ABSTRACT

New paradigms are needed to replace traditional and often dangerous methods of biocontrol. This article explains why native biocontrols have not been found for many non-native invasive organisms and offers guidelines on finding native biocontrols. The focus is non-native invasive plants since my research has been on *Ailanthus altissima*, Tree-of-Heaven. However, the principles set down here should apply to all taxa of invasive non-native organisms.

A NEW PARADIGM FOR LOCATING NATIVE BIOCONTROLS FOR NON-NATIVE INVASIVE PLANTS

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The ability to locate native biocontrols for invasive non-native species is the "Holy Grail" of pest control. The purpose of this article is to discuss why we have been unable to do so and why organisms become invasive if there are native biocontrols available. Since my area is plants, I will discuss this in relationship to the research I did at the University of Maryland ending in 2008 and expanded on in Lancaster County, PA during the spring and summer of 2010.

The question of, "If there are native biocontrols available, why did the plant become invasive and out of control?" is the key in understanding how to find and develop native biocontrols for these pest/weed plants. The issue comes down to five factors; time, space, density, local environmental conditions and the number of family members of the invasive species in an ecosystem. Each is critical in understanding why native biocontrols have not naturally worked for some invasive plants and in developing native biocontrols for these invasive organisms.

First and probably most important is space. A biocontrol and an invasive plant need to occupy the same physical space. If a plant is introduced in one location and the biocontrol is not in that same space, then the plant has an opportunity to establish itself before the biocontrol and the pest plant meet. In my research on *Ailanthus altissima* (Tree-of -Heaven), the plant was introduced in Philadelphia in 1784 (Hu 1979).

One potential biocontrol, *Atteva punctella* (Ailanthus web worm), was on *Simarouba glauca* (Paradise Tree) in Florida and other Simbouracae species throughout the extreme southern parts of the United States and the tropical areas of the Americas. This physical distance allowed Ailanthus time to establish itself in North America before meeting a potential biocontrol. Eventually, due to the aggressive nature of Ailanthus, extensive planting of Ailanthus and the apparent "wanderlust" of *A. punctella*, the two met. By that time, though, the density and geographic distribution of *A. altissima* was too great for *A. punctella* to act as an effective biocontrol and the size of the adult trees was too great for *A. punctella* to consume enough foliage to harm specific trees.

Secondly, time is an important consideration. Time in this case means seasonal time. Two plants may have the same or similar processes such as budding or flowering, but in a different part of the seasonal cycle. This means that an insect or disease that attacks a plant in March may not be available to attack an invasive relative in May. For instance, if a flower herbivore eats a flower from a plant that blooms in March, that same insect may be an effective biocontrol of a plant that blooms in late April, but that insect may be in a different part of its life cycle by then. If that insect can be raised for release in late April, perhaps it can be effective in controlling that plant. Maybe also, insects released in late April will adapt to a late April maturation and become an effective long term biocontrol.

Thirdly, density is important in two ways. A pathogen or insect needs a certain density of itself and its energy source to be effective. If 100 insects/hectare is ineffective, perhaps 1,000,000 insects/hectare may be effective as a control. In other words, there needs to be the requisite number of insects to be effective. This also applies to pathogens in the same way.

Basically an area that is lightly infested/infected needs to be taken up to saturation levels to be effective.

The same applies to the intended host. Ten plants in a hectare may not be enough plants to cause an insect or pathogen to effectively locate or dense enough for an effective infestation/infection. However, 100 plants/hectare may be enough. *A. altissima* has asexual clones from parent trees that are attached to the parent trees through the roots. Infection can spread through the roots and insects can locate a stand due to this trait of dense interconnected stands of trees.

A fourth and very important consideration which I am just beginning to understand is local environmental conditions and not only seasonal cycles, but both short term and long term weather patterns. What I am seeing is that pathogenic fungi may require wetter conditions, higher amounts of available water (Aw), to be effective as a biocontrol even though they may exist in drier conditions. Insects too may require certain local geographic and weather conditions to be effective biocontrols, even though able to tolerate less than ideal conditions. This is only supposition since I have not had enough time to thoroughly research it, but it appears that the various pathogenic fungi such as *Fusarium oxysporum* require wet years or damp locations to thrive. Two aspects I am looking at are the ability of fungi to thrive and the ability of plants to efficiently transport a fungus through its vascular cambium may be dependent on the amount of water immediately available either through rainfall or location such as field edges and rock falls. My experience has been that plant disease and death is in places where the available moisture is higher than drier nearby conditions. Near Gettysburg, PA a large stand of Ailanthus is dying. It is in an area that has relatively high moisture. This is evidenced by being in a shaded area with mosses and ferns around the roots of the Ailanthus trees. The same apparently holds true at the site I investigated near Urbana, MD. The trees at this site which are in the woods edge and in a wooded corner are either dead or dying. The ones nearby, in the open surrounding a power substation show no signs of disease, even though they have been fed on by *A. punctella*, which may the carrier of the pathogenic fungi.

I am not an entomologist, so cannot say much about the conditions a specific insect requires to thrive. However, what is apparent is that for an insect to be an effective carrier of a pathogen requires the conditions to be right for the insect and for the pathogen or disease the insect is transmitting from one plant to another or be right for the insect subsequently at a later time right for the pathogen. In the field I have seen instances of insect damage in the form of herbivory, but no signs of disease. Within 100 yards, I saw extensive plant death in a wooded area and evidence of the same insect, *A. punctella*.

In essence, wet years may prove more effective at controlling plants with a fungal pathogen than dry ones. Or moderate years with wet times or damp mornings may be the best conditions. Therefore, timing of an infection or infestation may be essential for effective biocontrols.

At the same time, there may be a window of plant maturity or seasonal growth that is required for a plant or disease to be effective. Juvenile plants may be susceptible to disease when temperature and moisture conditions are right. Whereas, adult plants may not have the window or conditions necessary to be infected or consumed. Also, the adults may have too much mass such as in leaf mass or trunk mass to be effectively controlled. At the same time, in the case of *A. altissima*, tree gender may play an important role in whether a specific plant is attacked, eaten or infected. This requires further study as it is commonly believed that male and female Ailanthus plants have different odors and may have different nutritional values (Cornelissen and Stiling 2005).

The fifth factor is the number and degree of relatedness of members of the taxa or family an invasive plant to that specific invasive plant species. *A. punctella* is a herbivore of the Simbouracae family in the United States. It is a specialist to the family and a generalist within the family (Powell, et. al. 1973). It was able to adapt from one food source to another because it is a generalist within the Simbouracae family, feeding on several different species. The addition of *A. altissima* as a food source was easy since it was already feeding on other members within the family. This brings up another point. The time between the meeting of a potential biocontrol with a new potential food source and the actual use of the food source may take many years. The biocontrol, if it follows the normal sigmoidal pattern of introduction, adaptation, exponential growth and balance, will allow the new potential host to establish itself and become invasive before the potential biocontrol is able to act as a biocontrol.

What does this mean for finding and developing native biocontrols? First, look at native relatives of an invasive plant for herbivores and pathogens. Do this in the short term, one season or set of environmental conditions and in the long term over many years and environmental conditions. At the same time look at how local environmental conditions affect native and non-native plants. This may give a clue to control and how to alter local conditions so a biocontrol may be effective or help in developing different methods for different conditions. This may involve removing brush or allowing a field to grow for a couple years instead of being mowed.

Once potential biocontrols are located, they need to be tested for food preference. Will a native herbivore prefer a non-native over a native? Is a pathogen going to hurt a native plant more than a non-native? Historically, non-native plants are preferred by native herbivores over native in a reverse of biotic resistance due to the lack of coevolved defenses that non-natives have and the coevolved defenses natives developed. This was evident in the work of controlling Eurasian water milfoil *Myriophyllum spicatum* and the native insect herbivore *Euhrychiopsis lecontei* (Blossey et. al. 2002). I am unsure if diseases are similar to insects in their specificity and preference for non-coevolved hosts. However disease introduction needs to be approached with especial caution due the extreme damage a disease can do to a non-target species. As a footnote here, apparently *Microstegium vimineum* (Japanese Stilt Grass), is being killed by a fungus called *Bipolaris* in West Virginia and *Rosa multiflora* (Multiflora rose), is being killed by a mite/virus interaction, where a native mite is helping spread Rose-rosette disease (Imlay, email 2011).

The complexity of controlling non-native plants with a native biocontrol may mean that a multi-stage or multi-level strategy needs to be developed. With disease, a pathogen needs to be found. Then a carrier organism that enhances or allows a pathogen to be effectively introduced or transferred may need to be located, such as an insect. For both insects and diseases, the right environmental conditions need to be determined. If more than one biocontrol has been located, as with *A. altissima*, the conditions for each biocontrol to be effective need to be determined, in addition to the interactions between the different biocontrols. With this, different environmental conditions may be ideal for one set of interactions and different environmental conditions for another. An adult tree may have a different effective pathogen or herbivore than an immature. Seeds may be the preferred food by some biocontrols, while others prefer the parent plant. Some diseases and organisms may travel through interconnected roots. Others may be wind borne, water borne or travel in an animal's gut or on its skin.

A mixture of biocontrols and chemical controls may be necessary to be effective. The biocontrol may be effective for one size or stage of a plant. Chemicals such as glyphosate may be needed to supplement or enhance the effectiveness of a biocontrol or deal with other stages of a plant. With *A. altissima*, young plants and seedlings were completely defoliated by *A. punctella* in research done during the summer of 2010. Mature trees in the same and other stands were not affected as much. Adult trees in other stands in Lancaster County were killed by disease. Therefore, a combination of pathogens, herbivores, mechanical methods and chemicals may be needed to rid an area of a pest plant.

In conclusion, it is my opinion that biocontrols for non-native invasive plants can be found if looked for and used effectively. This goes against traditional biocontrol methods. However, a native biocontrol does not carry the same potential liabilities that non-native biocontrols do, being more benign and lower risk than mechanical and/or chemical methods. At the same time, combinations of biocontrols, chemicals and mechanical methods may be necessary and used as conditions require.

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