The Effects of Climate Gradients on the life cycle of the *Galerucella spp.*

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Abstract

The invasion of foreign and native nuisances has becoming an increasing problem in society. Thus there is a constant need to find a better control in order to slow the progress or eliminate these species. One of the most well known invasives is *Lythrum salicaria* (purple loosestrife). Currently the most popular control for purple loosestrife is the use of beetles from the *Galerucella spp*. Currently there is some debate on the effectiveness of these beetles in the environment. This debate stemming from the issue of non-target feeding. A study incorporating potential limiting factors (i.e. temperature) for the beetles was conducted. It was hypothesized that when treated with these beetles areas that experience higher annual temperatures would see a greater amount of damage on purple loosestrife. Published papers were used as the primary source of data collection as well as several websites. It was found that there was little correlation between temperature and the amount of damage done on loosestrife. Other limiting factors could include the amount of precipitation an area receives.

Introduction

The problem of invasive species is not a new one. In fact over the past several centuries most "invasions" have involved the transportation of species either directly or indirectly by humans (McKinney & Lockwood 1999, Pysek et al. 2002, Daehler 2003). It is because of this long duration of time that invasive species are now considered to be a significant component in global change (Vitousek et al. 1996, Sakai et al. 2001). If nothing is done to slow the spread of these invasives scientists' fear that their impact will be expected to be severe throughout all ecosystems (U.S. Congr. Off. Technol. Assess. 1993, Sakai et al. 2001). One of the best-known invasive species is purple loosestrife, a perennial that invades waterfronts, mainly along rivers and lakes (WDNR). Purple loosestrife has effectively outcompeted many native plants in its inhabited ecosystem. This degradation of native plants leaves holes for the necessary niches needed to keep the environment healthy. Because purple loosestrife has spread to most of the continental U.S. (WDNR) it has become necessary that an effective control be introduced in order to stop the spread. These forms of control are categorized as being mechanical, chemical, or biological. Of these forms of control, biological has received the most attention recently.

Biological controls consist of a variety of organisms including disease, fungi, and animals (WDNR). For purple loosestrife beetles from the *Galerucella* species are used to treat and kill the plant. These beetles have been shown to be effective in controlling populations of this invasive (WDNR), however in some cases have been shown to feed on non-target plants. While this is not a common event it has given the *Galerucella* beetles some degree of risk in introducing. Thus it is important when introducing these beetles that a monitoring program is also implemented in order to determine if these beetles are truly an effective form of control more research is needed. Studies on how temperature and precipitation, these being predominate factors in the effectiveness of the beetles, could yield information necessary in convincing the public that this insect is a good or bad choice in eliminating populations of purple loosestrife.

Literature Review

Invasive Species and Comparative Studies

Invasive plants can be either nonnative plants that have successfully spread to regions outside of their native range or native plants that have become a nuisance (Williamson 1996, Richardson et al. 2000, Daehler 2003). While the presence of invasive plants has been known for quite some time it has only been recently that they have attracted so much attention due to high economic costs associated with their control (Pimentel 2002, Daehler 2003). It is estimated that over 3 million acres are lost a year to invasives alone and the amount of money spent on controlling or eradicating invasive plants is around $ 35 billion dollars a year (U.S. Congr. Off. Technol. Assess.1993, Pimentel et al. 2000, Sakai et al. 2001). The spread of invasive plants is in part due to the growing mobility of people and trade goods (Robbins, 2004). These “contact and introduction” processes can typically lead to invasion and thus alterations in ecosystem functions (Vitousek 1990, D’Antonio & Vitousek 1992, Daehler 2003, Robbins 2004). In response to the growing problem an Executive Order was released in February 1999 ordering federal agencies to prevent new and further spread of invasive species as well as to minimize ecological and economic damage (Fed. Regist. 64(25): 6183-86, Sakai et al. 2001). Studies in population biology have become more common, which include data about the history of invasive plants as well as information pertaining to the ecology and evolution of invasive and native plants. Interestingly, while there are many exotic organisms only some of these organisms are actually considered invasive (Daehler, 2001). The definition of "invasive" is heavily influenced by cultural and political views (Robbins, 2004). Ironically, because the manipulation of a landscape is usually the first steps in invasion, a step often pushed into play by people, it could be said that both culture and politics shape how society views invasive organisms (Daehler, 2003*).

Much of the research on how invasive plants invade has been done with organisms that are not just considered "pests", but environmental threats (Kolar & Lodge 2001, Rejmanek et al. 2003, Daehler 2003). These studies, however, fail to consider characteristics such as how susceptible to invasion a landscape is or how susceptible it is disturbance (Robbins, 2004). Thus these "overlooked" characteristics can sometimes make an invasive organism appear worse than it actually is in a given landscape. For example, if an ecosystem sees large masses of people each day, i.e. a campsite, it can be considered disturbed and thus more likely to be invaded. As a result, invisibility of these organisms can be overestimated, since perhaps those species would not do as well in less-disturbed habitats. Easy access to an environment does not serve as a good measure to how invasive a plant can be.

Typically in studies involving the invasiveness of a plant a comparative approach is taken (Daehler 2003). The comparative approach involves comparing the different physical and morphological characteristics of a native and invasive plant (Daehler 2003). These differences range from anything from seed production to nutrient utilization of plants. It can be assumed that if invasive plants consistently outperform native plants in multiple studies then the overall global biodiversity will decrease (Daehler & Carion 1999, Daehler 2003). The other possible outcome is that nonnative plants are rarely outperforming native plants. This would support the idea that invasives can only outcompete native plants under particular environmental conditions (Daehler, 2003). The key question in this argument, however, are under what circumstances (i.e. environmental conditions) must the invasive experience to produce so rapidly and what can be done to limit this “condition” (Daehler, 2003). In a controlled performance comparison native plants were shown to be equivalent or even stronger than invasive plants displaying advantages over the invasive plants (Daehler, 2003). Even invasives that are considered to be aggressive in nature display disadvantages to native plants (Daehler, 2003). Disadvantages such as a lack of access to necessary nutrients or to weather conditions can be limiting factors in invasives plants. The conditions that invasive plants were most successful included areas that were considered “high” in physical disturbance and resource availability (Daehler, 2003). To no surprise these conditions are often associated with human disturbance in the environment (Daehler, 2003).

Invasive competiveness

There are a variety of factors that can measure how competitive an invasive plant can be. Growing season, for example, is often associated with the timing of reproduction (Bradshaw & Holzaphfel 2001; Parmesan 2006). While it is generally accepted that invasive plants can outcompete native plants there have been few in depth studies analyzing why (Robertson 1895, Free 1968, Grabas & Laverty 1999). In order to fully understand how invasive plants spread and how best to control them, scientists must first understand their behavior. “Showy” invasive plants, for example, may be one contributing factor as to why these plants can spread so quickly (Free 1968, Waser 1978a, Gross & Werner 1983, Rathcke 1983, Armbruster & Herzig 1984). In a study coupled with the native growing plant *Lythrum alatum*, winged loosestrife, *Lythrum salicaria* was shown to outcompete the plant in almost every category (Brown et al. 2002). Not only did *L. salicaria* reduce the number of pollinators that the winged loosestrife received, but it also reduced the seed set in the species (Brown et al. 2002). *L. salicaria* effectively decreased the quality and quantity in pollinators and seed sets for *Lythrum alatum*, thus it could be hypothesized that interactions with other natives would yield similar results.

This study suggested that invasive plants may be more damaging than previously thought (Brown et al. 2002).

Another factor to consider for invasive plants is ability to spread over long distances. It has already been mentioned that growing season has an effect on the growth rate for invasives. However, studies on how the spread of invasives as compared to geographical gradients in climates are rather new (Colautti et al. 2010). Biological invasion causes a number of events to occur. The main point being that it shows how the invasive will adapt to fit the best local selection (Maron et al. 2004, Xu et al. 2010). In simpler terms how will the invasives genetic variation change in terms of natural selection? An invasive plant that spreads to a new geographical gradient in climate undergoes quite a challenge. Scientists have already identified that with the spread of invasive plants comes the decrease in genetic variance within populations as well as a limit on growth rate (Colautti et al. 2010). While it is already apparent that invasive plants, like *Lythrum salicaria*, have already spread to most of the continental U.S. one study suggests the invasive plants can only spread so far. In this particular study, involving purple loosestrife it was hypothesized that there are tradeoffs to the spread of invaders (Colautti et al. 2010). With the northward spread of *Lythrum salicaria* scientists found that there was a genetic correlation between the first flower and vegetative size of the plants (Colautti et al. 2010). What is interesting about this research is that it showed how *L. salicaria* could have stunted growth with northward geographical gradients. Of course while these results are promising, even considering the invasive plants shortcomings, there are still a variety of factors that could affect this experiment such as invasion history (genetic drift) and migration selection (MSB – Kirkpatrick & Barton 1997; Lenormand 2002). Still, this study shows great potential in uncovering weaknesses of *L. salicaria.* This experiment supports that how an invasives spread can be correlated to the genetic variation of that population (Colautti et al. 2010). Curiously, native populations in Europe have been known to exhibit similar behavior in varying geographical gradients in climate (Olsson & Agren 2002). This fact alone could give scientists clues on how to manage populations of invasive plants, in this case *L. salicaria*.

Thus this study and studies like it act as models and how scientists can estimate genetic variations in populations as well as indentifying “ecologically relevant traits” (Colautti et al. 2010).

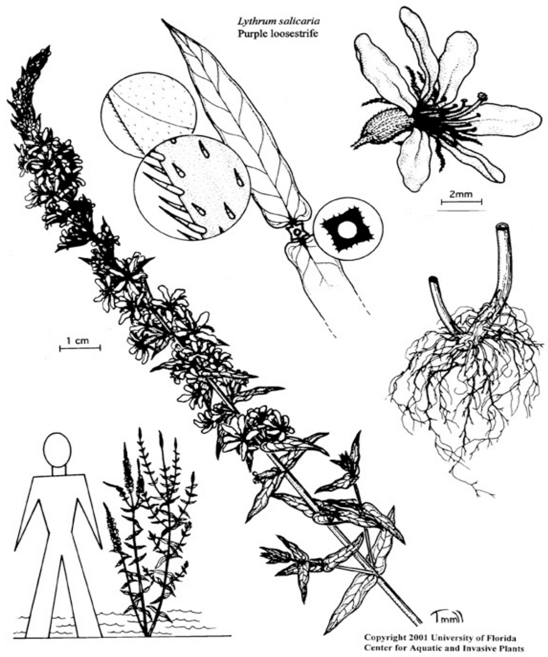


Figure 1: Purple Loosestrife

History of Lythrum salicaria (Purple Loosestrife)

Introduced in the 1800’s from Europe as a garden perennial, purple loosestrife has continued to spread inhabiting most of the continental U.S. (Unfortunately, only 24 states have laws restricting the importation and distribution of this plant (WDNR). This problem stems from 1) a lack of knowledge of purple loosestrife’s aggressive invasive behavior and 2) the plants use as by horticulturalists and beekeepers (WDNR). To make matters worse this plant had become highly adapted to various climates and environmental stresses with its range extending from Oregon all the way to New York. Such stresses include habitat disturbance as well as low nutrient availability. As versatile as purple loosestrife is to varying habitats it does prefer marshes, sedge meadows, and wet prairies as its primary area of invasion.

As mentioned before purple loosestrife has a variety of adaptations that has earned it its title as an aggressive invader. Not only can it grow in a variety of soil types, but it also has the capacity to live in a large pH range (WDNR). When purple loosestrife reproduces it usually does through seed dispersal, however it can also re-root through root and stem clippings (WDNR). In a year it can produce anywhere from 100,000 to 300,000 seeds, which can be very troubling for surrounding natives that do not produce as many seeds (WDNR) since there is a high seed survival rate at 60-70% (WDNR). Even seeds that have fallen in the water have been shown to be able to survive and remain viable for up to 20 months (WDNR).

Unfortunately this large slurry of adaptations only makes the job of getting rid of the plant even harder. Purple loosestrife is known best for degrading open water environments. This means displacing native plants as well as many vertebrates including turtles and waterfowl (WDNR). On top of this purple loosestrife can clog channels with dense populations inhibiting recreational activities (WDNR). For these reasons and more it has become essential that an effective control method be established in order to control the spread of this species. Control methods for invasives vary between chemical, mechanical, and biological techniques. Of course each method comes with its own set of pros and cons. The main question for scientists then is what method will be most effective and at the same time be the least degrading to the environment.

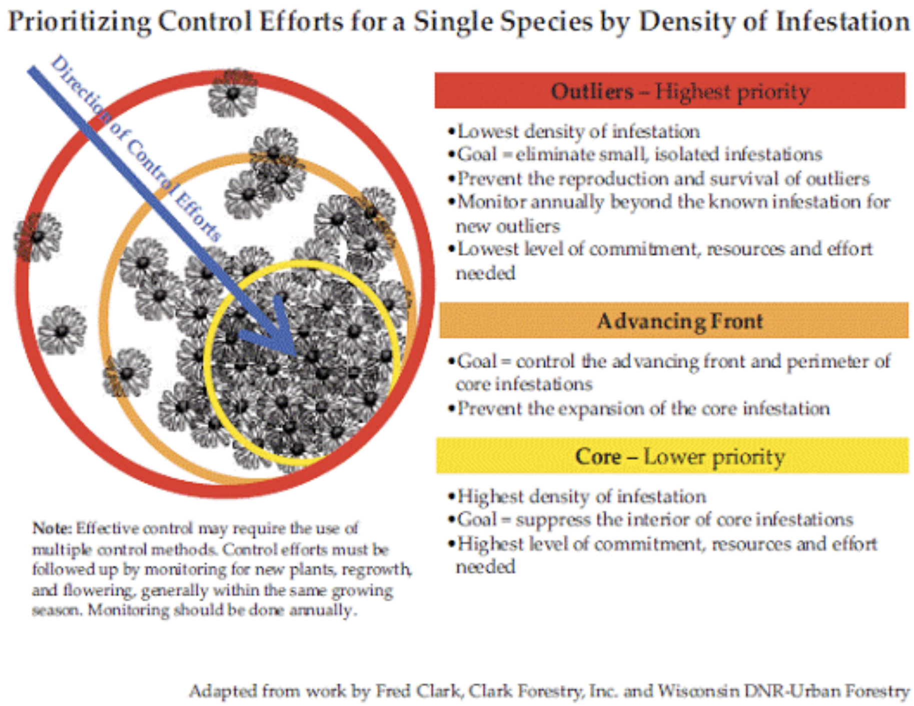


Figure 2: Determining factors in controlling an invasive population

Control Methods

Choosing the right control method for invasive plants has always been controversial. What remains to be the most effective method for invasives is prevention and monitoring (WDNR). While simple in definition monitoring can be very tedious. Despite this drawback, however, it does ensure that invasives are controlled. The simple act of removing new young plants from a habitat can ensure that invasives will not take a hold. Yet, as mentioned before this process can take a long time and people are often not patient enough to reap the full benefits of this method. Thus a great more deal of effort is put into discovering and perfecting mechanical, chemical, and biological controls.

Of the three control methods mechanical is the most self-explanatory. Cutting, digging, and drowning are all techniques used in mechanical control (WDNR). In the case of purple loosestrife cutting is done before the plant begins to flower because cutting afterwards only increases the chances that plant will grow back with even more flowering stems (WDNR). Digging up plants can be effective, however this method often creates more disturbance in the surrounding environment. In addition, bare ground left behind can be an ideal spot for other re-invasion by either purple loosestrife or other invasive plants (WDNR). For this reason this technique is not often used in areas where it could negatively effect native populations. Drowning is a largely ineffective method for several reasons one being that plants must be cut so that they are under the water. On top of this the plants must exist in a spot where they will be constantly covered by water for 12 months (WDNR). Plus other plants living in this area will also die during flooding events, however this is the only way to insure the invasives death. Because this process is extremely time consuming and has a low success rate it is very rarely used for purple loosestrife. Typically mechanical controls work best when coupled with the use of herbicides. In other words mechanical controls are often used in junction with chemical controls. The use of chemicals, however, can be a risky process as will be discussed next.

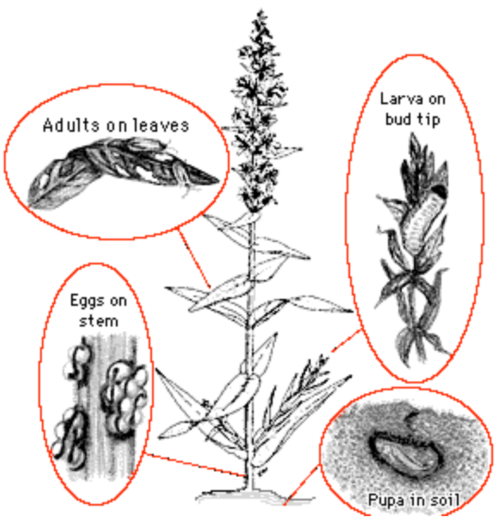
Chemical controls usually consist of herbicides and pesticides that can effectively kill the plant, roots and all (WDNR). Yet these treatments can have degrading effects on surrounding native plants and native plants that are especially sensitive often see more indirect damage of the chemicals than the actual invasive itself (WDNR). Regardless, it remains to be one of the most effective methods in controlling purple loosestrife, especially with mature plants (WDNR). In the case of purple loosestrife glyphosate herbicides are commonly used. These herbicides consist of products such as Roundup and Glyfos (WDNR). As mentioned before herbicide treatments work better when coupled with mechanical treatment methods. This means that it is not always enough to simply spray the plant. Thus purple loosestrife stems are often cut before they are sprayed to insure that the chemicals will be absorbed into the plant (WDNR). Another technique in chemical treatments is to use targeted foliar applications for herbicides. This technique is best used in areas where populations of purple loosestrife are extremely dense (WDNR). Triclopyr (Garlon 3A) is another herbicide used, in addition to glyphosate, for foliar spray treatments (WDNR). This herbicide has yet to receive full approval by the EPA, thus has not been applied heavily. It's important to make note that the DNR, regardless of state, requires users of herbicides and pesticides to acquire a permit when treating areas close to water.

The final control method has, in recent years, become one of the most researched methods for controlling invasives. Biological controls incorporate of the use of animals, fungicides, or disease to kill plants (WDNR). Typically organisms used as a control come from the native range of the invasive organism. This is important since one of the main issues with invasives is that they do not have natural predators in the non-native region in which they have established. This treatment does take more time than mechanical or chemical methods in producing results (WDNR). However, it has been shown to be extremely effective for some invasives, one being purple loosestrife. Treatments for purple loosestrife usually consist of insect application. One particular species of weevil (*Hylobius transversovittatus*) as well as two species of beetles from the *Galerucella spp.* (*Galerucella calmariensis* and *Galerucella pusilla*) are bred and applied to plants directly (WDNR). This particular species of weevil lays its eggs in the stem and root systems; larvae will then feed on the plants root tissues after they hatch (WDNR). The *Galerucella spp*. acts primarily as an herbivorous bug that serves to skeletonize the leaves of the plant killing it in the process.

Figure 3: *Galerucella pusilla*, absence of or faint triangular marks on back (top) *Galerucella calmariensis*, dark triangular marks on back (right)

History of the *Galerucella species*

Introduced in 1992 the *Galerucella spp*. was only an experimental control at the time (IDNR). Since this time, however, numerous studies have been conducted in the usage of this insect as a biological control. Two beetles of this species are most often used in treatments: *Galerucella calmariensis* and *Galerucella pusilla* (Figure 3). These insects are nearly identical and are almost always coupled in treatments. In fact one of the only ways they are set apart is by the thick black lines present on *G. calmariensis* and less apparent on the *Galerucella pusilla*. Both species are prolific reproducers. This means that they produce numerous eggs in one life cycle. For the *Galerucella spp*. a female can lay anywhere from 300-400 eggs in a year (IDNR). The life cycle of the Galerucella bugs are timed in accordance to purple loosestrife productivity. This means that plants are treated with either mature adults or eggs. In order for this method to work populations of the beetles must be given time to reproduce so that dispersion can occur. Adults typically emerge from hibernation in mid-May (IDNR). Adults will feed, reproduce, and then die. Come July the larvae will hatch, feed, and pupate. Larvae, like the adults, will feed on the leaves and skeletonize them. Finally around mid-July and through mid-August the insects will disperse, spreading to new patches of purple loosestrife. Unfortunately the *Galerucella spp*. does not spread quickly and usually takes several years to effectively diminish a population of purple loosestrife (WDNR). Furthermore, few studies have been done on treatments of large sites, thus the effect of the bugs are less known in big areas. Rather than act as a deterrent this should encourage more large-scale studies to further study the effectiveness of the insects. For example during colder months these insects will hibernate thus loosestrife damage decreases. If there is a longer warm season than the beetles will likely be more productive. However, such ideas have yet to be tested.



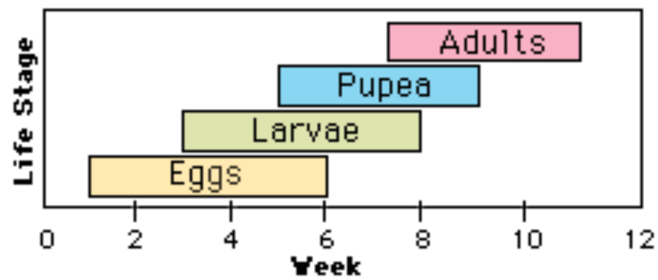


Figure 4: Life cycle of the Galerucella species on loosestrife (left) Time it takes for insects to fully mature (top)

*Cited: University of Minnesota – Biological Control of Purple Loosestrife

Galerucella spp. Risk Assessment

Of the many biological controls used for *Lythrum salicaria* the *Galerucella spp*. is among the most commonly used (Blossey et al. 2001). Consequently these beetles are often at the center of debate, whether the species is under fire for herbivory of native plants or its effectiveness at controlling loosestrife. One study suggests that the risks of releasing control insects into the environment far outweigh the benefits. The evidence for such claims, however, is not fully supported (Howarth 1983, Bennett 1993, Barratt et al. 1998, Follett et al. 2000, Stiling & Simberloff 2000, Lynch et al. 2002). Nonetheless some scientists suggest that these insect controls are actually causing the extinction of "non-target" plants (Howarth 1983, Simberloff & Stiling 1996a,b, Strong 1997, Lynch et al. 2002). Non-target plants meaning native plants that the Galerucella spp. doesn't typically feed on. To fully understand the usage of this biocontrol there needs to be an understanding of the risks in releasing it. The "spill-over" effect is used to describe the event of biological controls feeding on non-target plants (Lynch et al. 2002). The idea is that once a population of beetles establishes a "spill-over" effect will occur once food shortages get low. In other words when loosestrife populations decrease and the number of insects increase then non-target feeding is more likely to occur (Lynch et al. 2002). It is the idea that during these "transient periods" when spill-over is occurring extinction of non-target can occur (Tothill et al. 1930, Roberts 1986, Howarth 1991, Lynch et al. 2002). According to these studies models there are reasons to be nervous. A thorough analysis of the transient effects showed that non-target plants are at a heightened risk for depletion even perhaps extinction (Lynch et al. 2002). Furthermore, results also showed that these effects could occur even if target plant populations were not low (Lynch et al. 2002). The study suggests monitoring programs for locations that insect species will be released. This will insure that the biocontrol will perform its use without destroying other species. Regardless, while this study suggests that the use of insect controls can be a risky move there are a number of good reasons to use them.

Galerucella Case Studies

The idea to introduce exotic beetles to control loosestrife populations stems from the natural occurring process in Europe. In its natural environment purple loosestrife populations are fed on by a variety of arthropods living in the same community (Blossey 1995; Albright et al. 2004). When scientists first began to develop a program to control loosestrife techniques such as cutting, herbicidal treatment, water level manipulation, and burning were used, however these were largely unsuccessful (Malecki et al. 1993; Albright et al. 2004). It was after these failed attempts that scientists decided to use an insect instead. A study at the Goodyear Swamp Sanctuary on Otsego Lake, Otsego County has had a monitoring program for the *Galerucella spp.* since 1997. One particular experiment aimed to study the effectiveness of these beetles over a five-year period

(Albright et al. 2004). During this study there were a variety of high and lows in *Galerucella* populations attributed to temporal variations in the environment (Albright et al. 2004). As mentioned earlier the phenomena of non-target feeding did occur at the Goodyear Swamp Sanctuary. Reports showed that beetles were found on red osier in 2001 as well as speckled alder in 2002 (Albright et al. 2004). Evening more unnerving is the fact that scientists found populations of *Galerucella* 9 km off-site, which suggests larger mobility than previously considered (Albright et al. 2004). This is not to say that the beetles did not carry out their function. Loosestrife populations decreased greatly over the five-year period due to the abundance of the beetles (Albright et al. 2004). Ironically, this study too mentions the spillover effect and hypothesizes that this might be occurring at the sanctuary. In general the *Galerucella spp*. cannot complete its lifecycle without the presence of loosestrife (Kaufaman & Landis, 2000; Albright et al. 2004). However, it is believed that individual beetles are learning to recognize the host plant through the rejection of suboptimal species (Blossey et al. 2001; Albright et al. 2004). These exotic beetles can be an asset or a hindrance on the environment. Meaning they can either feed on the target plant eliminating the invasive problem or feed on native plants becoming a problem. In introducing this biological control there must be a monitoring program for the beetles as well as the plant (mentioned above). The *Galerucella spp*. is an introduced species and has potential to become invasive. In order to reap the full benefits of these beetles' scientists must constantly check up on population abundance. As widely dispersed as the beetles were in these experiments there are a variety of studies where *Galerucella* have not been successful. These studies usually experience a variety of geographical or environmental factors that could either break or make a beetle population.

The *Galerucella spp.* is often grouped with other exotic beetles during treatments of loosestrife thick areas. There have been few studies on the interaction between these differing species. Moreover, there has been little information on the predation of these beetles by bigger insects (Matos & Obrycki, 2007). A study in 2007, however, tested both of these variables in a closed experiment. First, when trying to decide which control would be the most effective for an invasive plant it usually comes down to the question of what will cause the most stress. Competing insects, for example, increase the damage on surrounding plants, thus plant growth decreases (Harris, 1981; Matos & Obrycki, 2007). Predator-prey interactions are also likely to be beneficial in reducing *Lythrum salicaria* populations (Matos & Obrycki, 2007). The idea is that increased stress of the plant will in turn kill it. Thus with plants where there is a higher interaction between these varying species the rate of growth was expected to decrease (Matos & Obrycki, 2007). Instead, not only was there not an additive effect of having two competing species, *Galerucella calmariensis* & *M. lythri*, on the plant, but also there seemed to be no additive effect from the predation of these species on the plant (Matos & Obrycki, 2007). Both *Galerucella calmariensis* and *M. lythri* both effectively reduced the populations of purple loosestrife, however there wasn't any additional reduction because of their interactions (Matos & Obrycki, 2007). Interestingly, in the same study several cage experiments were performed in which both herbivores beetles were placed in the same cage as *H. axyridis*, one of two insect predators. These experiments showed that in the presence of both *M. lythri* and *H. axyridis* there was an increased predation of *G. calmariensis* (Matos & Obrycki, 2007). Conversely, when *G. calmariensis* was alone with *H. axyridis* less predation occurred (Matos & Obrycki, 2007). These results have the potential to be beneficial in controlling Galerucella spp. when spillover events occur because it suggests that if treatments consisted of multiple species and later of predatorily insects then this could effectively control the "control" insects while still reducing the loosestrife populations.

Purpose of Study

The primary objective of this research is to analyze the effects, if any, that temperature has on the life cycle of the galerucella beetles. Furthermore if there is an effect on its lifecycle how this affects the amount of damage the beetle can do. Since there is a great deal of skepticism in the use of the galerucella beetles as an effective control for purple loosestrife the second objective is to determine from the given data whether these beetles are the right choice as a means of control.

Methods

Scientific data was collected from a multitude of locations. These sources included several internet sources, the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) and the National Oceanic and Atmospheric Administration (NOAA). Most of the data, however, that was collected came from published works located in Delaware, New York, and Massachusetts. These studies all involved the treatment of purple loosestrife with the use of the galerucella beetles. While this data was analyzed in excel, other data had to be uploaded via ArcGIS.

To download data from the GLIFWC website users simply have to click on the download data tab to access different base layer data. Once the appropriate folder was chosen (Invasive Species) and data layers (Biocontrol data & Purple Loosestrife Survey Routes) were selected the information was packaged into a link to download to the computer's hard drive. A separate link was provided to download the metadata for this information. Metadata contains crucial information on how the data was originally created. Data was saved in the form of .dbh, .prj, .shp, and .shx files. Each file contains different information ranging from geographic reference data to coordinate systems data. Again all of this data is in the form of shapefiles, which means that it is geospatial vector data. When importing this data into ArcMap you have to use the Add data icon, indicated by the square with a plus in it (you must have the program open to see this). Once the shapefiles have been successfully added to ArcMap the data must then be exported so that it is viewable. This can be done by right-clicking the shapefile in the attribute table choosing data and then choosing export. It is likely after the data is exported that some of the information will need to be deleted. This is data that isn't recognized in the attribute table. After the data files are joined together via the "join and relate" tab the information can be viewable on the screen in from of shapes, ultimately becoming a map.

Data from theses sources was also uploaded into ArcGIS, the primary mapping program used for this research. Since data from the Great Lakes Indian Fish and Wildlife Commission came in the form of both shapeflies and waypoints. Specifically, Galerucella treatment sites are shown as waypoints or on the map itself these points are represented by "bug" symbols. Since the "bugs symbols became largely clustered and difficult to read they were changed to red circles in order to more visibly see the treatment areas using the *Galerucella spp*.

To analyze the data several comparisons were made between the temperature and the percent damage done to the purple loosestrife via beetles treatments. The two variables were graphed and then were set to a trend line in order to show a better correlation between each data set. Other graphs were created mapping temperature and life cycle observations of the galerucella beetle. Finally, a graph was made analyzing the percent cover of purple loosestrife versus the annual fall temperature of the year.

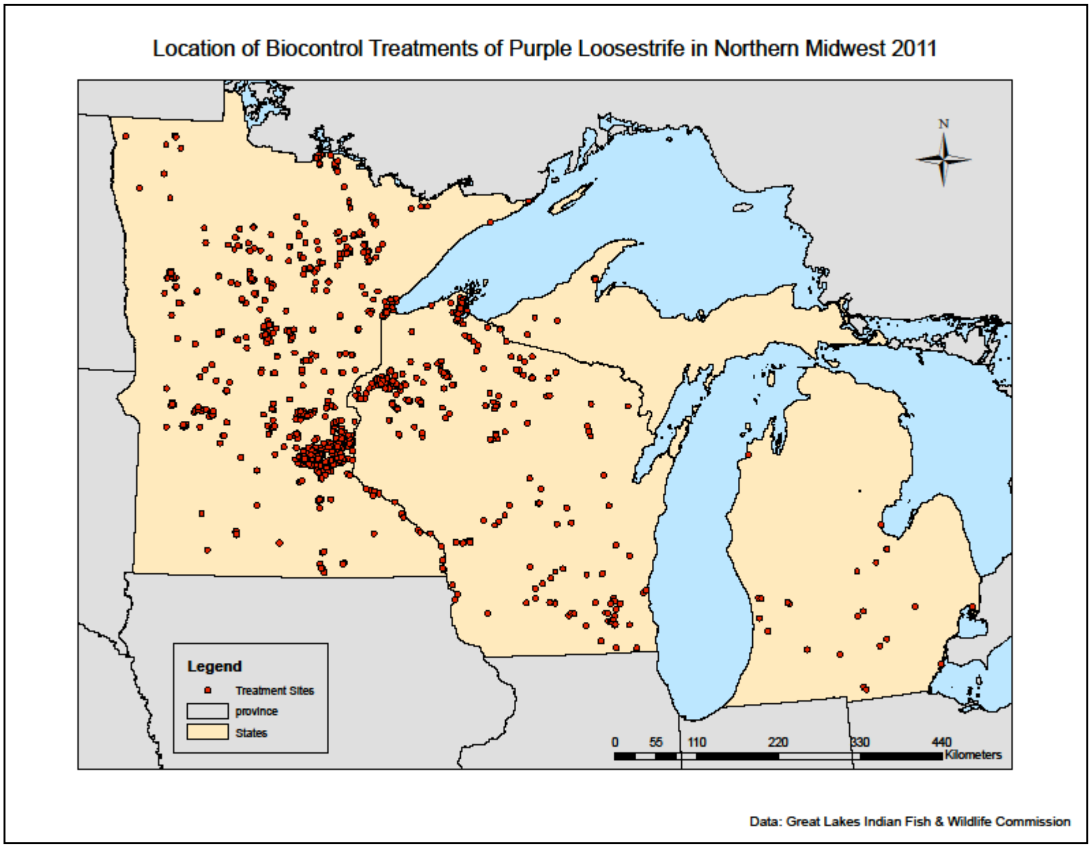


Figure 5: Biocontrol treatment sites in Minnesota, Wisconsin, and Michigan for Purple Loosestrife using Galerucella beetles

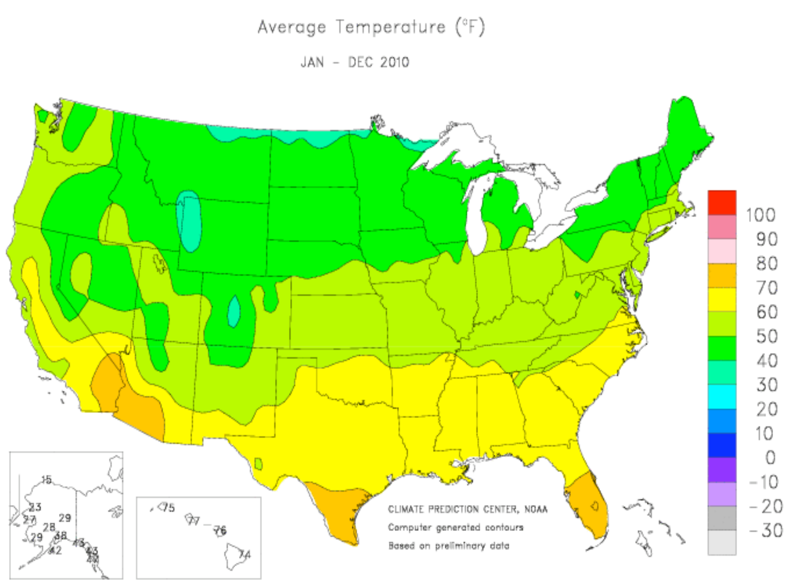


Figure 6: Climate Gradient for Continental US. Taken from the National Oceanic and Atmospheric Administration (NOAA)

Results

Data from the Delaware Water Gap National Recreation Area was combined with temperature data provided by the NOAA in order to analyze differing rates of damage on purple loosestrife by the Galerucella beetles. Figure 7 indicates that at higher temperatures there was an increased percentage of damage done by the beetles. More specifically at 88ºF the highest percentage of damage was done and at 74ºF the least percentage of damage was done.

The data from Otsego Lake in New York provided information on the number of eggs, larvae, and adults observed from 1998 to 2002. When the temperature decreased in 2001 in Figure 8 the number of eggs and larvae of the Galerucella beetles increased, however in the following year, after the increase in annual temperature, both larvae and egg counts decreased and the number of adults increased. The analysis of Lake Otsego's Galerucella damage in regards to temperature showed little correlation. While there appears to be a slight positive trend in Figure 9 the points lie far away from the line.

The Massachusetts Office of Coastal Zone provided data of the percent cover and number of stems of purple loosestrife after consecutive years of beetle treatments. In 2005 the temperature significantly decreased and the percent cover and number of stems increased as indicated in Figure 10. In the next year, 2006, the temperature had an average increase and the percent cover and number of stems decreased again.

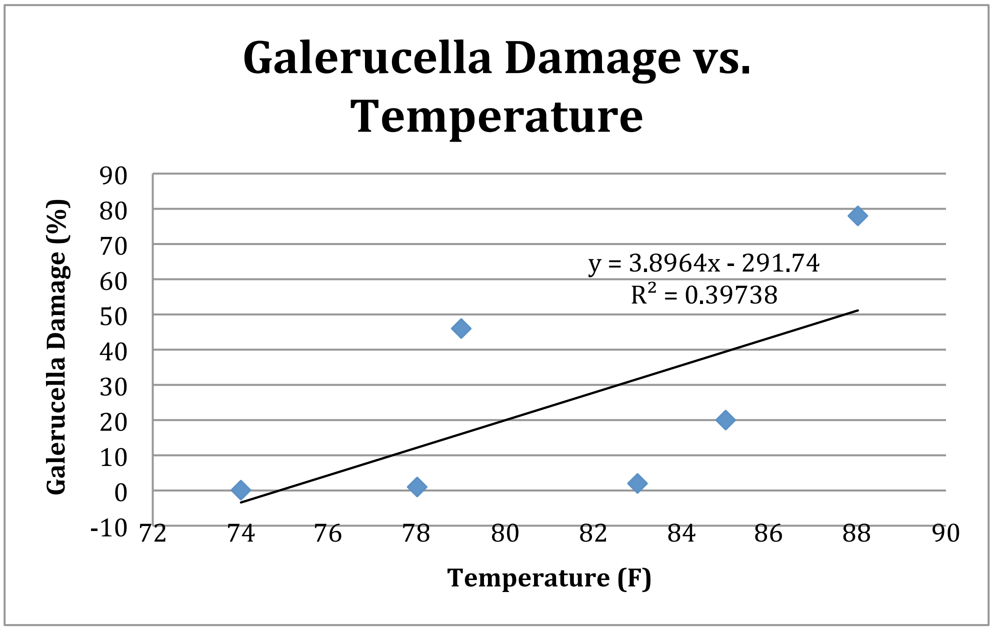


Figure 7: Percentage Galerucella Damage versus Temperature at Delaware Water Gap National Recreation Area

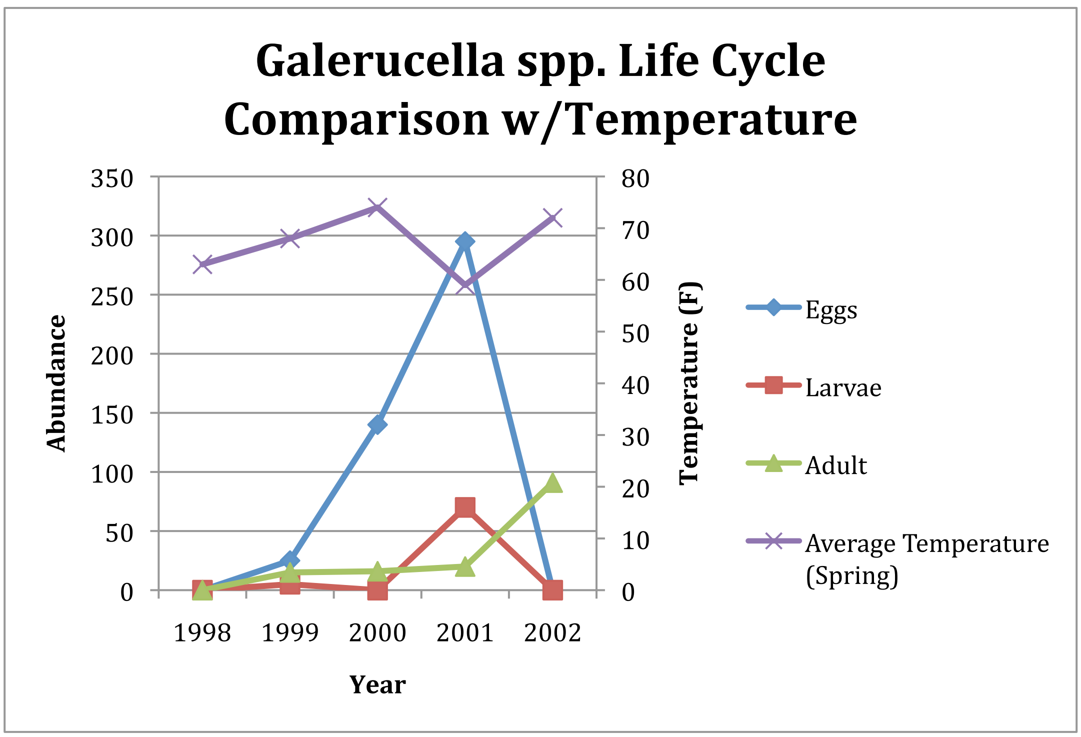


Figure 8: Galerucella spp. life cycle compared to annual spring temperatures at Otsego Lake, Otsego County, New York (1998-2002)

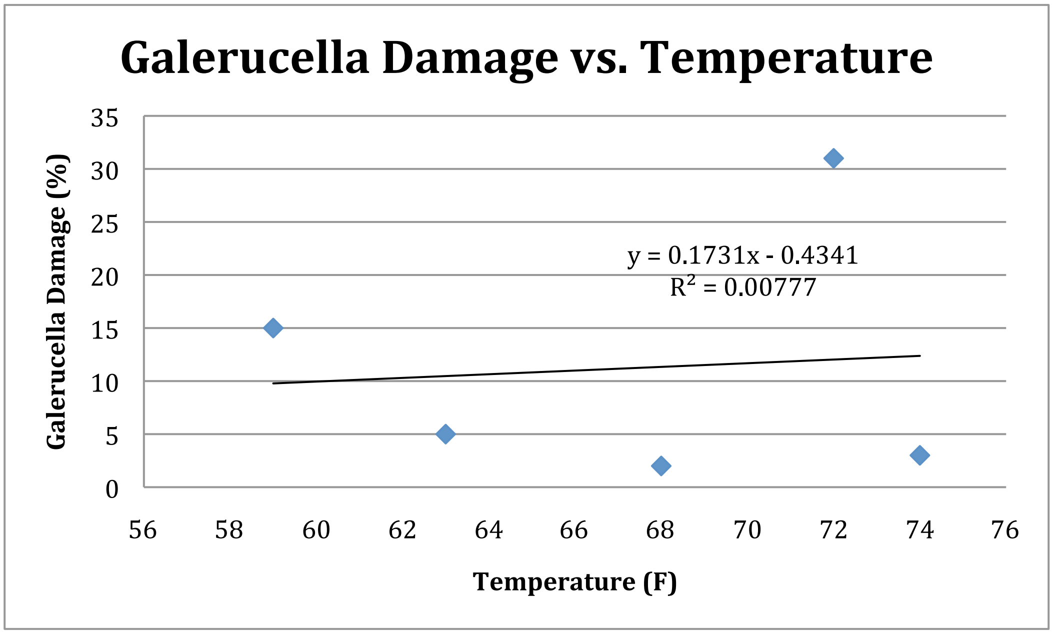


Figure 9: Percentage Galerucella Damage versus Temperature at Otsego Lake, Otsego County, New York

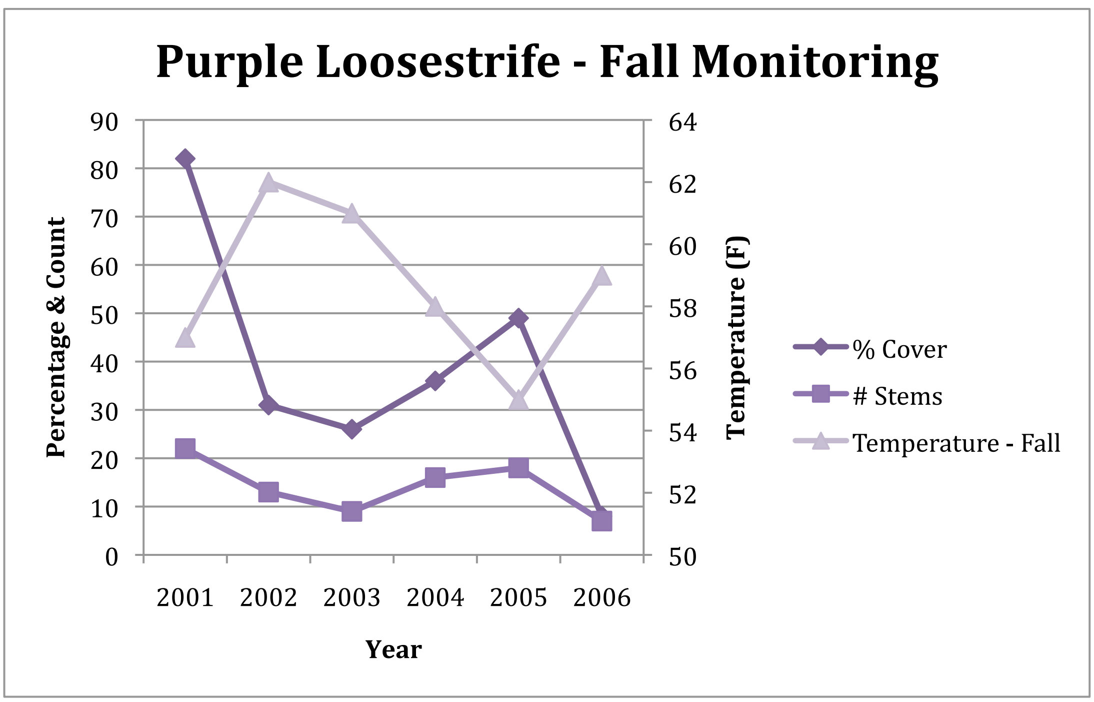


Figure 10: Percent cover and number of stems of Purple Loosestrife after Galerucella treatments at Massachusetts Office of Coastal Zone

Discussion

Preliminary Conclusions

Overall there was little correlation between temperature and the amount of damage the beetles did to a population of loosestrife. Furthermore, there were a considerable number of variables that could have contributed to the decline in populations of Galerucella beetles or purple loosestrife. For example, the annual precipitation at the study sites could have indicated further disturbance to loosestrife or beetle populations. Another variable that should be considered is that all of these research programs started collected data at the beginning of treatment. Since it takes many years for populations of beetles to establish it's hard to attribute damage to temperature alone. While the research from Delaware did show a correlation between the percent damage and the temperature there is not enough data to accurately support this claim. Since this pool of data was so small it cannot accurately refute the usage of the Galerucella beetles as the primarily biological control for purple loosestrife.

Challenges

After 4.5 months of silence I was finally able to talk to Brock Woods who is the head of the *Galerucella* treatment program for the Wisconsin DNR. After repeated attempts to receive data I was finally told that the information I was looking for doesn't really exist. According to Brock while the DNR does take record of the effects of the beetles on *L. Salicaria* and native plant populations it does not regularly correlate this data to other limiting factors (i.e. precipitation and temperature). Unfortunately the data they have will not be published until late spring, that being the first time it will be available to me. Instead Brock suggested the glifcw.org website to me as the source of my data, which I was already familiar with. This study would be more effective if it were to span over numerous years as opposed to a senior thesis. The results are inconclusive because 1) little to no research has been done on this topic and 2) the existing data on *Galerucella* treatments are based more off before and after photos of treated areas. This supports the need for research in this area as not all venues have explored to the effectiveness of these beetles as a biological control.

Unfortunately the shape flies downloaded from the Great Lakes Indian Fish and Wildlife Commission only provided layers showing the locations of beetle treatments across Minnesota, Wisconsin, and Michigan. As mentioned before, more specific data on these treatment sites will not be available until later in the year.

Future Studies

The methodology for this thesis could be changed in several ways to increase accuracy in future studies. As mentioned previously precipitation was not given much consideration in how it could affect the damage done on purple loosestrife. In addition, data collected from independent studies should be collected from similar years since how old a study is can affect how much damage purple loosestrife populations are receiving. Furthermore independent studies should have data collected during the same time of the year. When data is collected at different times of the year there are various new variable to consider i.e. weather. While no personal data was collected it's important to remember that other researchers can make mistakes. Thus results from another's data can be skewed if the original data collector made a mistake. Solutions for such problems could include reading about the mistakes made in the study or double-checking the source. The final suggestion to a revised version of this experiment would be to make sure the source your receiving data from has a complete set. During data conversation for ArcGIS some of the data was lost, leaving holes. Thus in the future asking the source for the original data set might yield the most accurate results.

This study stressed the importance in understanding the biological controls used for invasives species. Every year millions of dollars are spent in an attempt to eradicate invasive species. This is why it is crucial that when introducing a control in the environment any possible risk factors are known. The *Galerucella spp*. has a lot of potential in eliminating purple loosestrife. However, it is strongly suggested that a separate monitoring program is established for these beetles. Scientists must keep in mind that these are still exotic organisms and thus have the ability to spread and invade ecosystems. This is not suggesting that these beetles should not be used at all, because they do have a positive impact on the environment. It simply means that these treatments should be made cautiously and efficiently. The growth of purple loosestrife is occurring at an alarming rate. This again drives home the fact that idea that increased awareness of these species is important to slow the spread of these species. Thus, as effective as the beetles are it is equally important to spread the knowledge of these invasives to the public.

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