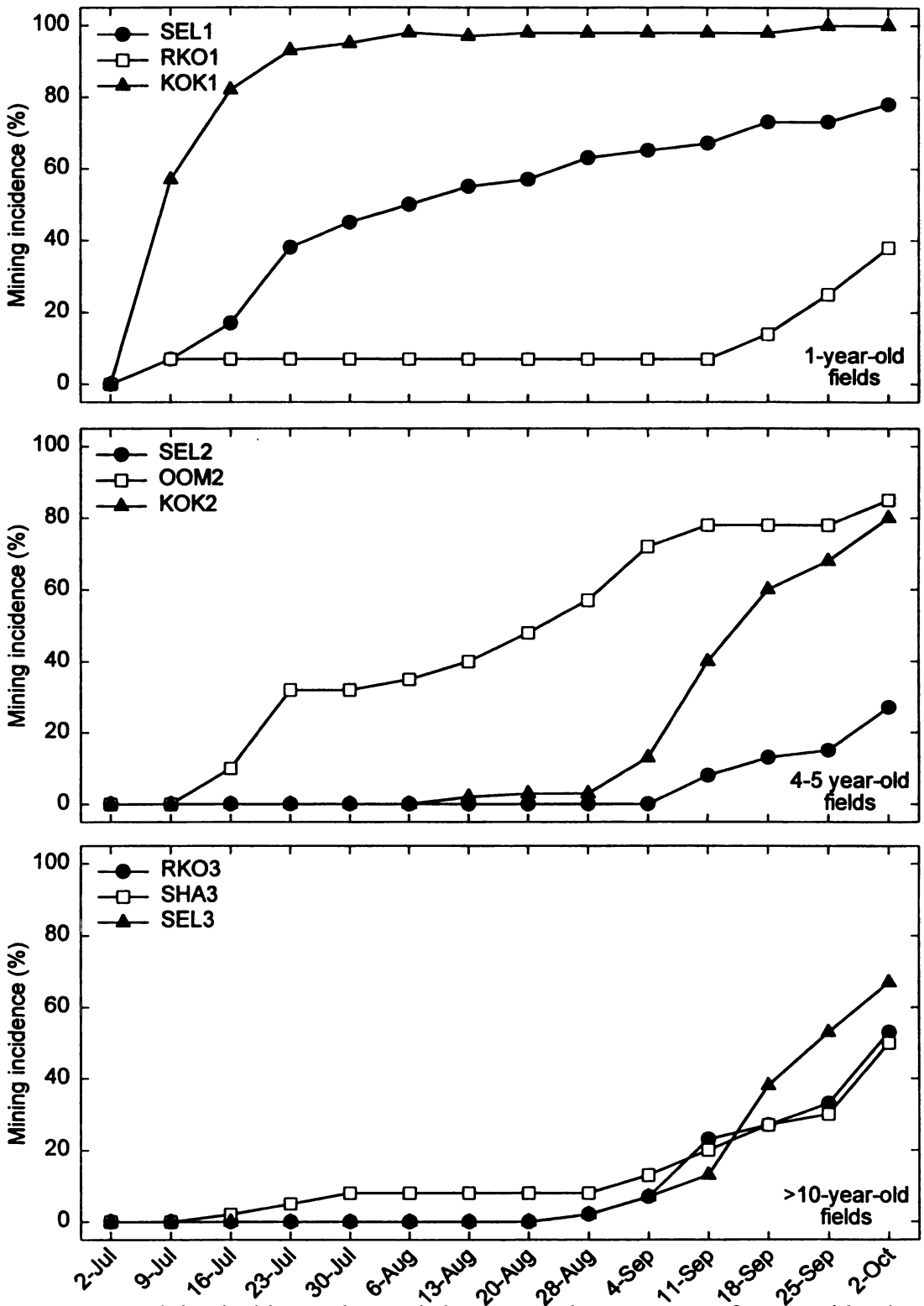


Figure 13. Mining incidence observed above ground as a percent of stems with mines visible above ground on 60 stems per fields examined weekly during 2002 in Oceana County, Michigan.

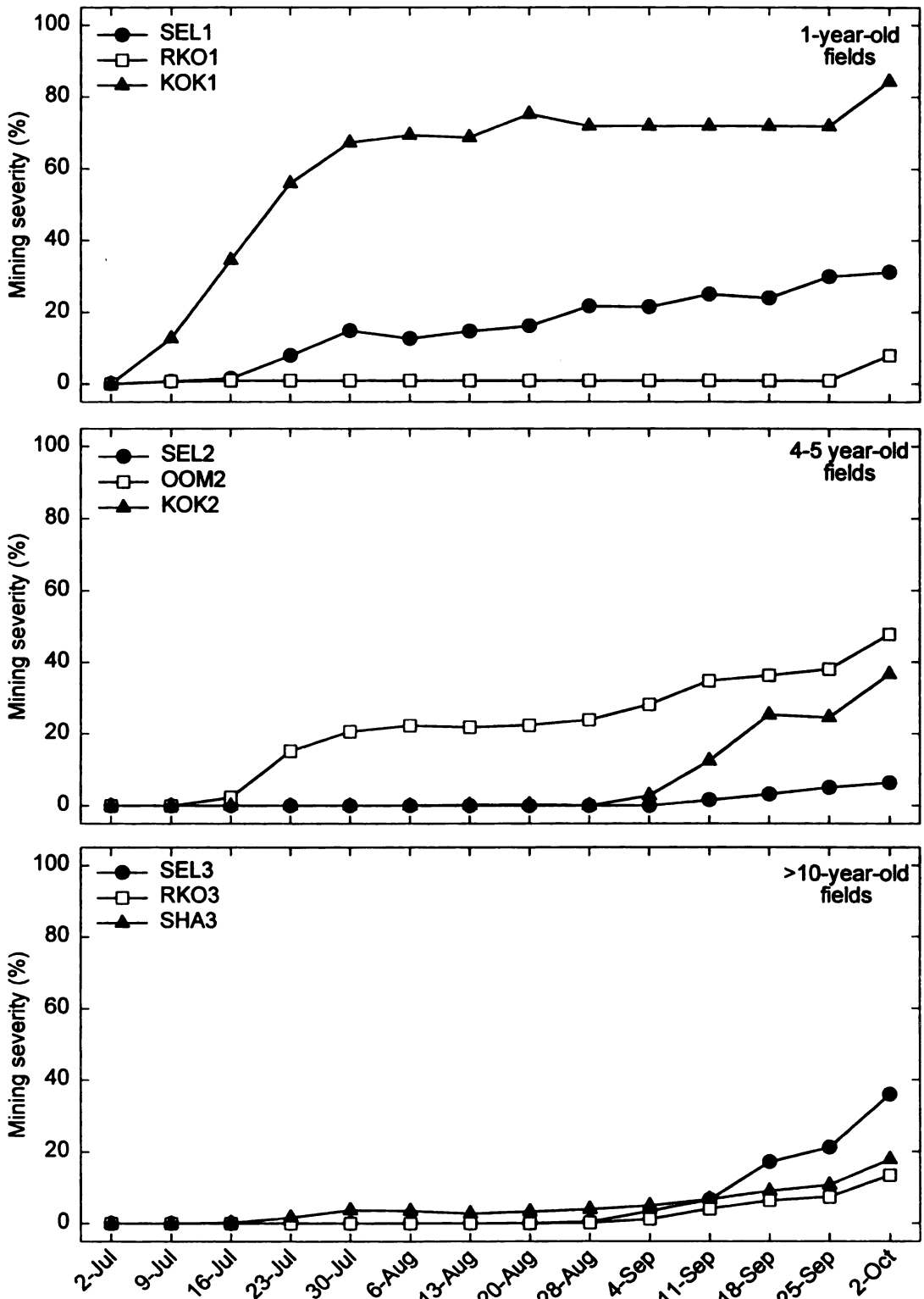


Figure 14. Mining severity observed above ground as a percent of the base of an asparagus stem girdled by mining damage measured weekly on 60 stems per field during 2002 in Oceana County, Michigan.

Table 3. Location and number of puparia, that either emerged in 2002 or were intact for over-wintering.

Condition[a] and location of puparia on stem	Age of asparagus field[b]		
	1 year	4-5 years	>10 years
Emerged, above ground	42	9	4
Intact, above ground	3	13	7
Total, above ground	45	23	11
Emerged, below ground	151	95	108
Intact, below ground	25	70	141
Total, below ground	176	165	250
Total puparia	222	188	261

[a] Puparia were crushed with forceps to determine whether they were already emerged or still intact.
[b] 180 stems were collected (60 stems from each of three fields within each age group).

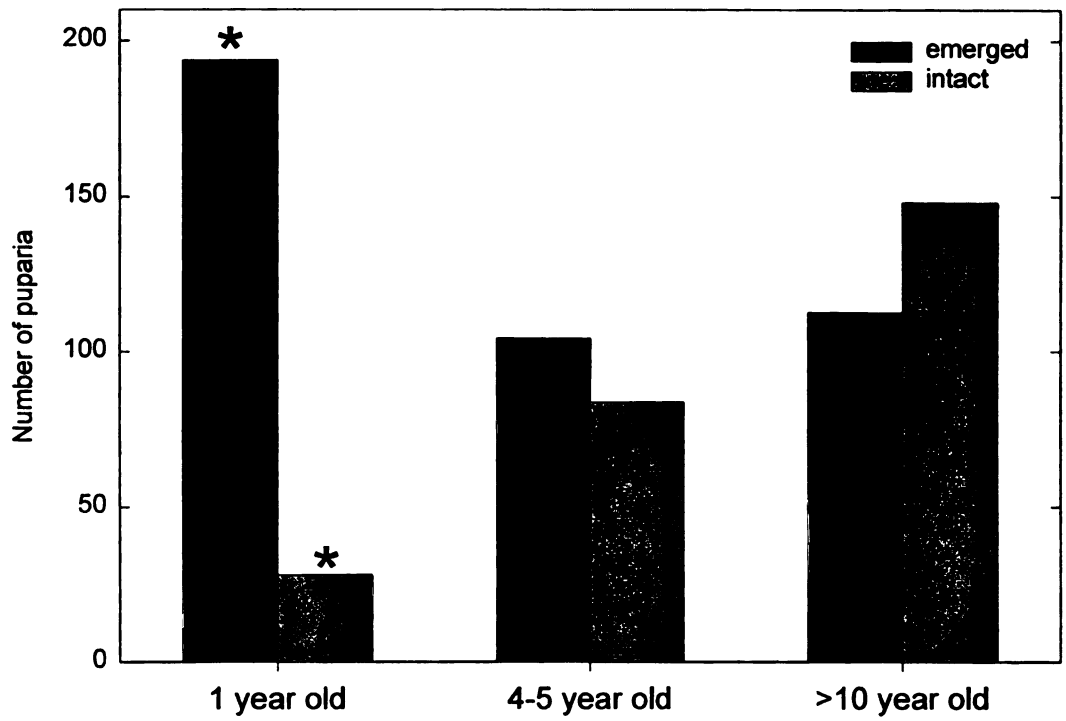


Figure 15. Average number of puparia per 120 stems collected in each field age range that were either emerged or intact in 2002. There was a significant (*) difference between the 1 year old fields and the 4-5 year old and >10 year old fields combined ($p<.00001$).

Table 4. Percentage of *O. simplex* pupae or mined asparagus stem tissue from which *Fusarium* spp. were isolated.

***Fusarium* spp. isolated**	**Above-ground mines**		**Below-ground mines**
	Pupae[a] (%)	**Stem tissue[b] (%)**	**Pupae (%)**
F. proliferatum	15	44	11
F. oxysporum f.sp. *asparagi*	3	4	17
Other *Fusarium* spp.	1	1	2

[a] 136 intact pupae collected predominantly from mines above ground in 2001.
[b] Tissue from 55 stems with mines above ground with intact epidermis in 2001.
[c] 278 intact pupae collected predominantly from mines below ground in 2001 and 2002.

DISCUSSION

Asparagus fern, unless it is in a severely declined and stunted field, usually reaches a height of up to 2 meters. In this study, we noticed that in 2001, as soon as the asparagus fern reached its maximum height, flies caught in ground level traps dropped dramatically, yet they were still seen active in the fern. Except for when females are oviposting at the base of asparagus stems, *O. simplex* adults spend most of their time copulating, feeding and resting in the asparagus canopy (12). This prompted us to add canopy height traps to try to document the activity of *O. simplex* after the asparagus was in fern, which is something Ferro and Suchak did not explore in their otherwise thorough trapping method study (11). We found that while the ground level traps caught few flies after asparagus was in fern, the canopy height traps enabled us to see a second peak in fly activity in August in most of the fields (Figure 16).

The bionomics and population dynamics of *O. simplex* have been examined in previous studies. Fink was one of the first to look at the development and behavior of *O. simplex* in the U. S. (13). Both Fink, and then later Barnes in the UK, observed two generations of the miner; the first generation developing in early summer and emerging mid to late summer, and the second generation developing during late summer and early fall, pupating over the winter and emerging the following spring (2, 13). Based on larvae and pupae collected throughout the season, Ferro and Gilbertson of Massachusetts proposed an additional generation between the two generations described previously (12).

Our findings correlate better with two generations proposed by earlier investigators. Trapping in both 2001 and 2002 revealed a two-peak trend in trap catch, which is what one expects to see in a bivoltine system (Figure 1). Although this trend

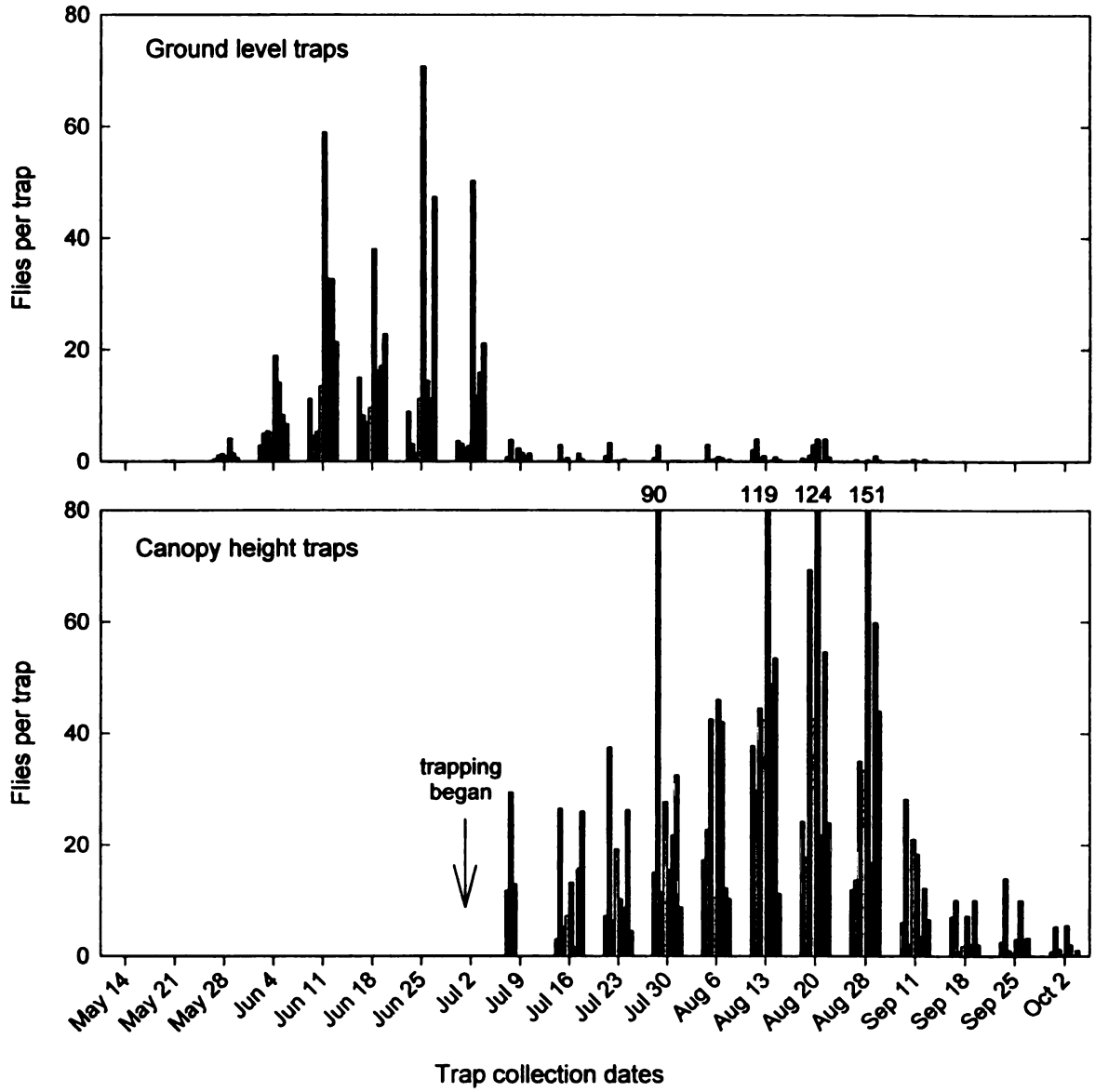


Figure 16. Comparison of trap catches throughout the 2002 growing season from traps placed at ground level and canopy height in eight fields in Oceana County, Michigan.

was seen in the first year transplanted field (RKO1) in 2001 (Figure 2), the two-peak trend was not seen in 2002 in the 1-year-old fields (Figure 3). In 2002, the 1-year-old fields were in full fern 4 to 5 weeks before the older fields and may have served as an attractant to *O. simplex* hatching elsewhere. In the case of 1-year-old fields with no or little harvest period, perhaps there may be enough time for a "third" overlapping generation to emerge during the season as suggested by Ferro and Gilbertson. That we did not see three peaks indicates that either the overwintering and first generation overlap in emergence, or the first peak is that of the over-wintered flies emerging over a period of weeks, and the second peak is the first generation emerging as adults. Further study to determine how far the flies travel from their site of emergence might help to explain why the 1-year-old fields did not show the two-peaks that the older fields displayed in 2002. Ferro and Gilbertson also suggested that *O. simplex* adults aestivate from early July to mid-August (12), but we found that other than the slight decline in adults trapped in mid-July between the two population peaks, aestivation was not observed (Figure 1).

Although it first appeared as though the southwest Michigan growing region had significantly lower populations of *O. simplex* than the central-west growing region (2001), when VANB was added (2002) it showed population levels comparable to fields of similar age in the central-west region (compare Figures 7 and 9). It would therefore be premature to suppose that the southwest region in general has lower populations of *O. simplex* than the central-west region until more fields are sampled.

In both 2001 and 2002, mining incidence and severity above ground was greater in the younger fields (OOM2 in 2001; the 1-year-old fields in 2002) than in the older fields until the last few weeks of the growing season (Figures 10 and 11), indicating that

the young fields are more vulnerable than older fields to damage from mines above ground. Because the young fields are in fern longer, due to shorter harvest, mining activity begins earlier and more of the first generation of the asparagus miner (the generation that emerges during the summer) develops in them, which is indicated by the higher number of empty puparia. The fact that all the fields had, on average, the same number of mines per stem (inferred from the number of puparia per stem at the end of the season) indicates the importance of timing of the mining damage. In young fields that are in fern for most of the season, mining begins earlier and as a result *Fusarium* infection begins earlier. Gilbertson et al. noted that Fusarium inoculum increased dramatically when the fungus sporulated on dead and dying epidermal and cortical tissue damaged by larval feeding (14). Since *F. proliferatum* is known to be dispersed aerially via wind or water (24), the inoculum levels in young fields should be a concern to growers trying to establish healthy vigorous stands.

Like Gilbertson et al. (14) we also found Fusarium sporulating out of mines caused by *O. simplex*, especially in one field (KOK1) in which above ground mining began quickly and extensively. We isolated *F. proliferatum* more frequently than *F. oxysporum* from pupae and tissue from above ground mines. This agrees with previous studies in which *F. proliferatum* (formerly *F. moniliforme*) was found to be associated with stem and crown rot on asparagus (14, 20). Pupae that were from predominantly below ground mines had more *F. oxysporum* associated with them than *F. proliferatum*, which supports previous work by Gilbertson et al. (14) and supports the idea that *F. oxysporum* is more often associated with the asparagus crown and roots (5, 10). Because pathogenic strains of both *F. oxysporum* f. sp. *asparagi* and *F. proliferatum* have been

associated with all life stages of the asparagus miner, it has been suggested that infected pupae serve as an additional overwintering source of inoculum (7, 14). However, it may be the increase in inoculum during the season that is of greater importance.

Various methods to control *O. simplex* have been suggested, but currently no measures are taken to control this pest in commercially produced asparagus. A mathematical model to predict fly populations for the following year based on the number of pupae found in a sample of stems was proposed by Lampert et al. (22), but never adopted due to lack of interest. Naturally occurring biological controls such as those discussed by Barnes, who found three different parasitoid wasps attacking *O. simplex* in England, appear to be low in number (2). However, no studies of this kind have been conducted in the U.S. to determine natural enemies of the asparagus miner. Cultural methods suggested for the control of *O. simplex* involve pulling and destroying fern at the end of the season (4); or using a section of a mature field as a trap crop to lure early emerging *O. simplex* adults to lay eggs on fern that is later removed and destroyed before their offspring have a chance to emerge (2). These cultural methods may be either too costly or ineffective for commercial applications and studies showing their efficacy would need to be conducted.

Early recommendations for chemical control of *O. simplex* involved tobacco derivative sprays (8, 13). Later diazinon insecticide applications were shown to successfully reduce mining damage as well as Fusarium disease incidence (7, 12), however this product is no longer registered for use on asparagus. Few currently registered products have been tested for efficacy or timing, and commercial growers in Michigan who regularly scout for asparagus beetles and cutworms, the two major insect

pests of asparagus, have until recently paid little attention to the asparagus miner (J. Bakker, personal communication). As concern over damage caused by the asparagus miner and its relationship to *Fusarium* increases, perhaps a phenology model to predict the development of *O. simplex*, coupled with an effective insecticide, might benefit commercial growers in their attempt to manage Fusarium crown and root rot in young asparagus fields.

LITERATURE CITED

1. Allen, J. C. 1976. A modified sine wave method for calculating degree-days. Environmental Entomology. 5:388-396.
2. Barnes, H. F. 1937. The asparagus miner, *Melanagromyza simplex* (H. Loew). Ann. Appl. Biol. 24:574-588.
3. Baskerville, G. L. and Emin, P. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50:514-517.
4. Chittendon, F. H. 1907. The asparagus miner. U.S. Dep. Agric. Bur. Entomol. Bul. No. 66: 10.
5. Cohen, S. I., and Heald, F. D. 1941. A wilt and root rot of asparagus caused by *Fusarium oxysporum* Schlecht. Plant Disease Rep. 25:503-509.
6. Damicone, J. P., Cooley, D. R., and Manning, W. J. 1981. Benomyl in acetone eradicates *Fusarium moniliforme* and *F. oxysporum* from asparagus seed. Plant Disease. 65:892-893.
7. Damicone, J. P., and Manning, W. J. 1987. Influence of management practices on severity of stem and crown rot, incidence of asparagus miner, and yield of asparagus grown from transplants. Plant Disease. 71:81-84.
8. Drake, C. J., and Harris, H. M. 1932. Asparagus insects in Iowa. Iowa Experimental Station. 12.
9. Eichmann, R. D. 1943. Asparagus miner really not a pest. Journal of Economic Entomology. 36:849-852.
10. Elmer, W. H., Johnson, D. A., and Mink, G. I. 1996. Epidemiology and management of the diseases causal to asparagus decline. Plant Disease. 80:117-125.

11. Ferro, D. N., and Suchak, G. J. 1980. Assessment of visual traps for monitoring the aspargus miner, *Ophiomyia simplex*, Agromyzidae: Diptera. Ent. Exp. & Appl&. 28:177-182.

12. Ferro, D. N., and Gilbertson, R. L. 1982. Bionomics and population dynamics of the asparagus miner, *Ophiomyia simplex* (Loew), in western Massachusetts. Environmental Entomology. 11:639-644.

13. Fink, D. E. 1913. The asparagus miner and the twelve-spotted beetle. New York (Cornell) Agricultural Experiment Station Bulletin. 331:410-435.

14. Gilbertson, R. L., Manning, W. J., and Ferro, D. N. 1981. Relationship of the asparagus miner fly to *Fusarium* stem rot of asparagus and inoculum increase by *Fusarium*. Phytopathology. 71:218-219.

15. Glendenning, R. 1943. Phenology: the most natural of sciences. Canadian Field-Naturalist. 57:75-78.

16. Graham, K. M. 1955. Seedling blight, a fusarial disease of asparagus. Can. J. Bot. 33:374-400.

17. Grogan, R. G., and Kimble, K. A. 1959. The association of *Fusarium* wilt with the asparagus decline and replant problem in California. Phytopathology. 49:122-125.

18. Hartung, A. C., Stephens, C. T., and Elmer, W. H. 1990. Survey of *Fusarium* populations in Michigan's asparagus fields. Acta Horticulturae. 271:395-401.

19. Inglis, D. A. 1980. Contamination of asparagus seed by *Fusarium oxysporum* f. sp. *asparagi* and *Fusarium moniliforme*. Plant Disease. 64:74-76.

20. Johnston, S. A., Springer, J. K., and Lewis, G. D. 1979. *Fusarium moniliforme* as a cause of stem and crown rot of asparagus and its association with asparagus decline. Phytopathology. 69:778-780.

21. Kleweno, D. D., and Matthews, V. 2002. Michigan Agricultural Statistics 2001-2002. Michigan Agricultural Statistics Service, MDA, USDA.

22. Lampert, E. P., Cress, D. C., and Haynes, D. L. 1984. Temporal and spatial changes in abundance of the asparagus miner, *Ophiomyia simplex* (Loew) (Diptera: Agromyzidae), in Michigan. Environmental Entomology. 13:733-736.

23. Manning, W. J., Damicone, J. P., and Gilbertson, R. L. 1985. Asparagus root and crown rot: sources of inoculum for *Fusarium oxysporum* and *Fusarium moniliforme*. 6th International Aparagus Symposium. University of Guelph, Ontario, Canada.

24. Nelson, P. E., Toussoun, T. A., and Cook, R. J., ed. 1981. Fusarium: Diseases, Biology, and Taxonomy. The Pennsylvania State University Press, University Park and London.

25. Reid, T. C., Hausbeck, M. K., and Kizilkaya, K. 2001. Effects of sodium chloride on commercial asparagus and of alternative forms of chloride salt on Fusarium crown and root rot. Plant Disease. 85:1271-1275.

APPENDICES

APPENDIX A

USE OF A PERMETHRIN INSECTICIDE IN THE CONTROL OF *OPHIOMYIA SIMPLEX* TO REDUCE MINING DAMAGE IN ASPARAGUS

INTRODUCTION

Asparagus is the fourth most important vegetable crop grown in Michigan with approximately 290,000 cwt at a value of $12.5 million produced in 2001 (11). Since it was first described in 1908, Fusarium crown and root rot has been implicated in decline and replant problems in production areas of asparagus throughout the United States (3, 8, 9, 10). The causal organism consists of a complex of *Fusarium* species, which in Michigan includes *Fusarium oxysporum* Schl.:Fr. f. sp. *asparagi* S.I. Cohen & Heald and *F. proliferatum* (T. Matsushima) Nirenberg (teleomorph *Gibberella fujikuroi* (Sawada) Ito G).

Over the past few years, extensive mining damage caused by *Ophiomyia simplex*, a fly commonly found throughout US commercial asparagus growing regions (1, 2, 5, 6), has been noticed in several newly established commercial asparagus fields in Michigan, where problems with Fusarium have also been noted (M. K. Hausbeck, personal communication). During the fern stage, adult asparagus miners oviposite eggs near the soil line on asparagus stems, from which larvae hatch, mine and pupate under the epidermis. Larvae are small (approx. 5 mm) and mining is confined to the parenchymous tissues of the cortex between the pericycle and the epidermis, leaving vascular tissue within the pericycle unaffected. Damage by *O. simplex* larvae has been considered alternately significant (1, 2, 3, 6) and insignificant (5). However, it is currently thought that feeding by the larvae, resulting in extensive stem mining damage, can lead to increased stem rot by Fusarium (4, 7).

Our primary objective was to determine whether the use of Pounce, a permethrin insecticide to control *O. simplex*, would decrease mining damage.

MATERIALS AND METHODS

In 2001, two commercial asparagus fields in Oceana County, Michigan (OOM2 and RKO3) were each divided into fifteen 225m^2 blocks separated by 2.25m buffers, and randomly assigned one of three treatments: untreated, insecticide applied on a seven day interval, and insecticide applied according to scouting-based observations. There were five repetitions of each treatment for a total of fifteen plots per field. Initial applications were triggered by flies trapped on the cards or when asparagus went to fern, whichever was later. A threshold of one fly per trap was used to determine subsequent applications in the scouting-based treatment. The insecticide used was permethrin, trade name Pounce 3.2 EC (FMC Corporation, Agricultural Products Group, 1735 Market Street, Philadelphia, PA 19103), at a rate of 4 ounces per acre, using a Solo Motorized Mister backpack sprayer. All treatments were applied in addition to the standard production practices of the grower cooperator. One of the fields (OOM2) was a 3-year-old stand of cultivar 'Jersey Giant' that was adjacent to a 4-year-old asparagus field. The other field (RKO3) was a 12-year-old stand of cultivar 'Franklim' that was adjacent to another mature asparagus field and rye fields.

Placed within the center of each block was a pair of Yellow Stiky Strips™ (3 by 5 inch) insect traps (Olson Products, P.O. Box 1043, Medina, Ohio 44258) to monitor adult *O. simplex* populations. One of the traps was placed at ground level and one was located in the canopy 1.5 m above ground. Ground level traps were held by wire loop holders duct-taped to 30cm wooden stakes, while canopy height traps were held by wire loop holders inserted into the top of 19 mm galvanized rigid steel conduit at a finished height

of 1.5 m within the canopy. Once harvesting for the season was completed and each field went to fern, traps were set out and changed every 7-10 days beginning 24 May until 4 October 2001.

Within the center if each block, a 25-foot section of the row was marked in which 25 stems were randomly chosen and labeled. These stems were examined every 7 to 10 days for above ground mining incidence and severity by measuring the height of mines visible above ground, the circumference of the stem covered with mines within 5 cm of the soil line and the approximate number of mines observed above ground. At the end of the season, the labeled stems were collected and brought back to the laboratory for examination. Mine length was measured on each stem and pupae were extracted from mines.

RESULTS AND DISCUSSION

Except for one week in one of the fields, there was no difference in the number of applications of insecticide between the 7-day and scouting-based programs, so the two treatments have been combined in the results as a single treatment named 'Pounce'. Also, there was no statistical difference in the number of flies trapped (data not shown) or in the incidence and severity of mining damage (Figure 17) between the control and insecticide treatments. To have applied as many as 13 applications of insecticide with no measurable effect, leads us to believe that either the application method was suspect, or this particular insecticide is not an effective control of this insect.

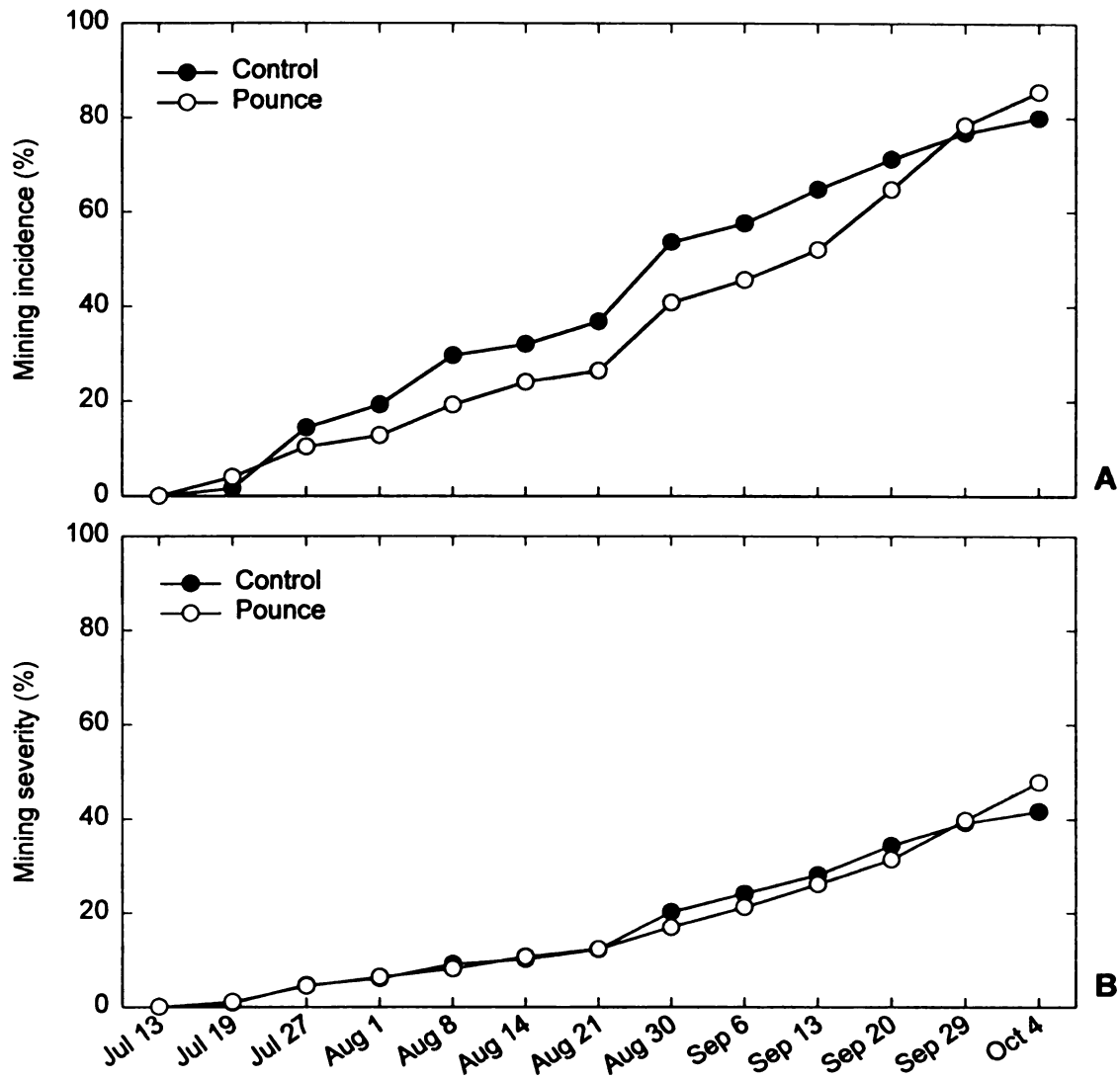


Figure 17. Percent of asparagus stems (n = 125/plot) that were mined above ground (A) and severity of stem girdling above ground caused by mining (B) in Oceana County, Michigan during 2001.

LITERATURE REVIEW

1. Barnes, H. F. 1937. The asparagus miner, *Melanagromyza simplex* (H. Loew). Ann. Appl. Biol. 24:574-588.
2. Chittendon, F. H. 1907. The asparagus miner. U.S. Dep. Agric. Bur. Entomol. Bul. No. 66: 10.
3. Cohen, S. I., and Heald, F. D. 1941. A wilt and root rot of asparagus caused by *Fusarium oxysporum* Schlecht. Plant Disease Rep. 25:503-509.
4. Damicone, J. P., and Manning, W. J. 1987. Influence of management practices on severity of stem and crown rot, incidence of asparagus miner, and yield of asparagus grown from transplants. Plant Disease. 71:81-84.
5. Eichmann, R. D. 1943. Asparagus miner really not a pest. Journal of Economic Entomology. 36:849-852.
6. Fink, D. E. 1913. The asparagus miner and the twelve-spotted beetle. New York (Cornell) Agricultural Experiment Station Bulletin. 331:410-435.
7. Gilbertson, R. L., Manning, W. J., and Ferro, D. N. 1981. Relationship of the asparagus miner fly to *Fusarium* stem rot of asparagus and inoculum increase by *Fusarium*. Phytopathology. 71:218-219.
8. Grogan, R. G., and Kimble, K. A. 1959. The association of *Fusarium* wilt with the asparagus decline and replant problem in California. Phytopathology. 49:122-125.
9. Hartung, A. C., Stephens, C. T., and Elmer, W. H. 1990. Survey of *Fusarium* populations in Michigan's asparagus fields. Acta Horticulturae. 271:395-401.

10. Johnston, S. A., Springer, J. K., and Lewis, G. D. 1979. *Fusarium moniliforme* as a cause of stem and crown rot of asparagus and its association with asparagus decline. Phytopathology. 69:778-780.

11. Kleweno, D. D., and Matthews, V. 2002. Michigan Agricultural Statistics 2001-2002. Michigan Agricultural Statistics Service, MDA, USDA.

APPENDIX B

SUPPLEMENTARY FIGURES

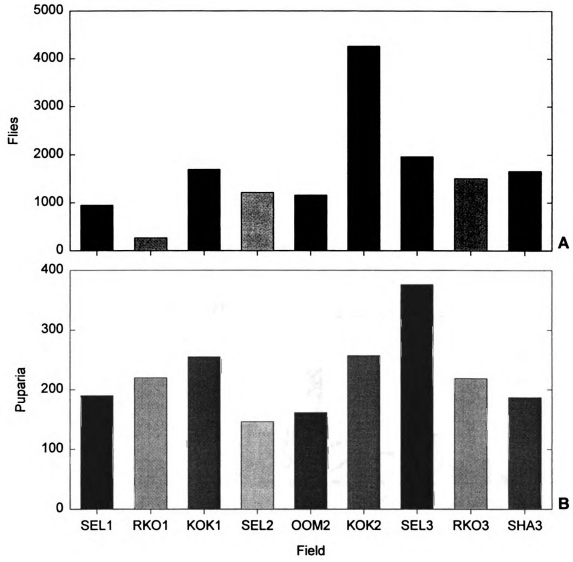


Figure 18. Total number of flies trapped throughout the 2002 season (A), and the number of puparia (whether emerged or intact for overwintering) collected from 60 stems per field at the end of 2002 (B) in Oceana County, Michigan. Though there appears to be variability between fields, there is no significant difference.

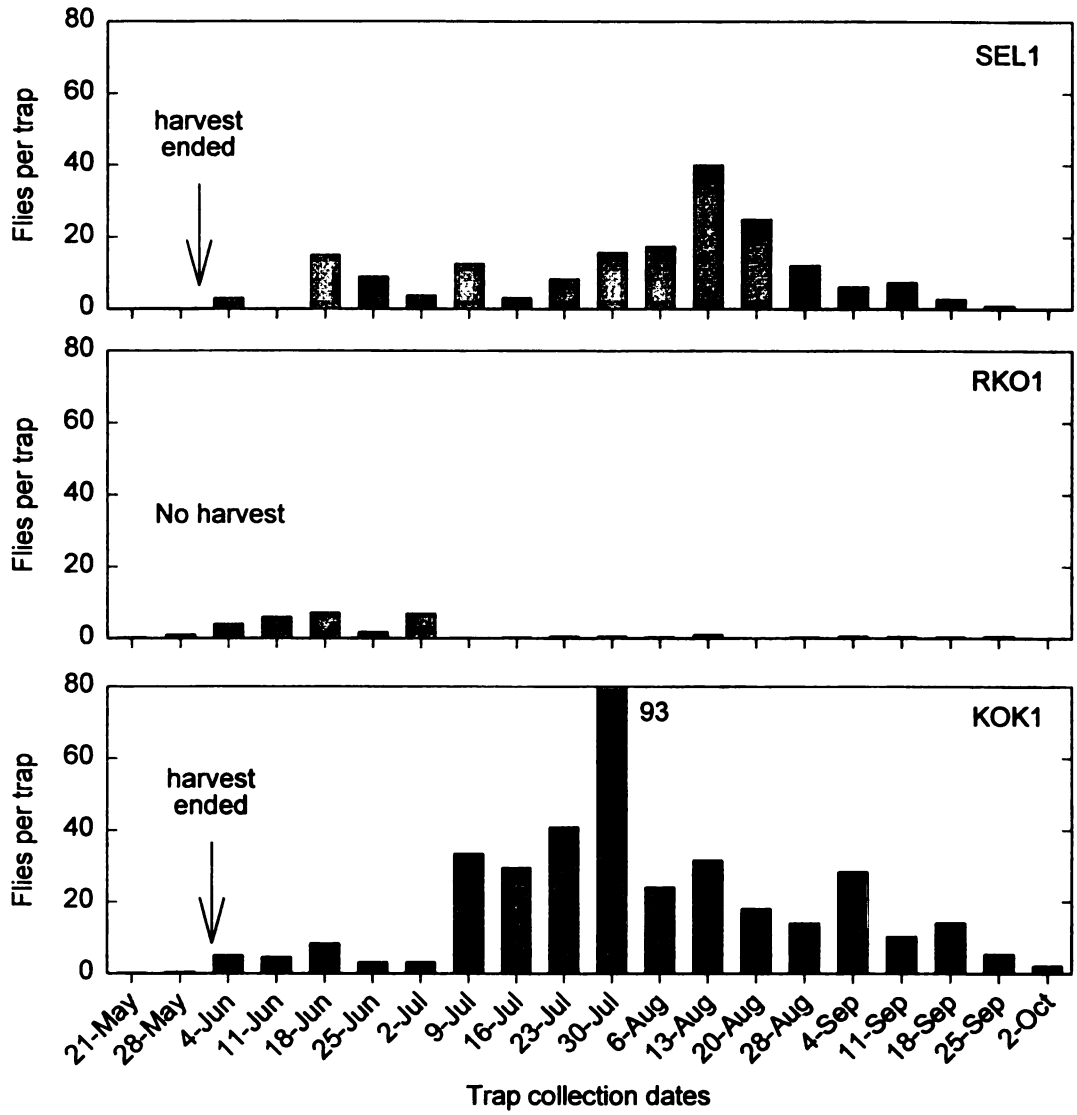


Figure 19. *Ophiomyia simplex* adults trapped in 1 year old fields in Oceana County in 2002.

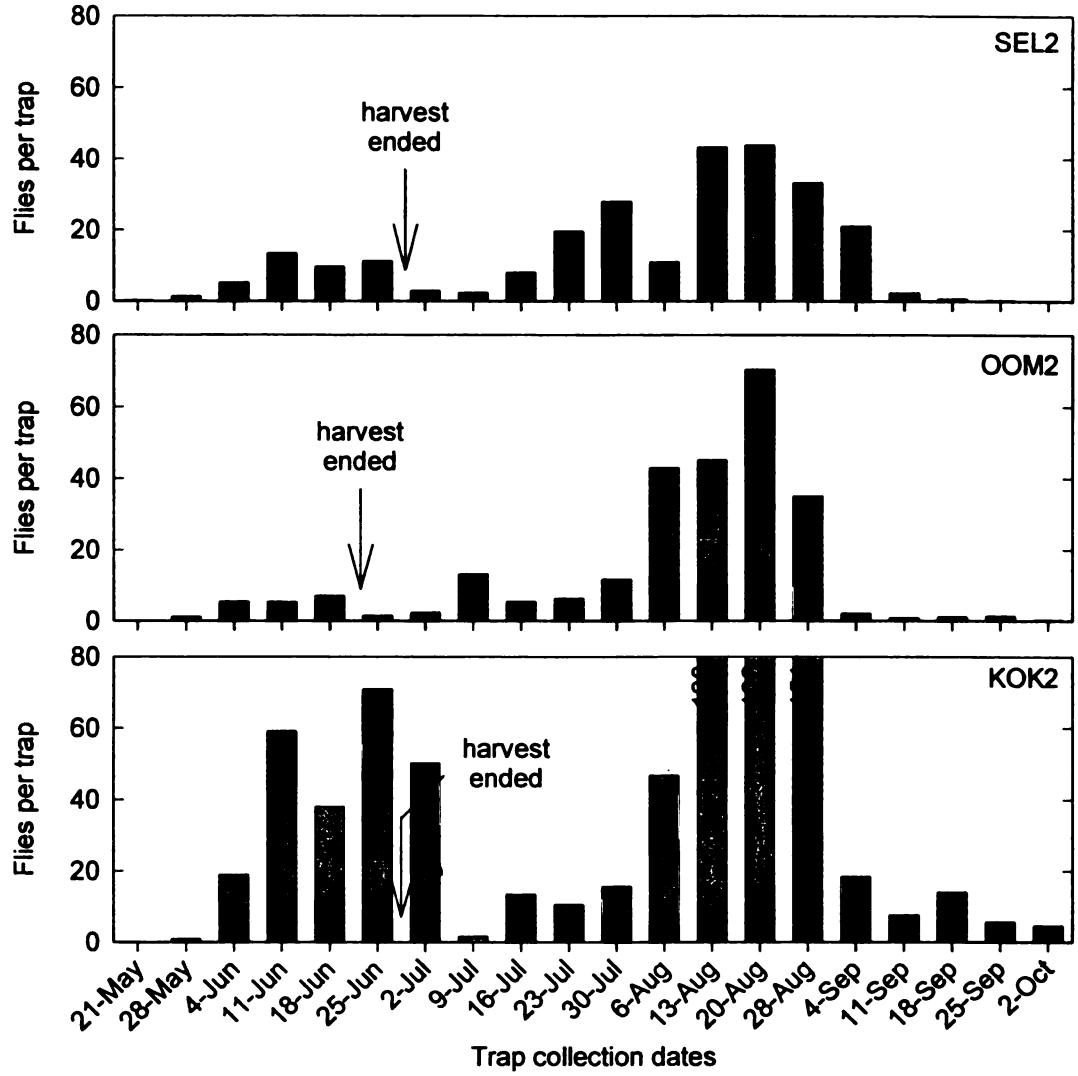


Figure 20. *Ophiomyia simplex* adults trapped in 4-5 year old fields in Oceana County in 2002.

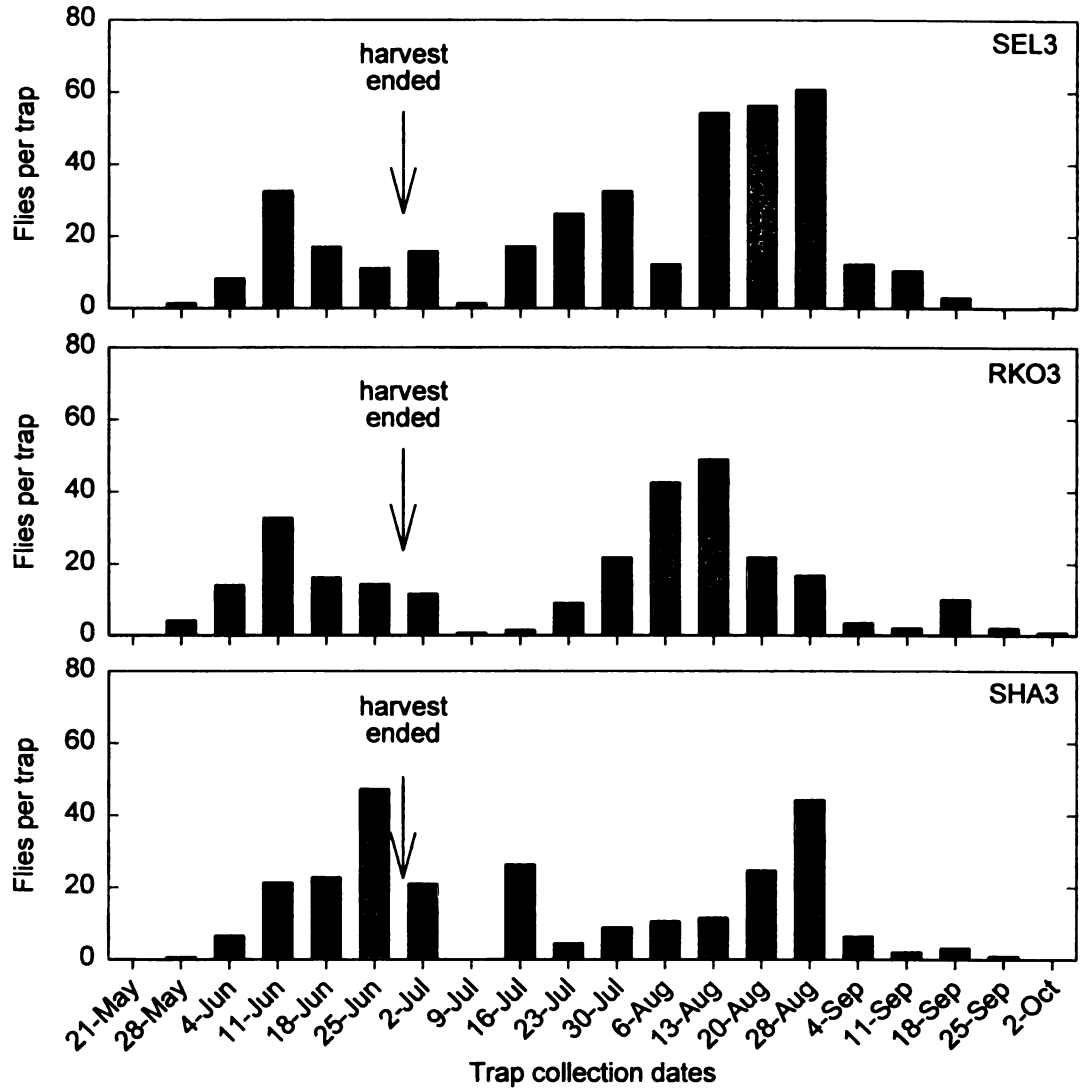


Figure 21. *Ophiomyia simplex* adults trapped in >10 year old fields in Oceana County in 2002.

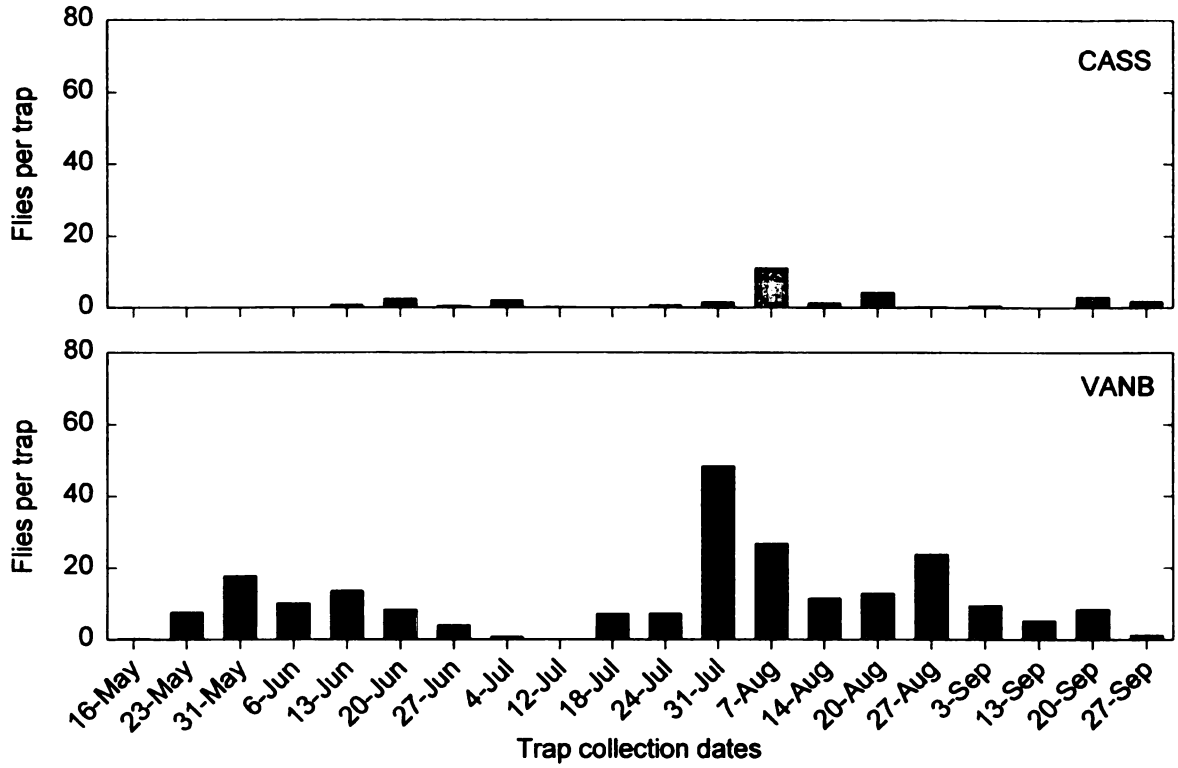
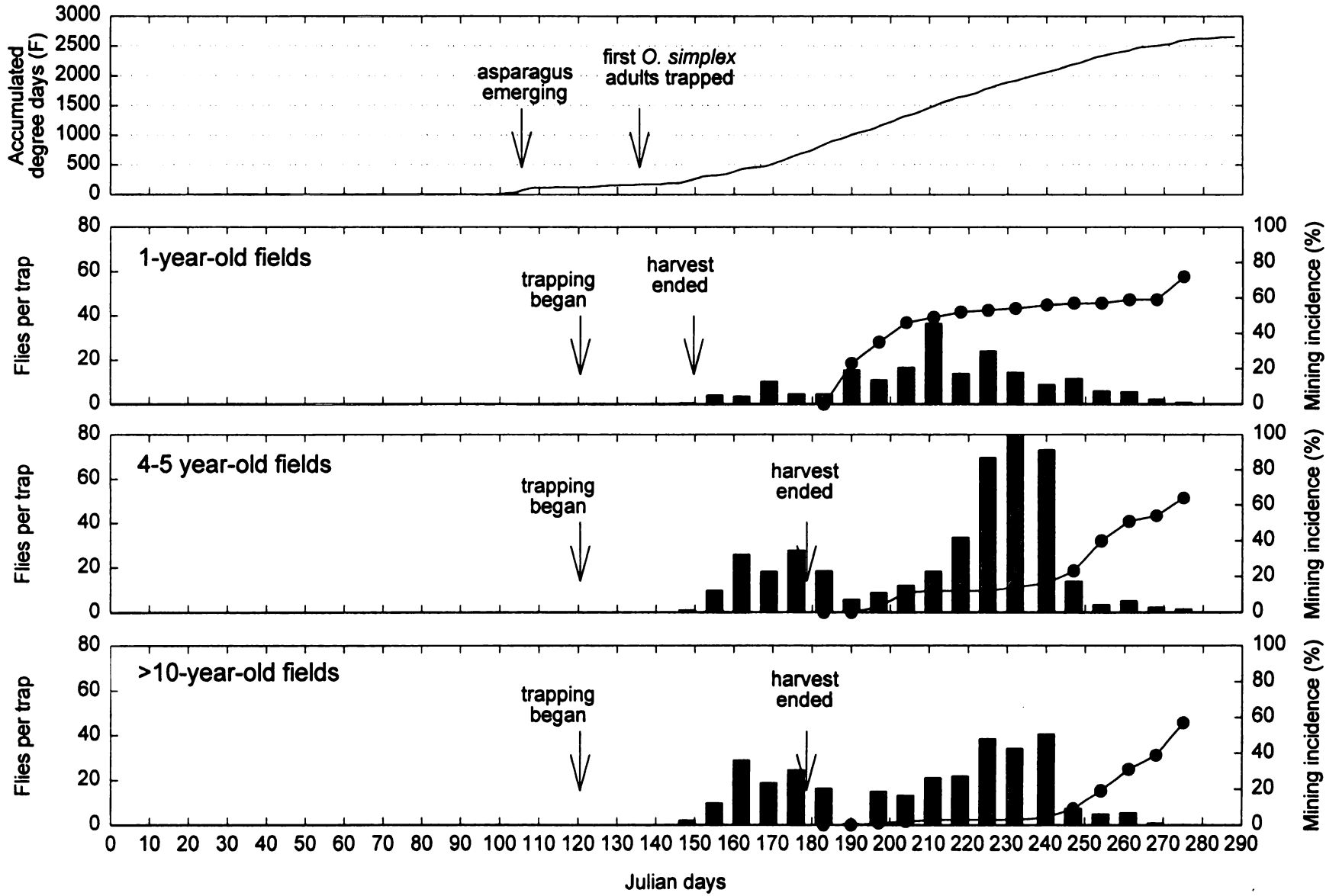


Figure 22. *Ophiomyia simplex* adults trapped in Cass (CASS) and Van Buren (VANB) Counties in Michigan in 2002.

Figure 23. Accumulated degree-days (base 50; numerical integration) compared with *O. simplex* adults trapped (bars) and mining incidence (line and scatter) in fields of three different age ranges in Oceana County, Michigan in 2002.


Accumulated degree days (F)
3000
2500
2000
1500
1000
500
0
asparagus emerging
first O. simplex adults trapped
Flies per trap
Mining incidence (%)
1-year-old fields
trapping began
harvest ended
4-5 year-old fields
>10-year-old fields
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Julian days