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Names and Institutions of PDs

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Project Title: Integrated management and resistance management of annual bluegrass weevil on golf course turf

Project Summary:

This multi-state research and extension project will evaluate biological and selective chemical alternatives to pyrethroids for managing annual bluegrass weevil (ABW) in low-cut golf course turf, and will improve the basic biological and ecological understanding of ABW relevant to its management. Over the past ten years golf course superintendents have become dependent on pyrethroids for managing ABW and other insect pests. Recent laboratory tests and field observations demonstrate that populations of annual bluegrass weevil are developing resistance to pyrethroid insecticides – resulting in control failures and severe injury to turf. We will determine the geographical extent of pyrethroid-resistant ABW populations throughout the northeast. Failure of pyrethroids due to insecticide resistance is anticipated to motivate superintendents to accept selective pesticides or biologicals for managing ABW populations, thereby opening the door to managers' acceptance of other IPM practices. Promising candidates for control of ABW that we will test include natural product insecticides and insect pathogenic nematodes. A transition away from broad-spectrum insecticides should reduce the risk to workers, golfers, and the environment, and permit greater activity of beneficial generalist predators and insect pathogens, improving ecological stability.

This proposal coordinates turf entomology expertise from the Northeast Region to find solutions to superintendents' problems with ABW. Dr. Koppenhöfer (Rutgers Univ.), an insect pathogenic nematode expert, will coordinate the nematode component. Dr. Cowles (Conn. Agric. Expt. Station) has expertise in dose-response testing to evaluate insecticide performance, and will bioassay weevils sent by all participants for pyrethroid resistance with Dr. Alm's Ph.D. student (Univ. RI). Dr. Li is a mycologist and will lead the laboratory-based testing of biocontrol fungi to determine their compatibility with fungicides used in the field. Dr. Peck (Cornell) has expertise in field and population ecology, will lead in phenology analysis, sampling methods and publication of extension literature. All other collaborators have special expertise in working with ABW, and they will be conducting field efficacy tests (all participants except Dr. Peck), and developing web-based resources (Dr. Vittum).

Project Description

Problem, Background and Justification

Economic importance of golf course turf and annual bluegrass. Turfgrass is a valuable and rapidly expanding component of our urban and rural landscape. Turfgrass covers 12 million ha in the U.S. (Potter & Braman 1991) and includes over 60 million lawns and more than 16,000 golf courses (Emmons 2000). Golf courses are an important component of the turfgrass industry. They are a source of green space in the urban environment and offer recreation and enjoyment for approximately 36 million Americans. Golf courses also generate jobs, commerce, economic development, and tax revenues for communities throughout the U.S. A recent report by the World Golf Foundation stated that golf contributes $62.2 billion worth of goods and services each year to the national economy (www.golf2020.com).

Few turfgrass species can tolerate the intensive management regimes (e.g., low mowing heights, low fertility, frequent cultivation, etc.) implemented on putting greens, tees, and fairways. Annual bluegrass (*Poa annua*) and bentgrass (*Agrostis* spp.) are well suited to these locations but are prone to many diseases and insect pests. Although most pest problems can be controlled with chemical pesticides, the general public is becoming increasingly concerned about the potential for pesticide exposure and long-term effects to humans and pets, as well as the possibility of ground and surface water contamination. The extensive use of chemical pesticides to control turfgrass pests also can reduce profitability of golf course operations. Current practices for managing putting greens and tees are very pesticide intensive, with upwards of six each of insecticide and fungicide sprays per year (Brian Johnson, Blue Fox Run Country Club, Avon, CT, personal communication). Many of the insecticides used are broad-spectrum products, which can be expected to negatively impact beneficial predator and parasitoid populations (Terry et al., 1993). An integrated approach to disease and insect management can help alleviate some of the public concern about pesticide use and benefit the golf industry by increasing the efficiency of pest control efforts.

Annual bluegrass is a common invasive species present on golf courses throughout the world. Biotypes of this species exhibit growth habits ranging from true winter annuals to long-lived perennials (Huff 2004). Golf course superintendents often consider annual bluegrass a weed, especially when it begins to encroach into newly seeded stands of creeping bentgrass (*Agrostis stolonifera*). Although some superintendents attempt to control annual bluegrass with herbicides, fumigants, or chemical growth regulators, these attempts often fail due to the competitive ability and prolific reproductive capacity of this grass species. In many cases, annual bluegrass becomes the dominant species in fairways and putting greens, and superintendents resort to managing it instead of the more pest-tolerant bentgrass species (Miltner et al. 2004). Annual bluegrass can provide an acceptable playing surface for putting greens and fairways when properly maintained, but this often requires extensive chemical inputs (Grant & Rossi 2005). Attributes of this species include its high tiller density, and tolerance of low cutting heights, shade and traffic. However, it is often maligned for its lack of stress tolerance, yellow-green color, prolific flowering habit, and its susceptibility to many diseases and insect pests (Beard 1973).

Two emerging pests have increasingly complicated the maintenance of annual bluegrass on golf courses in the Northeast and Mid-Atlantic: the annual bluegrass weevil (*Listronotus maculicollis*) and anthracnose diseases caused by the fungus *Colletotrichum cereale*. These pests emerged as special concerns to annual bluegrass on high maintenance golf course turf in the Northeast during studies of a previous NE Regional Turf Hatch Project, NE-187. Both pests can cause severe damage on annual bluegrass turf and can result in increased pesticide use and reduced golf-generated revenues. In severe cases, control of these pests depends almost entirely on synthetic pesticides. Reliance on multiple pesticide applications increases the possibility of insects and pathogens developing resistance to these pesticides, as well as the cost of control. There is an urgent need to refine our understanding of the biology and ecology of these pests, to develop better IPM tools to assess and monitor their impact, and to discover and deploy alternative pest management practices whenever possible. We seek to develop best management practices for the control of ABW on annual bluegrass, while promoting a model for environmental stewardship and cost effectiveness in other turfgrass systems.

Biology and management of annual bluegrass weevil. The annual bluegrass weevil (ABW), *Listronotus maculicollis*, formerly called '*Hyperodes* weevil', is a notorious and damaging pest of close-cut annual bluegrass on golf courses (greens, tees, fairways) and tennis courts of the Northeast (Potter 1998, Vittum et al. 1999). ABW injury to turfgrass was first reported in CT in 1931 (Britton 1932) and until the last 15 years has been concentrated around the metropolitan area of NY. Severe infestations are now being reported from all other states of the Northeast (MA, ME, NH, NJ, NY, PA, RI, VT), west into Ontario and north into Quebec. It was problematic for the first time in MD in 2004, and identified within the last two years from DE, WV and VA, representing the southern front of its expanding range of impact in the Mid-Atlantic. Although not always present in turfgrass settings, the species has been reported from more than 40 states - therefore, the potential exists for significant spread of impact across a wide geographic range of the U.S. and Canada.

ABW larvae can cause serious damage to annual bluegrass. Although there have been occasional reports of feeding on bentgrass, ABW clearly prefers annual bluegrass (Rothwell 2003). Young larvae tunnel the stems, causing the central leaf blades to yellow and die, whereas the older larvae feed externally on the crowns, sometimes completely severing the stems from the roots. The damage inflicted by the stem-boring and crown-feeding larvae severely impacts the visual and functional quality of the turf. The 1st generation older larvae, usually active around late May/early June in the NY metropolitan area, normally cause the most severe damage. Damage from the 2nd generation larvae, during early to mid July, is usually less severe and more localized. However, where the 1st generation is inadequately controlled, damage from the 2nd and 3rd generation larvae is exacerbated because annual bluegrass is least vigorous and at a competitive disadvantage during the summer months. Injury caused by the 3rd generation often is masked by other stresses (e.g., diseases, soil compaction); however, damage observed in August of 2006 clearly was caused by ABW outbreaks.

Adults overwinter in the protection of the upper soil layer. Observations suggest that protected areas (e.g. rough or litter) harbor higher populations than low mown turf (e.g. fairways, tees, greens, aprons) (Cameron & Johnson 1971). We also know that white pine litter can support high populations of overwintering adults, and that 85% are found in the top 1 cm of soil or the litter itself (Vittum & Tashiro 1987). But the factors that influence overwintering site and selection have not yet been tested. In April the adults migrate into annual bluegrass areas and, after a brief feeding period, the females start laying eggs under the annual bluegrass leaf sheaths. Development of the 1st generation in spring from eggs to adult takes about 6 weeks. The 1st generation adults become active on the surface around mid to late June, and their offspring emerge as the 2nd generation adults in late July to August. Adults from the 3rd generation migrate back to their overwintering sites from October into November.

Chemical insecticides have been the only consistent options for ABW control. Up until now, the most effective approach has been to preventively spray areas with high adult activity and an ABW history in late April with a pyrethroid or chlorpyrifos (Dursban). Due to their efficacy, superintendents have almost exclusively relied on pyrethroids. The spray has to be timed so that most of the adults are out of the overwintering sites but before too many eggs have been laid. In the best-case scenario and in the past, control is achieved with one well-timed perimeter spray. Using this approach, most of the ABW adult population may be intercepted as they enter the low cut turf from their overwintering sites. However, it is not uncommon now for superintendents to make 2-6 insecticide applications per season. A systemic insecticide, imidacloprid (Merit) can be applied in early May to kill the young larvae inside the plants, but has poor efficacy (see below). Finally, insecticides, principally trichlorfon (Dylox) can be applied as rescue treatments to kill the older larvae once they have started to come out of the stems to feed on the crowns. Because it is difficult to time the application to precisely target the appropriate larval stages, superintendents rarely achieve excellent control with larvicides.

Review of field management tests and pyrethroid resistance. A series of separate studies over the last ten years has assessed the field efficacy of products for ABW control, including conventional and alternative insecticides, biorationals and biologicals. Results from 44 studies have been published in Arthropod Management Tests from 1995 to 2004 based on research conducted in MA (15 studies), PA (20 studies), and elsewhere in the Northeast. New studies were initiated in NJ in 2004. As part of broader studies in PA addressing the suppression of pests in grasses, trials have shown that pyrethroids, not neonicotinoids (Merit) nor halofenozide (Mach 2), can consistently suppress ABW populations on golf courses (Heller, CRIS PEN03988 and PEN03655). Overall, up until now, superintendents have increasingly relied upon pyrethroids because of the outstanding degree of suppression achieved. Among the Arthropod Management Test results, pyrethroids gave 90% population reductions, averaged over more than 66 treatments. In comparison, over the same period, other products reduced populations as follows: Conserve SC, 80% (n = 3); Dursban, 73% (n = 18); Dylox, 66% (n = 3); Mach 2, 48% (n = 12); Merit 75W, 39% (n = 19); *Steinernema carpocapsae*, 24% (n = 3).

Because ABW control depends almost exclusively on pyrethroids, this species is under strong selective pressure for developing resistance to this chemical class. Fears of selection for pyrethroid resistant populations were realized in 2005, when golf course superintendents at several golf courses in CT reported lack of control following multiple sprays of λ-cyhalothrin (Scimitar insecticide) directed against a single generation of ABW adults. A sample of several thousand ABW adults was collected from a golf course in Avon, CT, to determine λ-cyhalothrin toxicity in a dose-response bioassay. After 6 days of continual exposure to treated filter paper, there was 35% mortality in the untreated checks, 50% mortality of weevils at the field-labeled dosage, and only 60% mortality at eight times the field-labeled dosage (Cowles, unpublished data). Similar results were obtained from another golf course in West Hartford, CT, in 2006, using the same filter paper test protocol. These results contrast with tests of two populations that had limited field exposure to pyrethroids, one from Somers, CT, and the other from New Hampshire. Both of these populations experienced 100% knock-down or mortality at 24 h exposure to the field dosage of Scimitar, and 100% mortality following 48 h exposure. Pyrethroid resistance in adult ABW may have become a reality, but the full implications for pest management need further investigation. Unanswered questions are: (1) What is the geographical distribution of pyrethroid resistance, (2) Do larvae remain susceptible to pyrethroids, (3) How may superintendents avoid pyrethroid resistance where it has not yet occurred, and (4) How may pyrethroid-resistant ABW populations best be managed?

The geographical area where these resistant weevils originated is in the same area (central Connecticut) where conspicuously poorer control of ABW adults was observed 6 years ago in a comparison of two sites (Vittum, 1999). Although reports of poor results with pyrethroids now are scattered across CT, the finding of no evidence of resistance at the Somers golf course (25 miles from West Hartford) suggests that there may be a fine grain (in a spatial sense) to the occurrence of pyrethroid resistance, very likely associated with the history of pyrethroid use at each course. While the course in West Hartford is known to have used pyrethroids several times each season over entire fairways, the course in Avon has only used pyrethroids for intensive management of weevils on tees, greens, and collar areas. Therefore, it appears that resistance may be selected efficiently with limited treatment areas.

The resistance of adult weevils to pyrethroids may not represent the status of larvae. Recent observations (PJV, unpublished data) suggest that pyrethroid applications may be useful for suppressing larval populations where they are no longer effective against adults. If this is true, then perhaps very carefully targeted application of pyrethroids may still be useful to protect the most valued turf (greens and collars) from larval damage, even at sites where perimeter treatments to control adults are no longer useful. However, larval populations from intensively selected populations need to be compared with those from non-resistant populations to determine whether larval pyrethroid resistance is present.

Where pyrethroids fail to kill ABW adults, turf managers will be facing the prospects of reverting to organophosphate insecticides to suppress the adult and larval populations. The fall-back strategy is currently to apply trichlorfon (Dylox) for larval control or chlorpyrifos (Dursban) for adult control. Dursban is no longer available for use on residential turf, but is still registered for use on golf courses. Ironically, even though the FQPA-induced changes to registration reduced the amount that could be applied to golf course turf in a single application, there are no restrictions on the frequency and number of Dursban applications. Since field trials have demonstrated that a chlorpyrifos dose of 2 lb. active ingredient per acre is usually necessary for control (Heller and Walker 1997, Vittum and Rothwell 1999), and the current limit is 1 lb active ingredient per application, an unfortunate outcome we predict from pyrethroid failure will be intensive repeated spraying of organophosphate insecticides to achieve effective dosages by golf course superintendents to control ABW.

<u>Past research on alternative options.</u> Past studies have evaluated the effectiveness of different non-pyrethroid alternatives to combat ABW larvae (note results given above for control with Mach 2, an insect growth regulator). It is intriguing that in two studies, spinosad (Conserve SC, a natural product insecticide) has been as effective as Dursban, the insecticide most likely to be substituted for pyrethroids (Vittum & Luce 2002; Heller & Walker 2003). As a short-residual product with low toxicity to most predators, spinosad could be an important IPM tool, but needs to be tested further to judge its reliability. In addition, insect pathogenic nematodes have been tested (see below). In all cases of pyrethroid alternatives, we have concluded that additional studies will be necessary to refine the timing of applications and to ensure reliability. The results of this work have reinforced the need for more studies to (1) identify alternatives to pyrethroids, (2) refine the timing of application in accordance with insect life stage, (3) compare and contrast

strategies that target larvae versus adults relative to their effectiveness in protecting turf. Ultimately, the goal from this project is to provide an improved management paradigm, one that is more stable (through conservation of biological control agents, or reliance on them to suppress populations in the lower-value turf areas) and will avoid resistance as has occurred with the pyrethroids.

Entomopathogenic nematodes. Entomopathogenic nematodes (Heterorhabditidae and Steinernematidae) offer an environmentally safe and IPM-compatible alternative to chemical insecticides, and have been used successfully to control insect pests in various crops including other weevil species such as the *Diaprepes* root weevil in citrus, the black vine weevil in cranberries and ornamentals, and billbugs (*Sphenophorus* spp.) in turfgrass (Shapiro et al. 2002, Grewal et al. 2005). Field tests in Ohio indicated that the bluegrass billbug, *Sphenophorus parvulus,* can be controlled with *Steinernema carpocapsae* (average 78% control) or *H. bacteriophora* (average 74%) (Georgis & Poinar 1994, Smith 1994). In Japan, *S. carpocapsae* was the main means of controlling the hunting billbug, *S. venatus vestitus* (average 84% control) (Smith 1994, Kinoshita & Yamanaka 1998) before the recent registration of Merit. Preliminary studies by the Vittum and Alm laboratories have indicated that entomopathogenic nematodes may also control ABW (Vittum 1995; Alm, unpublished data). The nematodes tested were not effective when applied in late April against the adult weevil, probably because the soil temperatures at that time still limit nematode activity. However, applications against the larvae in late May when soil temperatures are more favorable have given around 70% control. The data from RI were especially promising, demonstrating 76, 98, and 99% population reductions following application of *S. carpocapsae* at two sites (Alm, unpublished data). Nematode applications against the ABW summer generations need to be investigated. A well-adapted nematode may be able to provide control of the following ABW generation, or even multi-year benefit if permanently established in the soil (LaMondia et al. 2005).

Recent research in the Koppenhöfer laboratory (funded by the Golf Course Superintendents Association of America and regional chapters and by the United States Golf Association) is showing that adult ABW are much less susceptible than 3rd to 5th instars to entomopathogenic nematodes (*S. carpocapsae*, *H. bacteriophora*, and the more cold-active *H. megidis*, *S. feltiae*, and *S. kraussei*) even in the nematodes' optimal temperature range (22°C in the laboratory). This further explains the limited effect of *S. carpocapsae* applications against the adult ABW in late April, but also suggests that future work should concentrate on the more susceptible larval stages. Because of the low susceptibility of adult ABW we also no longer view application of nematodes to the typical adult hibernation sites as promising (as proposed previously). Observations in the Koppenhöfer laboratory have thus far not shown a clear difference in efficacy against ABW larvae among all the above listed nematodes under laboratory and field conditions. Application of nematodes against the larvae of the summer generation did not provide useful control levels in a test in New Jersey, but the conditions during that test were particularly hot and dry due to problems with the fairway irrigation system at the site. However, all the above experiments still need to be repeated during 2007. These observations also need to be validated in multiple locations outside of New Jersey as proposed below.

We also need to search for more virulent and better adapted pathogen strains/species in ABW infested golf courses. Intensive surveys for more effective nematode species/strains have already been conducted on several golf courses in central and northern New Jersey with a history of ABW problems, and have shown *H. bacteriophora* to be the most common species infecting ABW larvae, prepupae, and pupae, with less frequent infections observed for *S. carpocapsae*. The isolates tested so far have not proven to be significantly more virulent than commercial products containing *S. carpocapsae* and *H. bacteriophora*. However, isolating new and more effective nematode species/strains typically requires extensive sampling in many locations, and should therefore be geographically expanded beyond New Jersey as proposed below. It is notable that our project leader for insect pathogenic nematodes, Dr. Koppenhöfer, has collected a new species of nematode, *Steinernema scarabaei*, that looks very promising for control of exotic species of white grubs (Koppenhöfer & Fuzy 2003; Stock & Koppenhöfer 2003).

Cultural practices. Recent studies in MD (Frank & Shrewsbury 2004) are examining the role of conservation strips installed on golf course roughs. This work demonstrates how those habitats can be manipulated to restore predator/prey dynamics and be exploited as an ecologically based control measure for pests like ABW. Other research is identifying some of the key cultural conditions that impact ABW activity (MA), such as the impact of cutting height on larval activity and feeding behavior; this work indicates that larvae feed more on lower-cut grass, regardless of species. Studies on ABW population ecology have been relatively rudimentary until a new study was conducted in 2004-2005 to interpret the association between ABW and the golf course landscape through high-resolution population dynamics, directional movement of adults and overwintering behavior (Peck & Diaz 2005, Diaz 2006). Previous work has established general patterns of the number and timing of generations, and correlated degree-day accumulations and ABW development to create a basic model for management decisions, but this model has never been validated (Vittum, 1980).

Monitoring

Scouting for ABW is essential to proper timing of management decisions. Many factors complicate obtaining ABW population estimates such as nocturnal movement, cryptic habitats, and small size of early instar larvae. The collection of data can be time consuming but is critical to employing proper strategies at the right time, reducing harm to non-target and beneficial organisms, lessening exposure to humans, and decreasing costs associated with chemical treatments.

Many turfgrass managers rely on the use of environmental indicators, namely plant phenology, to time the first pesticide application targeting emerging overwintering adults. The initiation of migration of the adults onto fairways coincides with *Forsythia* spp. full bloom and terminates with the full bloom of flowering dogwood (*Cornus spp.*) and redbud (*Cercis canadensis*). Research has been conducted on developing degree day models for timing overwintering adult emergence and egg laying as well as summer generation stage development (Vittum 1980, Rothwell 2003, Diaz 2006). The threshold temperatures for egg and larval development as well as adult movement was determined in the laboratory to be 13.3^{o}C, however, temperature models have not been validated in the field (Rothwell 2003).

The most recent work on forecasting models is currently being conducted by the Peck lab (NY). Detailed population studies are underway at two sites over three years in order to describe the patterns of variation in various parameters of population ecology at the level of fairway, geographic site and year. Based on data from 2004 and 2005, degree-day models are a better fit than a Julian date model at predicting occurrence of the first generation. Given relatively low variation in R^2 values, using the most convenient base temperature model may be feasible.

Large larvae (instars 4-5) might be a better predictor than callow adults for forecasting maturation of the first generation. Once data from 2006 are analyzed and included, there should be good potential for a degree-day predictive model to be useful in ABW management, such as in scouting, assessing thresholds, decision-making and timing of control applications. As part of those studies, in 2007 a streamlined sampling protocol will be developed to study population development in one of the original sites plus three others across a wider area of NY. This will serve as our initial validation of the model.

Various methods can be used to monitor adult ABW. Flushes with household dishwashing detergents (1–2% soap in water, followed by waiting for 10-15 min) are effective in irritating adults hiding in the soil and thatch during the day to move to the surface. Adult movement onto and within fairways can be determined by pitfall trapping and vacuuming. A modified leaf blower can be used to vacuum adults from fairways but does not effectively pick them up from higher cut turf (Rothwell 2003). Examining the collection of clippings in mower baskets is a good indicator for the presence of adults on greens and collars but a poor indicator on tees and especially fairways due to the greater mowing heights. However, there is generally no correlation between numbers of adults and larval densities, probably due to the adults' ability to move great distances (Rothwell 2003, McGraw and Koppenhöfer pers. observations).

Monitoring for immature stages presently is not a widespread practice but can be a useful practice to assess the efficacy of preventative practices, new chemical products, or to gauge densities in historically infested areas. Some golf courses already choose to allow the 1st generation larvae to feed in lower value turf (i.e. fairways and tees), while only targeting curative controls in higher value turf (greens and collar areas). This approach will not be accepted by many golf courses with the highest aesthetic standards; however, it can be an effective method of assessing population density and the need for control tactics in lower value turf.

Population densities of immature stages can be gauged by placing turf cores on a tray and teasing them apart by hand. Late instar larvae and pupae can readily be seen with the naked eye. Young larvae that are still within the plant can be extracted by placing the turf core fragments into a beaker containing a lukewarm saturated salt water solution. Larvae become irritated by the salt and float to the top of the container as they try to escape. Correct timing of sampling is essential to make this approach useful. If conducted too early, ABW still in the egg stage will not be detected and some of the smaller larvae (L1 and L2) may not be detected due to their small size and their lower probability of emerging from the stems. If conducted too late, when the majority of the larvae are already L4 and L5, unacceptable damage to the turf may occur. The best timing to sample should be when the majority of the larvae are L3.

The development of a more reliable and, ideally also easier and faster, monitoring method for larvae is essential for the replacement of the present reliance on broadcast pyrethroid applications by more IPM-compatible, curative, as-needed spot treatments for ABW management. This would be particularly important for the wider adoption of many of the potential biorational or biological larvicidal products to be investigated in the below proposed research. We therefore propose to develop more reliable predictors for the optimal timing of monitoring for larvae and to optimize the method by testing a variety of irritants and different ways of handling the turf cores.

<u>Demonstration of stakeholder need.</u> In January 2001, a broad-based group of stakeholders interested in golf course IPM in the Northeast met at Rutgers University (NJ). This focus group, part of a project funded by the NSF Center for IPM, included superintendents, university

personnel, environmental and public health advocates, and representatives from the US Golf Association and the US EPA. The group discussed and prioritized key issues in IPM, including (1) alternatives to current chemical pesticides, (2) forecast and sampling protocols for important pests of golf turf, and (3) a comprehensive Web-based treatment of golf turf IPM. For a complete summary of the focus group's priorities refer to: http://northeastipm.org/priority/turf_2001.html. A response to these needs is the recently approved multistate turfgrass regional Hatch research proposal (NE 1025), which emphasizes the study and management of two pests of annual bluegrass, anthracnose disease and annual bluegrass weevil. The NE Regional Hatch project formalizes the collaboration among many scientists and institutions and is a long-term, multifaceted program, but generally does not provide funding to the participating researchers for carrying out its research objectives. Conveniently, in 2006 – 2007, this Regional Hatch project will be conducting a survey of golf course superintendents to determine their awareness of ABW problems and management options, which will be very useful for quantifying changes in practices resulting from this NERIPM project. This NERIPM proposal is a subcomponent of the Hatch proposal: it is a short-term project specific to carrying out the research and extension related components of the insect management mission, which is currently viewed by golf course superintendents to be an emergency situation.

<u>The importance of the work and the consequences if it is not done.</u> In the past, a single perimeter spray of pyrethroids was often sufficient to provide season-long protection of turf from damage by ABW. Disruption of the early season colonization process led to low populations for all three generations of ABW, negating the need for further sprays. As the pyrethroid perimeter spray strategy increasingly fails, we can anticipate a more extended duration of injury caused by ABW through the warm months, from June through August. In addition, we can expect more severe damage at individual golf courses, and an expanding geographical range of golf courses where this pest cannot be controlled. Therefore, if the proposed research on ABW is not conducted, the consequences will likely be (1) widespread resistance development to pyrethroid insecticides, (2) increased economic costs associated with the application of chemical pesticides used to control ABW, (3) loss of revenue in the golf course industry due to widespread turf failure, (4) continued insecticide practices that are inimical to beneficial insects, and (5) the lack of training and implementation of ecologically sound IPM practices. Golf course superintendents throughout the Northeast stand to benefit most directly and in several ways from this research and extension project. We anticipate finding selective chemical and biological tools that will be adequate for managing ABW populations. Adoption of these tools will not only provide relief from the disastrous loss of critical turf in greens, tees, and fairways, but will also broaden the IPM experience of these turf professionals. We expect that superintendents will gain an appreciation for selective insecticides and biologicals if it saves them from losing their critical turf. This may open the door for adoption of environmentally friendlier pest management tools for other turf insect pests. Biologicals/biorationals will have the advantage of being less hazardous to health, the environment, and natural enemies of ABW and other turfgrass insect pests. In addition, nematodes have no reentry interval, and may offer suppression over more than one ABW generation.

Other beneficiaries from this project will be golfers, who will be exposed to fewer residues of more toxic insecticides (Murphy et al. 1996). Of special concern is the potential exposure to OP insecticides, which the superintendents are likely to adopt following pyrethroid failure. Current labels permit public use of treated areas once sprays have dried – an exception to the usual rules of reentry to limit exposure found in agricultural crops. Reduced use of these broad-spectrum and organophosphate insecticides should also help the public interest in protecting nearby aquatic resources – which may nearly always be found as part of the landscape in golf courses.

The historic pattern is of an increasing importance of ABW to golf course turf. Economic damage was first observed in CT, then in the greater New York City metropolitan area, and now encompasses the Northeast Region states south to MD and north to Ontario and Quebec. If the pattern of suspected pyrethroid resistance follows the earlier pattern of spreading economic damage, then golf courses throughout this large region will benefit from this project by finding more sustainable alternatives to their current practices – before disastrous losses due to pyrethroid resistance occurs.

This proposal coordinates turf entomology expertise from the Northeast Region to find solutions to superintendents' problems with ABW. Dr. Koppenhöfer (Rutgers Univ.), an insect pathogenic nematode expert, will coordinating the nematode component. Dr. Cowles (Conn. Agric. Expt. Station) has expertise in dose-response testing to evaluate insecticide performance, will bioassay weevils sent by all participants for pyrethroid resistance with Dr. Alm's Ph.D. student (Univ. RI). Dr. Li is a mycologist and will lead the laboratory-based testing of biocontrol fungi to determine their compatibility with fungicides used in the field. Dr. Peck (Cornell) has expertise in field and population ecology, will lead in phenology analysis, sampling methods and publication of extension literature. All other collaborators have special expertise in working with ABW, and they will be conducting field efficacy tests (all participants except Dr. Peck), and developing web-based resources (Dr. Vittum).

Objectives and Anticipated Impacts:

<u>Research Objectives</u>

1. To identify and develop new chemical and biological control options for suppressing ABW on golf courses.
2. To improve monitoring methods for targeting management of ABW larval stages for control.
3. To determine the geographical extent of pyrethroid resistance in annual bluegrass weevil (includes an Extension component).

<u>Extension Objective</u>

4. To extend best management practices for ABW to golf course superintendents.

<u>Anticipated impacts.</u> Our interdependent research strategy will lead to the improved exchange of information among turfgrass entomologists and golf course superintendents in the Northeast Region. Golf course superintendents will adopt specific alternative pest management practices tested in this project. These improved management practices will include new biological and biorational strategies, and new cultural and ecologically based management techniques. Adoption and implementation of this information by practitioners will result in improved management of ABW on annual bluegrass with reduced pesticide inputs, particularly of broad-spectrum organophosphate and pyrethroid insecticides, and ultimately economic and environmental health benefits across the region. A publication containing BMPs for annual bluegrass will be developed and disseminated to turfgrass managers in the region via this

multistate effort. This and other applied publications developed from this project will be posted on our Website and will be extended through trade magazines. The project participants are leaders in turfgrass entomology in the Northeast, and will be extending the results of this research as part of their regularly scheduled educational seminars and field days. Project impact will be measured with a survey conducted throughout the Northeast region in Year 1 and 4 of the larger multistate Regional Turf Workgroup project.

Approach and Procedures

General information on biological material. Adult ABW for bioassays and to start laboratory colonies will be collected from white pine litter and other overwintering sites on golf courses, and from surfaces of putting greens and collars during the growing season (collected by hand, with vacuums, and from clippings in mower baskets). The adults can be kept for extended periods in plastic containers with annual bluegrass or endophyte-free perennial ryegrass and a general insect diet and bee pollen as a food source (Rothwell 2003). For rearing purposes adult ABW will be released in large clear plastic containers lined with annual bluegrass sod and developmental stages will be harvested as needed from the sod. As a backup for laboratory rearing we can collect 2.5" diameter cores from infested fairways and either extract the stages from them or use the undisturbed cores directly in experiments. Entomopathogenic nematodes, unless obtained as commercial formulations, will be maintained and produced in wax moth larvae following standard procedures. Soil for laboratory bioassays will be pasteurized in an oven.

Objective 1. To identify and develop new chemical and biological control options for suppressing ABW on golf courses.

Subobjective 1. Identification of active entomopathogenic nematodes through field surveys. Insect pathogens isolated from field sites infested with ABW are likely to be better adapted to local conditions and the pest species than other nematodes species/strains. Intensive surveys for ABW pathogens, particularly nematodes, have already been conducted on several golf courses in central and northern New Jersey with a history of ABW problems. However, we need to expand these surveys to areas outside of New Jersey. Thus, any infected ABW stages found during these proposed studies will be shipped to NJ for pathogen isolation, identification, and maintenance (all participants). Any promising pathogen isolates will be included in the ongoing studies in the Koppenhöfer laboratory. Two methods for isolation will be used. First, soil samples will be taken from the surveyed area and baited with wax moth larvae (highly susceptible to most entomopathogenic nematodes) and different ABW life stages. Second, any life stages collected during the survey will be incubated in the laboratory to determine whether they are nematode-infected. Cultures of any entomopathogenic nematodes isolated will be maintained in wax moth larvae (and ABW adults or larvae) and identified to the species level.

Subobjective 2. Determine the virulence to ABW of entomopathogenic nematodes. The virulence of new nematode isolates will be tested following the procedures already being used in the Koppenhöfer laboratory. The isolates will be tested in light- and temperature-controlled incubators in the laboratory (NJ). To simulate fairway conditions we will use 4" diameter clear plastic arenas sealed with weevil-proof mesh covers to allow for optimal light conditions. The bottom will be covered with annual bluegrass sod harvested from large containers in the greenhouse. Temperature and light conditions will simulate the average conditions in the field when the test stages of the spring and summer generations occur. Stages tested will be adults, large larvae (4^{th} to 5^{th} instar), prepupae, pupae, and callow adults (recently emerged from pupa with cuticle yet not hardened). Observations and evaluation timings will range from 1 wk for summer conditions to 1-2 wk for spring conditions. Experimental units will be destructively sampled to determine the number of surviving, dead, and nematode-infected stages. Infected stages will be placed on emergence traps to determine whether the nematodes are able to reproduce in them. Successful nematode reproduction in ABW stages would lead to ABW control, while also improving the persistence of the nematode populations and the likelihood of an impact on following ABW generations.

Subobjective 3. Determine the compatibility of fungal bioinsecticides with commonly used turf fungicides. Two commercially available fungal pathogens, *Metarhizium anisopliae* and *Beauveria bassiana*, need to be evaluated for their potential to control ABW. Like insect pathogenic nematodes, these organisms could reproduce in hosts and lead to long-term reductions in populations. However, the use of fungicides on golf courses could interfere with the establishment or survival of these fungi. Literature on the subject is divided regarding whether fungicide applications interfere significantly with the field population dynamics (Hummel et al. 2002, Clark et al. 1982, Shapiro-Ilan et al. 2002) and effectiveness (Moorhouse et al. 1992, Mietkiewski et al. 1997) of insect pathogenic fungi. There may be upwards of 12 fungicide applications per year on putting greens and collars, with the most commonly used products (chlorothalonil, propiconazole, azoxystrobin, and thiophanate-methyl) each applied more than once during a season (Brian Johnson, Blue Fox Run Country Club, Avon, CT, pers. comm.). Laboratory *in vitro* trials (CT and RI) will determine the EC_{50} of these and other less commonly used fungicides, incorporated in agar, based upon interference with spore germination and hyphal elongation (measured as a change in radial growth; methods of Hsiang et al. 1997). Four decade-step dilutions of technical fungicide diluted in acetone and added to water agar at 50 C, plus the appropriate acetone and water controls, will provide the dose-response series from which to calculate the EC_{50} values, using SAS PROC PROBIT. Small (50 mm diam × 11 mm) Petri dishes will facilitate microscopic evaluation for the spore germination test. While evidence of fungal inhibition may not necessarily indicate that field applications will interfere with commercial fungal biocontrol product performance, demonstrating the lack of suppression at concentrations similar to field use should indicate compatibility between a fungicide and biocontrol fungi. For laboratory *in vivo* trials, cores of grass grown without previous fungicide applications will be artificially infested with last-instar ABW larvae. Fungicides will be applied, and then fungal bioinsecticides later (RI). The effect of fungicides on suppression of biocontrol fungi will then be determined by any decrease in their effectiveness in killing larvae.

Subobjective 4. Determine the field efficacy of biologicals and insecticides. Nematode species/strains and insecticides will be tested against the spring and summer ABW generations in infested golf course fairways, tees, and collar areas of putting greens (all participating states). To avoid nematode contamination of insecticide plots, nematode plots may be isolated from the other treatments, but a chemical control standard (Dylox) will be included with the nematode treatments. Nematode treatments will be based on the most promising nematode species determined in the ongoing studies in the Koppenhöfer laboratory. Larvicidal products may be segregated additionally from the adulticidal products. Insecticides commonly in use (Scimitar, Dylox, and Dursban) will be included in the tests. Materials to be tested will include insect growth regulators (azadirachtin, diflubenzuron, and novaluron), neonicotinoids (imidacloprid, clothianidin), an anthranilic diamide (chlorantraniliprole), fungal pathogens (*Metarhizium anisopliae*, *Beauveria bassiana*) and other products (Bt *tenebrionis*, spinosad,and indoxacarb). Plots (usually 6' × 6' with 1' buffer zone spacing) will be arranged in a randomized complete block design with 4 - 5 replicates per treatment. Treatment timing will depend on our laboratory observations but are likely to be applied against the overwintered adults in late April and against 3rd- to 5th-stage larvae in late May. Treatments will be evaluated 2 wk after the last application. The sampling procedure varies somewhat with each investigator: one method takes 5 cores (4.25" diam × 3" depth) from the center of each plot and searching through them for ABW stages. Nematode populations will be monitored by taking soil samples directly before and after application, at evaluation, and at various times thereafter depending on whether the previous samplings indicate that the nematodes are persisting. The samples will be baited with wax moth larvae following standard procedures and counting the number of nematodes establishing in the larvae.

Objective 2. To improve monitoring methods for targeting management of ABW larval stages for control.

The wider adoption of a curative, treatment-as-needed approach to ABW management, particularly for most of the biorational larvicides we propose to test, will require the development of a more reliable, and ideally easier and faster, method for monitoring larvae. The challenges facing superintendents are (1) when to sample, and (2) how to sample for ABW larvae.

<u>Subobjective 1. Development of a better predictor for timing monitoring for larval populations.</u> We will approach this objective through studies on degree-day models and on plant phenological indicators. The earliest work on degree-day models (Vittum 1980, Rothwell 2003) focused on predicting ABW adult activity. This specific approach, however, has had limited practical value due to considerable variation in microclimate across a single golf course. The detailed assessment of spatial, temporal and geographic variation in population ecology being conducted by the Peck lab (NY) has overcome some of the previous limitations and led to a preliminary degree-day model with a high degree of predictive value for adult and larval developmental stages (Diaz 2006). That research, funded by the USGA Green Section, will culminate in an initial validation in 2007 across five sites in upstate NY. Funds are therefore requested for a final year of validation across the Northeast in 2008. Based on adjusted protocols and an improved model, we will conduct coordinated population surveys over the geographic area where ABW is a pest. Each Co-PI will carry out this work in one site in their state (CT, MA, NJ, NY, PA, RI). By validating this model in a multilocational study across the climate conditions of ABW's range, we will have a geographically robust, sufficiently precise and functionally practical model to forecast insect phenology and improve IPM.

We recognize, however, that the practicality of degree-day models may be limited in golf course habitats, particularly if variation in microclimate cannot be overcome in a generalized predictive model based on degree-days. We suggest that placement of ornamental indicator plants within plantings near greens or fairways may assist superintendents in identifying the correct timing to sample for critically important stages of ABW larvae. Therefore, we will investigate the application of plant phenological indicators as a tool for identifying when to sample for ABW larvae.

Installing the 50 or more plants of interest as phenological indicators near each of our study sites would be impractical. Ironically, then, the most efficient way for us to pinpoint plant phenological indicators for ABW larval monitoring will be to use data loggers and calculation of degree-days at specific sampling sites, which together with observations at these sites on the detection of mid-instar ABW, can be matched with an extensive list of plant phenological events and the known cumulative degree-days when these events occur (Herms 2004). During the first year of the study, 10 cores (2 3/8" diameter x 2 inch depth) will be taken on a weekly basis from fairway sites and extracted with the Berlese funnel method to optimize detection and age classification of L1 to L5 stages. Samples will be collected from one or two golf courses in each of three states (CT, NJ, and RI), for adequate geographical representation of climates within our study area. Data loggers (HOBO Temp, Onset Computer Corp., Bourne, MA) will be placed in small protected enclosures at the base of trees near each target larval sampling sites to collect localized temperature data, and for later processing to determine degree-day accumulations. The earliest detection of L1 and L2 larvae will allow us to focus on making observations of blooming trees or shrubs near the golf course sampling sites in the succeeding few weeks. These observations will then be used to validate the published expected phenological event for the accumulated degree-day coinciding with and matching (Herms 2004) the optimal timing for sampling L3 larvae.

<u>Subobjective 2. Development of an effective monitoring method for larvae.</u> Participants in CT, MA, NJ, and RI will collaborate on this subobjective. Turf cores (2 3/8 inch diameter x 2" depth) will be taken from ABW infested fairway areas during the time when larvae can be expected to be present in spring and summer (preferably mostly in the L2-L4 stages), packed individually in plastic bags inside a cooler, and brought to the laboratory for processing. Treatments will involve submerging the cores into different concentrations of different irritants (table salt, dishwashing detergents, capsaicin, or piperonyl butoxide). The samples will be submerged into 500 ml water or irritant solutions in 750 ml plastic deli containers and stirred after 0, 10, 20, and 30 min. Larvae will be collected from the surface after 5, 10, 20, and 45 min to determine the time required for effective irritation of the larvae to the surface.

As controls, one set of cores will be completely searched through by hand and then submerged into irritant solution (initially saturated table salt solution) and another set will be extracted with modified Berlese funnels. The modified Berlese extraction uses the following procedure: cores in the lab are inverted and placed in cups with a screened bottom, and held inside another cup with glycerin (a preservative) on the bottom. The cups are then placed in a growth chamber for 3-4 days at 30ºC where the heat and desiccation drives larvae out of the core, down through the screen, and into the glycerin. Unlike inspecting soil cores by hand, this method controls for differences in degree of search effort and sorts out small larvae as efficiently as large larvae; two disadvantages are that it does not capture pupae, which cannot move through the soil, and larvae may molt to later instars during the extraction process. The Berlese funnel method has already proven to be more effective in extracting young larvae (Peck laboratory) but is obviously not feasible for adoption by superintendents due to the equipment and time required.

Superintendents will need to be able to determine the larval stages of the extracted larvae so that they can decide how soon they need to treat after sampling if high ABW numbers are detected. Superintendents cannot be expected to be able to measure head capsule size, so an alternative printed guide to distinguishing these larval stages will need to be developed (as part of the extension portion of this project). All this information, including a key to size determination will be incorporated into educational fact sheet.

Objective 3. To determine the geographical extent of pyrethroid resistance in annual bluegrass weevil.

Research component. Preliminary data (Cowles 2005 and 2006) suggest that the field-labeled dosage of λ-cyhalothrin applied to filter paper permits discrimination in 24-h of as few as 40 individual beetles into pyrethroid-susceptible and -resistant populations. Investigators from each participating state will be asked to submit samples of ~50 live adult ABW from at least one cooperating golf course in their state, and from as many golf courses as may wish to participate with this survey. In addition to this broad geographical survey, laboratory tests will be conducted to determine the validity of this discriminating-dosage filter paper assay, and to establish the relationship between more extensive filter paper dose-response contact bioassays and conventional topical application dose-response bioassays. In order to accomplish this, large numbers of ABW adults (~500 per site) will be collected from three sites each of golf courses with suspected pyrethroid resistance and where the populations are believed to still be susceptible (as determined via the quick filter paper assay). Subsets of these adult weevils will then be subjected to dose-response bioassays separately through contact with treated surfaces and with the conventional topical dose-response bioassay (Robertson & Preisler 1992). The resulting LD_{50} and slope parameters will be used to describe the extent to which pyrethroid resistance is emerging as a problem (Cowles and Alm laboratories will conduct these tests).

To determine whether larvae are susceptible or resistant to pyrethroids, late-instar larvae will be field-collected from locations where the adults are known to be pyrethroid-resistant and –susceptible, and compared with respect to their survival in topical dose-response exposure assays (Alm laboratory will conduct these tests).

Extension component. Kits will be made available for superintendents to test weevils for resistance. These kits consist of disposable petri dishes containing a filter paper precisely dosed with λ-cyhalothrin at the standard labeled field dosage or another appropriate discriminating dosage (Mink & Boethel 1992, Zhao & Grafius 1993). The filter paper, shipped wrapped in aluminum foil to protect it from sunlight, is first wetted by the superintendent with 1 ml of water, and then a sample of at least 50 adult weevils are added and the kit is held at room temperature for 2 days. The number of knocked down and dead weevils are then counted to determine the extent to which resistance is a concern. The superintendents asking for these kits will be asked to report their data back to Cowles. Superintendents will be asked the number of applications of pyrethroids in the past year to the sample site, and will be asked their opinion on the adequacy of control at that site when using pyrethroids.

Objective 4. To extend best management practices to golf course superintendents.

All participants will collaborate to develop a best management practices publication for annual bluegrass based on the findings from this multistate project. Publications developed from this project will be distributed by participating states and will be posted on our Website, associated with the NE1025 Website, and any appropriate web sites of collaborating universities (e.g., www.umassturf.org). Members of this project will continue to make research results available through scientific journals, both refereed and non-refereed, extension bulletins, and national and international conferences and workshops. Information to the general public will be disseminated via publications in the popular press, trade magazines, oral and written presentations at workshops and at turf field days. A list of all publications developed by NE1025 members will be updated annually and posted by CT on the NE1025 Website in NIMSS (www.lgu.umd.edu). Research results from this project will be extended to practitioners as they become available via regional workshops throughout the Northeast.

Evaluation Plans

Surveys of golf course superintendents to determine their past experiences with ABW and chemical control practices will be carried out under the auspices of the NE1025 Regional Hatch Project, and will collect information relevant to both anthracnose and ABW management. As we are only asking for 2 years of funding, the full impact of this research and extension program is anticipated to be more relevant at approximately 4 years, the time when a repeat survey of superintendents is anticipated for the NE1025 Project. Indicators for successful impact of this project will be (1) reductions in the use of pyrethroid and organophosphate insecticides, (2) adoption of alternative, less environmentally disruptive products, (3) adoption of cultural practices enabling better ABW management, (4) better monitoring of ABW populations on golf courses, (5) less damage to critical turf, and (6) success in gradual transition to less susceptible varieties or species of grass. Questions specific to measuring these effects will be incorporated in the initial and final surveys.

References

Beard, J. B. 1973. Turfgrass: Science and culture. Prentice Hall, Englewood Cliffs, NJ.
Britton, W. E. 1932. A new pest of lawns. Conn. Agric. Exp. Sta. Bull. 52:25-28.
Cameron, R. S. & N. E. Johnson. 1971. Biology of a species of Hyperodes (Coleoptera: Curculionidae) a pest of turfgrass. Search Agriculture 1(7):1-29.
Clark, R. A., R. A. Casagrande & D. B. Wallace. 1982. Influence of pesticides on Beauveria bassiana, a pathogen of the Colorado potato beetle. Environ. Entomol. 11: 67 – 70.
Dernoeden, P. H. 2000. Creeping bentgrass management: summer stress, weeds and selected maladies. Sleeping Bear Press, Chelsea.
Diaz, M. D. 2006. Population dynamics, phenology and overwintering behavior of the annual bluegrass weevil, *Listronotus maculicollis* Dietz (Coleoptera: Curculionidae), in the golf course landscape. M.S. thesis, Department of Entomology, NYSAES. Cornell University, Geneva, NY. 92 pp.
Emmons, R. D. 2000. Turfgrass science and management, 3rd ed. Delmar, Albany. 528 pp.
Frank, S. D. & P. M. Shrewsbury. 2004. Effect of conservation strips on the abundance and distribution of natural enemies and predation of *Agrotis ipsilon* (Lepidoptera: Noctuidae) on golf course fairways. Environ. Entomol. 33:1662-1672.
Georgis R. & G. O. Poinar, Jr. 1994. Nematodes as bioinsecticides in turf and ornamentals. In: Leslie A. R. (ed.) *Integrated Pest Management for Turfgrass and Ornamentals*. Lewis Publishers, Boca Raton, FL, pp. 477-489.
Grant, J. A & F. S. Rossi. 2005. Evaluation of reduced and non-chemical pest management systems for golf course putting greens. J. Internat. Turfgrass Soc. 10**,** in press.
Grewal, P. S., R.-U. Ehlers & D. I. Shapiro-Ilan (eds.). 2005. Nematodes as Biocontrol Agents. CABI Publishing. Cambridge, MA, 505 pp.
Heller, P. A. & R. Walker. 1997. Suppression of annual bluegrass weevil on a golf course fairway with split applications of chlorpyrifos and experimental formulations, 1996. Arthropod Management Tests 22: 362.
Heller, P. A. & R. Walker. 2003. Annual bluegrass weevil management comparing registered pyrethroids with spinosad, 2002. Arthropod Management Tests 28: G11.
Herms, D. A. 2004. Using degree-days and plant phenology to predict pest activity. In: V. Krischik and J. Davidson, eds. *IPM (Integrated Pest Management) of Midwest Landscapes*, pp. 49 – 59. Minnesota Agricultural Experiment Station Publication SB-07645, 316 pp.
Hsiang, T., L. Yang and W. Barton. 1997. Baseline sensitivity and cross-resistance to demethylation-inhibiting fungicides in Ontario isolates of *Sclerotinia homeocarpa*. Europ. J. Plant Pathol. 103: 409 – 416.
Huff, D. R. 2004. Developing annual bluegrass cultivars for putting greens. USGA Turfgrass and Environmental Research Online 3(9):1-8. (http://usgatero.msu.edu/v03/n09.pdf).
Hummel, R. L., J. F. Walgenbach, M. E. Barbercheck, G. G. Kennedy, G. D. Hoyt & C. Arrellano. 2002. Effects of production practices on soil-borne entomopathogens in western North Carolina vegetable systems. Environ. Entomol. 31: 84 – 91.
Kinoshita M. & S. Yamanaka. 1998. Development and prevalence of entomopathogenic nematodes in Japan. *Japanese Journal of Nematology* 28, 42-45.
Koppenhöfer, A. M. & E. M. Fuzy. 2003. Ecological characterization of *Steinernema scarabaei*, a scarab-adapted entomopathogenic nematode from New Jersey. J. Invert. Pathol. 83: 139 – 148.

LaMondia, J. A., R. S. Cowles & L. Los. 2005. Prevalence and potential impact of soil-dwelling pests and insect pathogenic nematodes in strawberry fields. HortScience 40: 1366 – 1370.

Mietkiewski, R. T., J. K. Pell & S. J. Clark. 1997. Influence of pesticide use on the natural occurrence of entomopathogenic fungi in arable soils in the UK: field and laboratory comparisons. Biocontrol Sci. & Technol. 7: 565 – 575.

Miltner, E. D., G. K. Stahnke, G. J. Rinehart, P. A. Backman & W. J. Johnson. 2004. Establishment of *Poa annua* var. *reptans* from seed under golf course conditions in the Pacific Northwest. Crop Sci. 44:2154-2159.

Mink, J. S. & D. J. Boethel. 1992. Development of a diagnostic technique for monitoring permethrin resistance in soybean looper (Lepidoptera: Noctuidae) larvae. J. Econ. Entomol. 85: 1056 – 1062.

Moorhouse, E. R., A. T. Gillespie, E. K. Sellers & A. K. Charnley. 1992. Influence of fungicides and insecticides on the entomogenous fungus Metarhizium anisopliae, a pathogen of the vine weevil, *Otiorhynchus sulcatus*. Biocontrol Sci. & Technol. 2: 49 – 58.

Murphy, K. C., R. J. Cooper & J. M. Clark. 1996. Volatile and dislodgeable residues following trichlorfon and isazofos application to turfgrass and implications for human exposure. Crop Science 36: 1446 – 1454.

Peck, D. C. & M. Diaz. 2005. Challenges and perspectives for managing the annual bluegrass weevil, p. 23-24. In: D. Gimenez & B. Fitzgerald [eds] Proceedings of the Fourteenth Annual Rutgers Turfgrass Symposium, Rutgers University, New Brunswick (13-14 January). (www.turf.rutgers.edu/research/turfgrasssymposium).

Potter D. A. 1998. Destructive Turfgrass Insects: Biology, Diagnosis, and Control. Ann Arbor Press, Chelsea.

Potter, D. A. & S. K. Braman. 1991. Ecology and management of turfgrass insects. Ann. Rev. Entomol. 36:383-406.

Robertson, J. L. & H. K. Preisler. 1992. Pesticide bioassays with arthropods. CRC Press. Boca Raton. 127 pp.

Rothwell N. L. 2003. Investigation into *Listronotus maculicollis* (Coleoptera: Curculionidae), a pest of highly maintained turfgrass. Ph.D. dissertation, Department of Entomology, University of Massachussetts, Amherst, MA, 170 pp.

Shapiro D. I., D. Gouge & A. M. Koppenhöfer. 2002. Factors affecting field efficacy: analysis of case studies in cotton, turf, and citrus. In: *Entomopathogenic Nematology* (R. Gaugler, Ed.), pp.333-356. CABI Publishing, Wallingford, UK.

Shapiro-Ilan, D. I., C. C. Reilly, M. W. Hotchkiss & B. W. Wood. 2002. The potential for enhanced fungicide resistance in *Beauveria bassiana* through strain discovery and artificial selection. J. Invert. Pathol. 81: 86 – 93.

Smith, K. A. 1994. Control of weevils with entomopathogenic nematodes. In: Smith, K. A. and Hatsukade, M. (eds.) *Control of Insect Pests with Entomopathogenic Nematodes*. Food and Fertilizer Technology Center, Republic of China in Taiwan, pp. 1-13.

Stock, S. P. & Koppenhöfer, A. M. 2003. *Steinernema scarabaei* n. sp. (Rhadbiditida: Steinernematidae), a natural pathogen of scarab beetle larvae (Coleoptera: Scarabaeidae) from New Jersey, U.S.A. Nematol. 5: 191 – 204.

Terry, L. A., D. A. Potter & P. A.Spicer, 1993. Insecticides affect predatory arthropods and predation on Japanese beetle (Coleoptera: Scarabaeidae) eggs and fall armyworm (Lepidoptera: Noctuidae) pupae in turfgrass. J. Econ. Entomol. 86: 871 – 878.

Vittum, P. J. 1980. The biology and ecology of the annual bluegrass weevil, *Hyperodes* sp. near *anthracinus* (Dietz) (Coleoptera: Curculionidae). Cornell University. Ithaca, NY. 117 pp.

Vittum, P. J. 1995. Effect of date of application on efficacy of entomopathogenic nematodes against annual bluegrass weevils, golf course fairway, 1994. Arthropod Management Tests 20: 285.

Vittum, P. J. 1999. Field efficacy of three pyrethroids, alone or in tank mixes with chlorpyrifos or imidacloprid, against annual bluegrass weevil, golf course fairway, 1998. Arthropod Management Test 24: 362.

Vittum, P. J. & N. J. Luce, 2002. Field efficacy of two pyrethroids and spinosad against annual bluegrass weevil, golf course fairway, 2001. Arthropod Management Tests 27: G25.

Vittum, P. J. & N. L. Rothwell. 2000. Field efficacy of bifenthrin, alone or in tank mix with chlorpyrifos, against annual bluegrass weevil on golf course fairway, 1999. Arthropod Management Tests 25: 375.

Vittum, P. J. & H. Tashiro. 1987. Seasonal activity of *Listronotus maculicollis* (Coleoptera: Curculionidae) on annual bluegrass. J. Econ. Entomol. 80:773-778.

Vittum P. J., M. G. Villani & H. Tashiro 1999. Turfgrass insects of the United States and Canada, 2nd edn. Cornell University Press, Ithaca.

Zhao, J. Z. & E. Grafius. 1993. Assessment of different bioassay techniques for resistance monitoring in the diamondback moth (Lepidoptera: Plutellidae). J. Econ. Entomol. 86: 995 – 1000.

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Project Title: Integrated management and resistance management of annual bluegrass weevil on golf course turf

Project Type: Joint Research-Extension

Project Summary:

This multi-state research and extension project will evaluate biological and selective chemical alternatives to pyrethroids for managing annual bluegrass weevil (ABW) in low-cut golf course turf, and will improve the basic biological and ecological understanding of ABW relevant to its management. Over the past ten years golf course superintendents have become dependent on pyrethroids for managing ABW and other insect pests. Recent laboratory tests and field observations demonstrate that populations of annual bluegrass weevil are developing resistance to pyrethroid insecticides – resulting in control failures and severe injury to turf. We will determine the geographical extent of pyrethroid-resistant ABW populations throughout the northeast. Failure of pyrethroids due to insecticide resistance is anticipated to motivate superintendents to accept selective pesticides or biologicals for managing ABW populations, thereby opening the door to managers' acceptance of other IPM practices. Promising candidates for control of ABW include natural product insecticides and insect pathogenic nematodes. A transition away from broad-spectrum insecticides should reduce the risk to workers, golfers, and the environment, and permit greater activity of beneficial generalist predators and insect pathogens, improving ecological stability.

Description of Problem, Background, and Justification:

Turfgrass is a valuable and rapidly expanding component of our urban and rural landscape. Turfgrass covers 12 million ha in the U.S. and includes over 16,000 golf courses. Few turfgrass species tolerate the low mowing heights and low fertility implemented on putting greens, tees, and fairways. Annual bluegrass (*Poa annua*) and bentgrass (*Agrostis* spp.) are well suited to these locations but are prone to many diseases and insect pests. Their pest problems have been controlled with chemical pesticides, but the general public is increasingly concerned about the potential for pesticide exposure, as well as the possibility of ground and surface water contamination. Current practices for managing putting greens and tees are very pesticide intensive, with upwards of six each of insecticide and fungicide sprays per year; this extensive spraying reduces profitability of golf courses. Reliance on broad-spectrum products can also be expected to negatively impact beneficial predator and parasitoid populations. An integrated approach to disease and insect management can help alleviate some of the public concern about pesticide use and benefit the golf industry by increasing the efficiency of pest control efforts.

In January 2001, a broad-based group of stakeholders interested in golf course IPM in the Northeast met at Rutgers University (NJ). This focus group, part of a project funded by the NSF Center for IPM, included superintendents, university personnel, environmental and public health advocates, and representatives from the US Golf Association and the US EPA. The group discussed and prioritized key issues in IPM, including (1) alternatives to current chemical pesticides, (2) forecast and sampling protocols for important pests of golf turf, and (3) a comprehensive Web-based treatment of golf turf IPM. For a complete summary of the focus group's priorities refer to: http://northeastipm.org/priority/turf_2001.html. A response to these needs is the recently approved multistate turfgrass regional Hatch research proposal (NE 1025), which emphasizes the study and management of two pests of annual bluegrass, anthracnose disease and annual bluegrass weevil.

The annual bluegrass weevil (ABW, *Listronotus maculicollis*) causes severe damage on annual bluegrass turf and results in increased pesticide use on golf courses. ABW injury to turfgrass has now been reported from all states of the Northeast (MA, ME, NH, NJ, NY, PA, RI, VT), west into Ontario, north into Quebec, and is expanding south into DE, WV and VA. Young larvae tunnel the stems, causing the central leaf blades to yellow and die, whereas the older larvae feed externally on the crowns, sometimes completely severing the stems from the roots. The damage inflicted by the stem-boring and crown-feeding larvae severely impacts the visual and functional quality of the turf. The 1st generation older larvae, usually active around late May/early June in the NY metropolitan area, normally cause the most severe damage. Damage from the 2nd generation larvae, during early to mid July, is usually less severe and more localized. However, where the 1st generation is inadequately controlled, damage from the 2nd and 3rd generation larvae is exacerbated because annual bluegrass is least vigorous and at a competitive disadvantage during the summer months.

Chemical insecticides have been the only consistent options for ABW control. Until now, the most effective approach has been to preventively spray areas with high adult activity and an ABW history in late April with a pyrethroid or chlorpyrifos (Dursban). Due to their efficacy, superintendents have almost exclusively relied on pyrethroids. In the best-case scenario and in the past, control was achieved with one well-timed perimeter spray. Using this approach, most of the ABW adult population may be intercepted as they enter the low cut turf from their overwintering sites. However, it is not uncommon now for superintendents to make 2-6 insecticide applications per season. A systemic insecticide, imidacloprid (Merit) has poor efficacy against ABW. Organophosphates, principally trichlorfon (Dylox) or chlorpyrifos (Dursban) can be applied as rescue treatments to kill the older larvae once they have started to come out of the stems to feed on the crowns. Because it is difficult to time the application to precisely target the appropriate larval stages, superintendents rarely achieve good control with larvicides, and often repeat these chemical treatments.

Fears of selection for pyrethroid resistant populations were realized in 2005, when golf course superintendents at several golf courses in CT reported lack of control following multiple sprays of λ-cyhalothrin (Scimitar insecticide) directed against a single generation of ABW adults. After 6 days of continual exposure to filter paper treated at the field-labeled dosage with λ-cyhalothrin, ABW adults collected from golf courses in Avon and West Hartford, CT, only experienced 50% mortality of weevils. Populations where pyrethroids had been used less intensively experienced 100% mortality at 48 h exposure to the field dosage. Pyrethroid resistance in adult ABW may have become a reality, but the full implications for pest management need further investigation.

This proposal coordinates turf entomology expertise from the Northeast Region to find solutions to superintendents' problems with ABW. Dr. Koppenhöfer (Rutgers Univ.), an insect pathogenic nematode expert, will coordinate the nematode component. Dr. Cowles (Conn. Agric. Expt. Station) has expertise in dose-response testing to evaluate insecticide performance, and will bioassay weevils sent by all participants for pyrethroid resistance with Dr. Alm's Ph.D. student (Univ. RI). Dr. Li is a mycologist and will lead the laboratory-based testing of biocontrol fungi to determine their compatibility with fungicides used in the field. Dr. Peck (Cornell) has expertise in field and population ecology, will lead in phenology analysis, sampling methods and publication of extension literature. All other collaborators have special expertise in working with ABW, and they will be conducting field efficacy tests (all participants except Dr. Peck), and developing web-based resources (Dr. Vittum).

Project Objectives and Antipated Outcomes

Research Objectives

1. To identify and develop new chemical and biological control options for suppressing ABW on golf courses.
   Subobjective 1. Identification of active entomopathogenic nematodes through field surveys.
   Subobjective 2. Determine the virulence to ABW of entomopathogenic nematodes.
   Subobjective 3. Determine the compatibility of fungal bioinsecticides with commonly used turf fungicides.
   Subobjective 4. Determine the field efficacy of biologicals and insecticides.
2. To improve monitoring methods for targeting management of ABW larval stages for control.
   Subobjective 1. Development of a better predictor for timing monitoring for larval populations.
   Subobjective 2. Development of an effective monitoring method for larvae.
3. To determine the geographical extent of pyrethroid resistance in annual bluegrass weevil

Extension Objective

4. To extend best management practices for ABW to golf course superintendents.

Anticipated impacts. Our interdependent research strategy will lead to the improved exchange of information among turfgrass entomologists and golf course superintendents in the Northeast Region. Golf course superintendents will adopt specific alternative pest management practices tested in this project. These improved management practices will include new biological and biorational strategies, and new cultural and ecologically based management techniques. Adoption and implementation of this information by practitioners will result in improved management of ABW on annual bluegrass with reduced pesticide inputs, particularly of broad-spectrum organophosphate and pyrethroid insecticides, and ultimately economic and environmental health benefits across the region. A publication containing BMPs for annual bluegrass will be developed and disseminated to turfgrass managers in the region via this multistate effort. This and other applied publications developed from this project will be posted on our Website and will be extended through trade magazines. The project participants are leaders in turfgrass entomology in the Northeast, and will be extending the results of this research as part of their regularly scheduled educational seminars and field days. Project impact will be measured with a survey conducted throughout the Northeast region in Year 1 and 4 of the larger multistate Regional Turf Workgroup project.