Biological Control: at work in Massachusetts
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At UMASS, several members of the Entomology Dept., including myself, Joe Elkinton, Ron Prokopy, Dave Ferro and Anne Averill, are working on ways to create pest controls based less on use of pesticides and more on use of natural enemies. The three examples mentioned above, come from my lab.

A wetlands restoration project is planned for part of the Concord River: local Conservation Commission representatives discuss plans with federal and state wildlife agents. The discussion focuses on restoring water flow to a eutrophied bay cut off from the main channel by a road with inadequate physical structures for water passage. Engineers plan the solution. Then biologists shift the planning meeting to the restoration goals – what plants are intended to grow in the wetlands and what contributions each will make to fish, waterfowl and other components of the system. Then, someone asks “what are we going to do eggs. These dry pond basins are often called “vernal pools”. In our area, vernal pools generally fill in the autumn and remain full throughout the winter and spring, drying up again in the summer. After the adults mate, the eggs are deposited and guarded by the females until the ponds fill with water. Within days, the eggs hatch and the larvae develop slowly over the winter and await the springtime smorgasbord when the food supply is virtually unlimited. Prior to

Dense populations of Galerucella larvae defoliating purple loosestrife

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the ponds drying up in the summer, the juvenile salamanders emerge from the ponds and disperse into the uplands.

While this autumn breeding adaptation may seem strategic, it is not without risk. In particular, variable autumn rains can cause repeated filling and drying of pools, resulting in egg and larval mortality from dessication. Another hazard could be the ponds filling too early in the autumn before the adults have a chance to mate and lay eggs. In our area, below freezing temperatures early in the season can cause high mortality or, in very shallow ponds, can result in the complete freezing of the water column and mortality of all larvae. Indeed, autumn weather patterns may be an important factor in limiting the northern distribution of the species to southern New England.

For these and other reasons, the marbled salamander is rare in the northeast. Consequently, the Massachusetts Division of Fisheries and Wildlife (MDFW) has listed the species as threatened under the Massachusetts Endangered Species Act. In addition to these natural environmental hazards, there are some major human-based threats to the species’ viability. First, because of increasing urban and residential development of forestland, the marbled salamander habitat is increasingly threatened. The ponds themselves are sometimes protected from development by the state’s wetland laws, but only after they have been certified as vernal pools by the state’s Natural Heritage and Endangered Species Program (NHESP). Thus, many uncertified pools are destroyed during development. Perhaps the most significant threat to habitat is the loss and degradation of the upland forestland that their life cycle depends on. Here, little consideration is given to the needs of these small, forest floor vertebrates. Unfortunately, there is virtually nothing known about the extent of upland habitat use or the species’ habitat preferences. Yet this information is critical for informed land use decisions involving uplands around vernal pools.

Increasing development means more roads. Roads fragment the upland forest into smaller patches and alter the microclimate along their edges, affecting the loss of interior forest conditions that this species undoubtedly prefers. Perhaps more importantly, roads serve as an impediment to movement and can be a major source of direct mortality. Roads may indeed be the greatest threat to this species’ viability because of the critical role that movement of individuals among populations (ponds) plays in this species’ population dynamics.

As you might suspect, each separate vernal pool probably does not support a viable population of marbled salamanders—one that will likely persist for the next 100 years or so. The population associated with a single pond is simply too small in most cases to persist over the long run with out the interaction of individuals from nearby ponds. Indeed, this is true of most small populations; they are subject to the random vagaries of the environment, fluctuations in their own population processes, and the adverse genetic consequences of having too few individuals. Populations that are spatially structured into many small populations, each of which is not viable, and that depend on occasional movement of individuals among populations to rescue declining ones and recolonize sites that have suffered local extinctions, are referred to as "metapopulations". In such populations, movement of individuals among local populations is the key to the species’ viability. Any factors that interrupt the flow of individuals may potentially affect the viability of the metapopulation.

Unfortunately, little is known about the metapopulation dynamics of marbled salamanders or the factors that control these dynamics. To better understand these and other things and inform conservation decisions, Scott Jackson, myself and my graduate students; Chris Jenkins and Lloyd Gamble, initiated a study in 1998, in South Hadley, in cooperation with NHESP. We identified a cluster of fourteen vernal pools, nine of which currently support marbled salamander populations. The ponds are distributed over a few square kilometers such that there is a wide range of distances between ponds. There are several forest roads and a powerline corridor bisecting the study area. Several houses exist on the perimeter of the study area and a portion of the area is being developed for residential purposes. This setting provides an ideal opportunity for study. To date, we have installed drift fences around eleven of the fourteen ponds and have collected information on the movement of all individuals into and out of each pond. Based on this information, we have quantified local population sizes and the timing and orientation of adult and juvenile movements, as well as habitat use in the vicinity of the ponds. Our preliminary data indicates dramatic variations in local population sizes. While it is too early to tell for certain, it appears that pond hydrology may be the key to explaining these differences. In addition, there appears to be strong orientation in the movement patterns of adults to and from ponds, perhaps indicating a selection for certain upland environments in favor of others, but the juveniles appear to disperse from the ponds in a random fashion. More importantly, we have documented the movement of juveniles between ponds. As expected, the frequency of pond-to-pond movement decreases exponentially with increased distance between ponds.

We are beginning our third year of study and are excited about the potential for this to shed light on many questions associated with the ecology and conservation of this threatened species. In particular, we hope to be able to quantify the spatial structure of this metapopulation and to explain the factors that influence the metapopulation dynamics. Most importantly, we hope to provide land managers with scientifically credible information on which to base conservation decisions for this species.
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to get rid of all the loosestrife?” A flower grower moves along the benches in his lily house, cutting stems with partly open buds to ship to the Boston Flower market that day. All is going well, long stems, good color, beautifully formed flowers and buds, until he goes into the third of his seven greenhouses. As he continues to harvest cut flower stems, he finds he has to throw away a flower stem here, another one there, three on the back bench. At the end of the hour’s harvest, 15% of his flower crop lies in the reject basket, blossoms that can be sold only by feeding by a tiny insect has distorted the petals. The grower consults with his pest manager and asks, “What are we going to do about western flower thrips? It is getting worse each year.”

Purple loosestrife is an invasive exotic plant that has filled up wetlands from Massachusetts to Seattle, Washington. Spraying the plant with herbicides is ineffective (roots survive) and damaging to the very native plants we do want growing in these wetlands. Also, applying herbicides to water is objectionable in itself. UMASS is participating in a nationwide project to use plant-eating insects imported from Europe to suppress this plant. The project was initiated by the federal Fish and Wildlife Service and much of the work was done by Dr. Bernd Blossey of Cornell University. Currently, several species of beetles that feed on the leaves or roots have been found and tested for their host ranges (to ensure their feeding is narrowly focused and not dangerous to native plants). These beetles are being released at sites in both eastern and western MA and at one set of sites, my lab is taking data annually to document the decline of the pest loosestrife plants and the increase we expect to see in beneficial plants such as cattail. In some other states, where releases were made a bit earlier, there is already clear evidence of such restoration. And, the solution is permanent. Once these biological control agents reach all our wetlands, they will persist and declines in the weed will be sustained year after year because the insect will breed and sustain their populations.

Robert Blaksley, a lawyer by day and suburban gardener by evening and weekend, cuts off broccoli heads from his plants. Size is good, color nice. But wait, green worms again! He prefers not to spray his plants with pesticides (his wife won’t eat them if he does), but if there are caterpillars on the plants, his kids won’t even try to eat their vegetables. He asks a friend at his gardening club, “Any ideas on how I can control those green worms on broccoli?”

“Greenworms” on broccoli are larvae of the imported cabbageworm, an invasive insect that damages all cole crops (cabbage, collards, etc.). To reduce the numbers of this pest, I introduced a specialized parasite of the pest from China in the 1980s. This parasite, a tiny braconid wasp called Cotesia rubecula, lays its eggs inside the caterpillars while they are so small they are very hard to see. The larvae of the wasp grow inside the caterpillars and kill them while they are still small. This prevents an enormous amount of damage, as well as suppressing the number of the butterflies in the next generation. Currently we have this useful insect established in the Connecticut River Valley. Further work to spread it throughout the state is needed. These wasps cannot eliminate the pest, but they will make them scarcer and make it easier for both gardeners and vegetable farmers to grow nice broccoli.

Answers: Galerucella beetles, A. cucumeris mites, and Cotesia rubecula parasites. These are just a few biological control agents busy at work in Massachusetts helping real people with their problems thanks to work done at the University of Massachusetts and elsewhere.

The problems we have with pests such as invasive plants and insects or mites that damage our crops, are problems of biology and need biological, not chemical or mechanical solutions. Biological control is the use of natural enemies to suppress pests. As we call such efforts to use biology to solve pest problems. It works with the forces that shape population growth, rather than trying to use chemical pesticides to impose a solution. Pesticide use, while needed at times for some problems, often creates new problems – of unwanted residues, worker exposure, or resistant pests that are not susceptible anymore to our pesticides.

Western flower thrips, while not exactly exotic in the US (it is native to California) is a newcomer to the East. It spread worldwide on plants moved commercially among greenhouses in the 1980s. Now it is the dominant insect pest for MA flower growers, for all crops except poinsettia (which is a very poor host for this insect). Damage comes about because thrips damage the buds and when these open, the flower is spotted or twisted and has to be thrown away. This pest is hard to control, even if pesticides are applied frequently, because it lives between layers of petals and leaves and is not easily contacted by the spray. One bedding plant grower working with us in 2000 year trials reported having made 9 pesticide applications over the course of the 12 week crop in 1999 to suppress this pest. Unfortunately, besides being expensive, such intensive pesticide use also selects for pesticide resistant populations. Can we suppress this species without so many pesticides? We think we can, by combining releases of several predatory mites (mainly Amblyseius cucumeris, sold commercially by several companies) and one or two applications of pesticides such as spinosad, which seems to be less damaging to mites than other materials. This spring, we have trials underway both at newly built experimental greenhouses at UMASS (our Biocontrol Floriculture Ed Center; come and visit!) and in the greenhouses of commercial bedding plant growers. In a few years, with persistent work, we will be able to advise growers on how to suppress western flower thrips with something more sustainable than simply frequently applying pesticides.

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A new management approach that, in theory, can delay the spread of resistance genes is to set aside untreated “refuges” for pests that are susceptible to a pesticide treatment (or other control strategy). The basic idea is that insects from these refuges will spread out over a treated field and mate with any newly resistant individuals that have arisen there. The offspring of these susceptible-resistant crosses will still be susceptible to the treatment, whereas offspring from resistant parents will be resistant. This only works genetically if the resistance gene is recessive, so that offspring of a susceptible-resistant cross are susceptible. Fortunately, most resistance genes that have evolved naturally in pest populations have turned out to be recessive. Even if these offspring are partially resistant, high doses of insecticide can make them effectively susceptible. It seems counterintuitive, if not ridiculous to protect the very pests that we are trying to control, but in a well-designed system, the short-term losses to susceptible pests in the refuges will be much less than the longer-term losses to resistant pests in the entire field. The plan is to design the size and placement of the refuges so that both the short and long-term losses will be minimized.

At the heart of the refuge strategy, and of our study of Colorado potato beetles, is that beetles must move from the refuges into the treated areas and mate with any resistant survivors. How far beetles move will determine the pattern in which refuge sites should be planted. If the beetles range widely and orient well towards cultivated fields, then a large refuge separate from the treated area will be sufficient. If they do not move as far, many smaller refuge sites will be needed within treated fields. We are taking two approaches to measure movement of Colorado potato beetles in Massachusetts potato fields; an indirect method using resistance itself as a marker, and a direct method using microwave reflector tags to follow individuals in the field.

The pesticide most commonly used to control Colorado potato beetle is familiar to anyone who has had to deal recently with fleas on their pets. Imidacloprid (manufactured by Bayer) is found in Advantage® flea control and since its introduction five years ago, it is the most widely used potato beetle treatment. Beetle populations partially resistant to imidacloprid have recently been found in Massachusetts. The variation in resistance now present offers a tremendous opportunity to measure movement. We may not be able to mark thousands of beetles and recapture them reliably, but we can use resistance itself as a marker. By introducing resistant and susceptible beetles on opposite sides of a field and treating only the side with resistant beetles with imidacloprid, we create adjacent populations that are very different in their degree of resistance. We then walk the length of the field collecting clutches of eggs, and assay the resistance of hatched larvae in the lab. The sharpness of the transition from susceptible to resistant larvae gives us information about the rate of movement of the parents. A gradual shift from mostly resistant to mostly susceptible larvae shows that beetles move quite a bit. If beetles do not move far, there will be a sharp shift in the proportion of resistant larvae across the field. The actual movement rates can be obtained statistically.
In most mammalian species, eggs (oocytes) are ovulated while arrested prior to completion of maturation. They remain arrested until the time of fertilization, when the sperm unlocks the developmental program, which culminates in the birth of live young. The sperm signals the initiation of development in all species studied to date including sea urchins, frogs, and mammals, by inducing a change in the intracellular concentration of calcium. In mammals, the changes in calcium levels occur as oscillations for two to twenty hours. These oscillations are responsible for triggering specific changes in proteins in the oocyte allowing the oocyte to become fully mature. As a result, chromosomes in the sperm combine with those of the oocyte and development of the embryo begins.

The signal pathway by which the sperm triggers the calcium oscillations remains to be determined. It was initially suggested that a sperm receptor might be present on the surface of the oocyte and that, upon sperm binding, a signaling cascade that leads to calcium release is activated. However, there is no direct evidence for a sperm-surface receptor on the surface of mammalian oocytes capable of stimulating calcium release. The second hypothesis proposes that after fusion of the sperm with the oocyte, the sperm introduces a factor that triggers calcium oscillations by interacting with a presently unknown target(s). Evidence for this hypothesis comes from our work that shows that microinjection of sperm extracts into oocytes induces calcium oscillations similar to those stimulated by the sperm during fertilization.

As a result, the oocytes begin parthenogenetic (without participation of the sperm) development by dividing to the final stage prior to implantation. The active component(s) of these extracts is highly conserved between species since injection of pig sperm extracts elicits calcium oscillations not only in oocytes of other mammalian species but also in frog oocytes.

Calcium oscillations in mammalian oocytes are essential for normal development of the embryo. They may also play a very important role in ensuring that only developmentally competent oocytes are fertilized. For example, injection of the sperm factor into oocytes ovulated eight hours earlier (old oocytes) stimulated a group of enzymes known to be involved in cell disassembly and, subsequently, induced death of the oocytes by fragmentation. This response was in marked contrast with the normal activation induced by sperm factor in young oocytes. Induction of a single rise in calcium was without effect. Thus, we speculate that in the case of aged oocytes, which are less developmentally competent, sperm-induced calcium oscillations prevent early embryonic development and decrease the chances of implantation of a compromised embryo.

In summary, our data revealed that release of calcium induced by the sperm at fertilization can induce embryo development or death according to the quality and/or age of the oocyte. Identification and isolation of this factor may have important practical applications such as increasing the efficiency of assisted reproductive technologies including in vitro fertilization and cloning techniques in animals. In addition, it may also allow the elucidation of the molecular changes that render old oocytes susceptible to cell death by fragmentation. The latter may be important in developing methods to reverse infertility associated with increasing age in women and animals.
The American chestnut restoration will be the first restoration of a wild tree species ever attempted. Research underway at UMass is preparing the way for several aspects of the restoration.

In colonial times, roughly ten percent of all trees in Massachusetts were American chestnuts. Mountain ridges were often pure chestnut. In early summer, when their creamy white flowers were in bloom, the ridges looked like they were covered with snow. With white pine and yellow poplar, American chestnuts were the dominant over-story tree, growing to a height of 100 feet or more. The trunks were commonly five feet in diameter. Unlike oak, they provided a dependable bounty of nuts every year, which were eaten by both wildlife and people. The wood was straight-grained, easy to work, and as rot resistant as redwood.

Release of spores from an infected trunk

Only a few people alive today have seen mature American chestnut trees in Massachusetts, however. By the 1920s most mature chestnut tree trunks in the Commonwealth were dead, killed by a disease called chestnut blight. The causal agent, a fungus named *Cryphonectria parasitica* was probably imported with breeding stocks of Asian chestnut around the turn of the century. It can cause non-lethal cankers in the bark of other trees such as post and scarlet oak, but it girdles and kills the vascular cambium of American chestnut.

In Massachusetts, American chestnut is still frequently found in forests and especially on long-abandoned pastureland near ridge tops. The root systems are not killed by the blight, and can send up new shoots as the old stems die. The stems rarely become larger than three inches in diameter before the blight enters the bark through wounds. Once infected, a three-inch stem will usually be dead within two years.

Since different chestnut species freely interbreed, it may be possible to bring resistance from the Chinese and Japanese chestnuts into the American gene pool. Such an effort has been underway for the last fifteen years, primarily under the auspices of the American Chestnut Foundation. Several crosses between American and Chinese chestnut have been made.

After the third backcross and an intercross step, the trees should be essentially pure American, breed true to type, and their offspring should carry enough resistance genes to grow and reproduce in the wild. Each of these requirements can be facilitated and enhanced by the use of genetic markers. Our lab is contributing to these objectives through the development of markers based on DNA sequences from chestnut.

Advanced breeding lines are being backcrossed repeatedly to American chestnuts in six states. This year Massachusetts will join the effort. Volunteers across the state are needed to find flowering trees and pollinate them with resistant pollen.

It will be important to select pure American trees for the breeding program. This may be somewhat of a challenge in Massachusetts, where hybrids between American and the Asian species have been planted over the years. Work underway in our laboratory may provide a DNA-based method for detecting such hybrids and their offspring.

American chestnuts require full sun to establish themselves as canopy trees, so clear-cuts and reclaimed strip mines could potentially be used as restoration sites. This spring, in cooperation with Pennsylvania’s Game Commission and Department of Environmental Protection, mine owners, and a waste management company called Bio Gro, Timothy McKechnie will plant 240 American chestnuts on three reclaimed Pennsylvania strip mines. This study will primarily seek to evaluate the use of biosolids (sewage sludge) in these stressful environments.

Since stress can affect the level of disease resistance in chestnut, it may be necessary to use some form of biocontrol to protect even genetically resistant trees during establishment on stressful sites. Early work at UMass was done by Dr. Mark S. Mount, using a fungal antagonist to blight. Such work is being continued by Dr. Terry Tattar and graduate student Patricia Groome using Bacillus megaterium, a bacterium normally found in soil.

One objective of any species restoration is to establish populations capable of continued evolutionary adaptation. Toward this end, Dr. Bernatzky has been studying the genetic diversity at the population level of the species, again using molecular markers, in order to establish a baseline of natural variation. The chestnut breeding program will seek to incorporate a level of genetic variation that mirrors the natural variation found in surviving wild chestnuts.
The other approach to measuring movement is to tag and follow individual beetles. We take advantage of recent developments in downhill skiing safety to make this needle-in-haystack approach feasible. Avalanche victims buried in the snow can be found quickly using microwave reflector tags attached to their ski boots. These tags are extremely light and do not emit a battery-powered signal. Rather, they take a 9 mhz microwave signal from a transmitter-receiver device and reflect it at 18 mhz. These tags are small enough to be attached to individual Colorado potato beetles and allows us to find them even in dense vegetation. It has been used to track other species of beetles in Sweden and New Zealand, as well as caterpillars and moths in Alberta, Canada. The tags do not reflect a uniquely identifying signal, so we also mark each beetle with a unique pattern by making tiny punctures in their wing. The spots formed as the punctures heal are permanent as can be seen in the picture to the right. We will measure movement rates from the paths of individual beetles.

We will use these measures of movement to design the size and spacing of the untreated refuges that best slows the spread of resistance while minimizing crop losses. Unfortunately, resistance to imidacloprid is already too widespread for us to save it as an effective treatment. However, the refuge designs we develop can be used to slow resistance to new pest control treatments that are being developed, including new genetically engineered plants that express transgenic insecticides. We’ll never be able to stop the evolution of resistance entirely, but postponing it for even a few years can provide substantial economic benefits.
Excerpts From: The Massachusetts Collegian, Thursday, May 22, 1941.
Professor W.W. Chenoweth, Founder of Horticultural Management Department, Retires This Year

Twenty-seven years ago this fall with six gall plates and four or five dollars worth of equipment set up in the basement of a small wooden building north of the Physics Building, Professor Walter W. Chenoweth, conducted the first laboratory work in Horticultural Manufactures at Massachusetts State College.

Professor Chenoweth came to the college as instructor in pomology in 1912. In less than six months he became a convert to Professor Frank A. Waugh’s dream of a type of work, which would enable growers to market their culls and poor grades of fruit and vegetables through canning and the manufacture of fruits and vegetables into usable products. Pioneering work was carried on in the basement of Wilder Hall during the years 1913 and 1914, and in the fall of 1914 a laboratory course in horticultural manufactures was offered to the senior majors in pomology. This was the first course of its type to be established in this country.

“I had about fifteen students in two sections,” said Professor Chenoweth; “we were limited in everything—knowledge, material, equipment. The first courses offered only six or eight exercises, and I taught them all I knew at the time. The only sources of information, except on canning, were homemakers’ bulletins and cookbooks, and they weren’t very illuminating on the whys and wherefores.”

“It was a new and fascinating work for men,” he said. “I had to put a lock on the door and keep them out of the laboratory, or the boys would have used up all the sugar we could buy!”

Because of this study and experience, the college was in a position to put on an extensive state-wide program in food preservation during the two years following the entrance of the United States into the World War, and in 1918 a petition was granted authorizing the establishment of a new Department of horticultural manufactures—the first of its kind in the country. Walter W. Chenoweth, who had done the pioneering work, was appointed head of the new department.

The almost entire lack of reliable literature made it necessary for the department to develop and perfect its own methods of procedure during the first half-dozen years or more.