INTENSIVE ROTATIONAL TARGETED GRAZING (IRTG)

AS A MANAGEMENT TOOL FOR *ROSA MULTIFLORA*

by

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Abstract

The efficacy of intensive rotational targeted grazing (IRTG) for suppression of the invasive shrub, multiflora rose (*Rosa multiflora*) was investigated in upstate New York. Sheep stocked at high density were rotated through a circuit of enclosures at a frequency of 3-d per enclosure, from May-September, 2011 and 2012. The photosynthetic surface areas (PSA) and vitality of *R. multiflora* plants were evaluated before (May 2011) and after treatment by grazing (Sept 2011). Changes over time were compared with similar measurements of ungrazed plants. Species richness (S) was estimated in each enclosure before (May) and after (September) treatment. PSA in grazed enclosures declined by 56.8% over the 2011 season and by 62.5% during the 2012 season. One year after ITRG treatment, healthy *R. multiflora* plants in grazed enclosures had declined by 91% and unhealthy and dead plants had increased by more than 200%. The distributions of healthy, unhealthy and dead plants, in grazed and ungrazed enclosures, though not different before treatment (chi square goodness of fit test; $p>0.05$), were different one year later ($p<0.001$). Mean S in grazed enclosures increased by 27% over the season and by the end of the study, S was 12% higher than ungrazed enclosures. Evidence of stress in *R. multiflora* (clumping, dwarfing and reddening of leaves) at the end of the 2011 season led me to investigate the possible presence of rose rosette disease (RRD) during 2012. Potential stress was confirmed in plants experiencing leaf reddening. Chlorophyll a concentrations were significantly lower in red than green leaves (Student's $t = 5.20$, df=28, $p<0.001$). Not unexpectedly, Normalized Difference Vegetative Index (NDVI) lso differed in red and green leaves (Student's $t = 2.76$, df=32, $p<0.01$). Green leaves had higher dry weights than red leaves (Student's $t=14.13$, df=151, $p<0.001$). Wool from the sheep, and *R. multiflora* leaf and petiole samples were collected to determine if the eriophyid mite, *Phyllocoptes*

fructiphilus, a vector for RRD was present. No significant evidence of *P. fructiphilus* in leaf and petiole (Mean=0.00 N=414 SD=.71) or wool samples (Mean=0.00 N=11 SD=0) was found. This was unexpected, although it would only take one mite to be the vector if that particular mite was carrying the rose rosette virus. Further studies would be required to test whether rose rosette was confirmed in this population. Visual evidence of RRD symptoms were more prevalent in grazed enclosures than ungrazed locations, and a greater decline in grazed enclosures was clear.

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Appendix 1: Weekly flock-health assessment

1.0 Introduction

1.1 Invasive Species

Invasive species, as defined by the Convention on Biological Diversity, are alien species which "are introduced, established, naturalized, and spread outside of their home range, and whose impacts involve significant harm" (Perrings et al. 2002). Harm includes impacts to health, the environment, and the economy. International trade and suburban sprawl have rapidly increased the distribution of invasive plant and animal species (Perrings et al. 2002). Exotic plant invasions result in tens of billions of dollars in losses to agriculture and agricultural communities in the United States each year (Pimentel et al. 2000; Simberloff 2000). Invasive plants are considered to have negatively affected biodiversity when their cover exceeds 10% (Qi et al. 2014). In some New England states non-native plant species represent 35-45% of the vegetative community (Mehrhoff 2000). Forty-two percent of the plants and animals listed as threatened or endangered under the Endangered Species Act are primarily threatened because of exotic species (Wilcove et al. 1998).

Environmental management agencies have used a variety of approaches to control the spread of invasive plants by methods including mechanical removal of plants, herbicide application, and biological control, with varying success. Invasive plants and animals face reduced pressure from predators and diseases, relative to natives in the ecosystems into which they are spreading. Once established in a new location, the invasive plant adapts and can develop a competitive advantage by being able to invest in growth and reproduction instead of defense, as native consumers are not adapted to handle their existing chemical defenses. Invasive plants tend to grow earlier in the season and to dominate resource pools. They may grow taller than their native counterparts, creating shade and eventually forming dense monocultures. Such monocultures may reduce biodiversity within the plant and ultimately animal communities, and, therefore, they would be expected to reduce ecosystem stability and functionality (Tilman et al. 2012).

Eradication was previously considered the measure of successful management of exotic species. However, eradication may actually increase susceptibility to re-invasion and the introduction of additional invasive plants (Carrion et al. 2011). Controlling or suppressing invasives, and mitigating their effects may be a more feasible and fiscally realistic approach. For instance, the landscape might be managed for the co-existence of invasive plants alongside native plants by reducing the dominance of the invasive (Leger and Espeland 2010). The intermediate disturbance hypothesis would support the notion that by applying pressure to the invasive, the invasive will have to adapt and compete within the ecosystem (Strum et al. 2015, Catford et al. 2012). If the intensity of the disturbance, i.e. grazing, is too high the location may become more vulnerable to invasion (Strum et al. 2015), particularly in early successional stage ecosystems such as grasslands (Catford et al. 2012; Hayes and Holl 2003; Hickman et al. 2004; Marion et al. 2010). By disturbing the ecosystem, at the appropriate intensity, native plants can compete while invasives are knocked back, allowing biodiversity in the plant community to increase. In this study, I examined the effectiveness of using sheep to control the spread of the invasive plant *Rosa multiflora* in an abandoned dairy farm in Albany, NY. I used a management approach called intensive rotational targeted grazing (IRTG) that is popular in small and medium scale livestock farming and which has been shown to be effective at managing other invasive plant species (Kleppel and LaBarge 2011; Girard-Cartier and Kleppel 2015).

1.2 Rosa multiflora

Rosa multiflora is among the most insidious and damaging plants to have invaded the Americas in the past century. *R. multiflora*, was brought to the United States as horticultural rootstock in the 1800s (Hindal and Wong 1988). During the early twentieth century, the USDA actively encouraged farmers to plant *R. multiflora*, "which can grow 'horse high, bull strong and goat tight' and are more permanent and economical than wire fences" (Hindal and Wong 1988). *R. multiflora* is a thorny plant that grows to a height of 5m, forming dense hedgerows which can confine livestock (Epstein and Hill 1995). State conservation departments also recommended *R. multiflora* as refuge for wildlife (Masse and Vulniec 2010). The United States Soil Conservation Service encouraged the use of this plant in the 1930-1940s to prevent soil erosion (Luken and Theriet 1997). Until recently, *R. multiflora* has been planted in highway median strips to serve as crash barriers and reduce automobile headlight glare (Kleinpeter 2011).

The shrub has since escaped cultivation, however, and spread into cattle pastures, meadows and grasslands reducing available pasture for dairy and beef production (Kriegl and McNair 2005). The Wisconsin Department of Agriculture (2010) estimates the cost to the dairy industry associated with managing *R. multiflora* to be on the order of $45 million annually. In 2005, it was estimated that more than 18 million hectares in the Eastern US have been invaded by *R. multiflora*, which has a negative economic impact on both agriculture and recreational activities (Loux et al. 2005).

Current management techniques are expensive, time consuming and labor intensive. Removal of large plants may require heavy equipment and considerable manpower, as well as herbicides. In this paper I suggest that livestock grazing is a viable alternative for the suppression of *R. multiflora* and the restoration of grassland and pastoral ecosystems.

2.0 An Alternative Management Technique for Invasive Plants

2.1 Grazing in Conventional Agriculture vs. Natural Grazing Systems

Grazing has historically been viewed by conservation organizations as detrimental to the health of ecosystems (Kiage 2013; Savory 1983; McNaughton 1985; Sidell and Bowman 1988; Karyotis et al. 2011; Podwojewski et al. 2011; Saberwall 1996). This has placed grazing at odds with conservation and landscape management goals. However, the impact grazing has is influenced by a number of factors including environmental and climatic changes (Ibáñez et al. 2009; Buckley and Schmidt 2003; Augustine and McNaughton 1998). In wild ecosystems such as the Serengeti, ungulates move freely across the landscape in dense herds. As they move they forage for food. Conversely ungulates that move constantly across a landscape (for instance, in response to predator pressure), allowing the plant community to rest for extended periods of time may enhance the health of the plant community and its biodiversity (Collins et al. 1998; Frank and Groffman 1998; Cingolani et al. 2005; Creel and Christianson 2009).

In Yellowstone National Park, Marshall et al. (2014) examined the impact that the removal of wolves had on the ecosystem. The banks of the Gallatin River were historically lined with willow trees, which stabilized the soil and reduced erosion into the river. The wolf population in Yellowstone was eliminated with the implementation of the Yellowstone National Park Act of 1872. This had a cascading effect, allowing elk populations to increase substantially (Tercek et al. 2010; Chadde and Kay 1991; Wagner 2006). The increase in the number of elk coupled with the prolonged aggregation of elk along the river banks led to increased pressure on bank-stabilizing vegetation, increased erosion and causing a reduction of water quality that ultimately impacted trout populations, which were supporting the ecotourism in the area (Tercek et al. 2010). When the grey wolf was listed as Endangered, and reintroduced to Yellowstone they began to manage the elk population. This allowed the willow community to re-establish itself along river banks, which, in turned, stopped erosion and allowed the river to re-populate with trout (Creel and Christianson 2009; Ripple et al. 2001; Larsen and Ripple 2003). The impact to vegetation seen in conventional grazing practices mimics the removal of predator pressure seen in Yellowstone; in each case grazers were allowed to remain near their food supply for extended periods of time. While it may not be feasible to re-introduce predators into human dominated landscapes, it is increasingly apparent that the livestock should be managed in a manner that mimics natural systems and not be allowed to remain stagnant as then it is more likely to result in degradation of the plant community.

Conventional agriculture has developed unsustainable practices that degrade the soil and foliage, and placed ungulates, although domesticated, in unnatural situations (Abril and Bucher 1999). This practice encourages two things: 1) that there will be an increase in the number of unpalatable species over time by increasing selectivity (Villalba et al. 2004; Villalba and Provenza 2009), and 2) grazers will likely overgraze the landscape (Abril and Bucher 1999). Management of this kind has led to desertification, reduction in plant biodiversity, habitat degradation, and erosion (Briske 1993; Briske et al. 2003) and has negative impacts the diversity of the grazer's diet (Villalba et al. 2009, Villalba et al. 2004). In a natural environment, large, herd-forming ungulates are usually densely aggregated and frequently moving across the landscape to avoid predation and food contaminated with their excrement (Voisin 1959; Frank and Groffman 1998; Creel and Christianson 2009). By eliminating natural predators and seeding with grass to ensure near monocultures, plant diversity is discouraged and the livestock cannot follow nutrient cues (Frank and Groffman 1998; Villalba and Provenza 2009) or respond to predation. Conventional agricultural does not mimic wild systems because there is nothing pushing the ungulates to move from one location to the next, thus ecosystems not meeting specific criteria (e.g., trophic complexity, drought conditions, etc.) are susceptible to degradation (e.g. soil erosion, reduction of species richness and vegetative cover) as a result of grazing (Kiage 2013), which often leads to increased rates of evaporation, decreased water absorption, and loss of carbon. Conventional agricultural grazing techniques exacerbate the stress already input into the system rather than mitigating it causing undesirable impacts on the environment which is being grazed. In this study we want to manage plant communities using a grazing system which applies an appropriate amount of pressure on invasive plants but also allots recovery time for native species which are more grazing tolerant.

The livestock used in my study were moved at frequent intervals (every 2-3 days) mimicking, in some respects, the movement of elk in Yellowstone after reintroduction of the wolf population. The pressure of predation caused a frequent movement of the elk away from the river bank. In this study, I moved sheep through a series of enclosures. The efficacy of rotational grazing in this study is examined to determine the recovery of the plant community by removal of an invasive shrub *R. multiflora*, while eliminating the opportunity for the flock to overgraze. This technique has been highly successfully for invasive forbs and grass management, but prior to this study had not been tested on shrubs (Kleppel and LaBarge 2011; Kleppel et al. 2011; Girard-Cartier and Kleppel 2015). Sheep have been used in invasive management grazing approaches for woody plants, such as sweet brier, (*Rosa rubiginosa*), but the rotation of grazers is not noted (Sage et al. 2009). It also has been found to restore biodiversity to ecosystems in the Hudson Valley (Kleppel et al. 2011; Girad-Cartier and Kleppel 2015).

2.2 Targeted Grazing

Targeted grazing is a bio-control approach joining plant-grazer dynamics. Launchbaugh and Walker (2006) describe targeted grazing as "the application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape management goals." This approach embraces ecosystem complexity by accounting for variation in location, climate, and plant composition (Wallace et al. 2008). Targeted grazing requires managers to understand what the management goal is. Different grazer species will perform differently within the environment based on their specialization and the plants available in the landscape where they are used (Rinella and Hileman 2009; Searle and Shipley 2008; Sullivan et al. 2000; Voth 2009).

2.3 Rotational Grazing

With the renewed interest in organic and sustainable farming, agricultural practices are beginning to shift away from conventional low density grazing practices, to higher density, rotational livestock management approaches (Brummel and Nelson 2014). Rotational grazing is a broad term describing a management strategy by which livestock (at any density) are moved from one section of pasture to another at intervals ranging from portions of days (every few hours) to portions of seasons (e.g., monthly). A subset of this is mob grazing which stocks at a high density and moves the herd at very high frequencies, e.g., hourly (Laliberte et al. 2012). The rapid rotation of the flock/herd through the landscape causes a twofold impact on the landscape. The livestock trample vegetation returning litter (nutrients) to the soil. It also encourages the removal of undesirable vegetation and is a very intense grazing technique for short duration. This reduces selective feeding and permits an "even" grazing of the plant community.

Rotational grazing has several benefits. First, the health of the animal is increased as a function of this frequent movement (Laliberte et al. 2012; Colvin et al. 2008; Colvin et al. 2012; Hao et al. 2013; Villalba et al. 2004; Goodman et al. 2014). Rotational grazing shifts the flock away from parasites. Parasites from the herbivores excrement can be re-ingested if the flock remains in the same location where animals have defecated. If they are moving from one enclosure to the next as they graze however, their parasites will typically die in the soil in 14-30 d (Colvin et al. 2008; Colvin et al. 2012). Secondly, as ungulates move to new feeding grounds, they are consistently being introduced to new nutrients and thus are able to diversify their diet, which has been shown to increase their health (Villalba et al. 2004). Additionally, body condition scores of livestock in upper Hudson Valley pastures were closer to optimal as diversity in the plant community increased (Giroux, C. 2013. Differences in the health of domesticated sheep (*Ovis aries*) pastured in wild and agricultural landscapes. Honors thesis. University at Albany, SUNY). The IRTG approach thus leads to better livestock health.

Rotational grazing also enhances the pasture where grazing occurs (Villalba et al. 2004; Frank and Groffman 2004; Collins et al. 1998). A diverse plant community resists damage from environmental disasters (e.g. drought, flooding, and virus) and is more resilient after a disturbance. A rotational management strategy allows the vegetation the time needed to recover from grazing. Allowing the vegetation time to regrow prior to re-grazing is critical for ensuring the recovery of diversity in the plant community (Augustine and McNaughton 1998; DeBruijin and Bork 2006). The regrowth and litter will help stabilize the soil, whereas if the grazers are left on the landscape for prolonged periods of time, bare ground can be created by the grazers, causing a loss of soil moisture and enhancing the possibility of invasion and erosion.

2.4 Intensive Rotational Grazing

Intensive rotational grazing (IRG) pulls together pieces of both of these concepts (dense aggregation rotational grazing) by stocking at high, moving the livestock through the landscape (generally $\leq$3 d or when canopy height has been reduced by about half), and allowing the vegetation to rest for a set period of time (generally about a month, but ranging from 14 to 150 days) (Holecheck and Galt 2000; Holecheck et al. 2000; Kintzel 2012; Ralphs et al. 1990; Wilkins 1992). . IRG is performed in a circuit and the cycle is repeated unlike mob grazing which is typically a onetime or periodic treatment The idea behind IRG is to re-create the pressure that predators place on ungulates in the wild, causing them to aggregate into dense herds and move frequently.

2.5 Intensive Rotational Targeted Grazing

IRTG combines the concepts from IRG (Teague et al. 2013) with the management-based techniques of targeted grazing. It retains the framework that targeted grazing protocols should be used to attain specific management goals, but adds a high density of grazers per unit area for a specified duration and rotates this high density of grazers through a series of enclosures allowing for a prolonged rest period for each enclosure prior to redeployment of grazers to that location. Caggiano and Kleppel (2010) reported on the use of targeted grazing at Glynwood Center, a farm in New York's Hudson Valley. In 2009-2010, they deployed Boer goats into an enclosure infested with *Rosa multiflora*. Within two seasons most of the *R. multiflora* plants in the enclosure were dead. No sign of recovery of the invasive was evident a year after treatment. The problem with this approach was that the goats overgrazed the herbaceous plants in the enclosure and by mid-season required supplemental feeding. This type of grazing could impact the drainage and hydrology of the site. This study (Caggiano and Kleppel 2010) and others

(Blanchet et al. 2003; Cadwallader and Cosgrove 2010; Teague et al. 2013; Brummel and Nelson 2014) suggests rotational grazing as an effective management tool.

IRTG can suppress both the sexual and vegetative growth of several species of herbaceous invasives and to restore biodiversity to plant communities (Girard 2011; Kleppel and LaBarge 2011; Kleppel et al. 2011). Until now, the potential effectiveness of IRTG for invasive plant suppression has been investigated only with herbaceous species. The objectives of present study were to determine, for the first time, the impact of the IRTG protocol on invasive shrubs and to ascertain the effect of the protocol on species richness in the plant community.

The protocol described in this paper used sheep, rotated at 2-3d intervals through a series of enclosures, to manage an invasive plant, *R. multiflora*. The sheep were not returned to the original site until the full circuit has been completed, allowing the plant community time to rest for about 27-d (Figure 1). Sheep and goats have evolved digestive tracts and dental adaptations which enable these species to handle woody and thorny plants that other grazers are less physiologically adapted to handle. In a temperate grassland community, this is ample time for forbs, grasses, and other low-to-the-ground vegetation to recover.

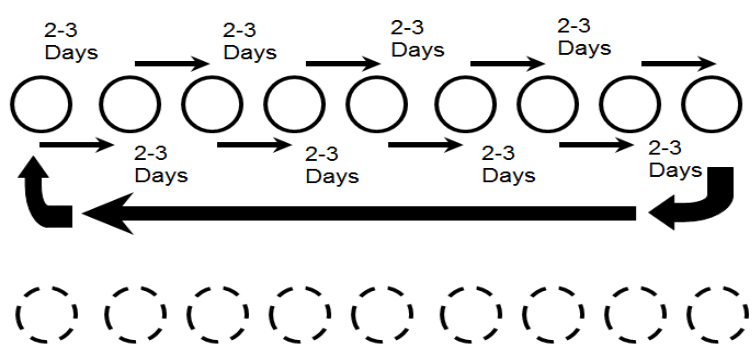

Figure 1: Conceptual design of an Intensive Rotational Targeted Grazing study across a landscape. Solid ovals represent grazed enclosures. Dashed ovals indicate corresponding un-grazed control sites adjacent to grazed enclosures.

Laliberte et al. (2012) suggests that an intensive grazing disturbance promotes prevalence of grazing tolerant plants with rapid growth strategies. *R. multiflora* has a slow growth model taking three to five years to mature with focused energy on thorny defense mechanisms. It is not the type of plant that Laliberte et al. (2012) suggests would thrive under IRTG.

In the first year of this study (2011) I sought to determine whether *R. multiflora*, a woody plant, could be managed with the IRTG approach the way it had been shown to manage grass and forb-based invasions (Kleppel and LaBarge 2011; Kleppel et al. 2012). In the second year of the study (2012) the longer-term effects of grazing management on *R. multiflora* and a potential cause of stress on the invasive shrub were studied.

3.0 Sheep grazing for management of *Rosa multiflora*

3.1 Methods

3.1.1 Study location

The experiment was conducted at Normanskill Farm in Albany, New York during the 2011-2012 field seasons. The goal for this project was to ascertain the efficacy of IRTG for managing *R. multiflora* on an early successional stage, pastoral landscape.

For more than a century, the Normankill Farm was an active dairy with approximately 63 ha of pasture and hayfields under management. In 1976 the dairy closed and part of the property was purchased by the City of Albany. A small portion of the property is currently used by the mounted and canine units of the City of Albany Police Department (APD). In addition, several governmental and public services (e.g., a dog walking park, hiking trail, and community garden) are located on the farm. Several years ago, an attempt was made to graze Angus cattle on the farm, but the terrain proved too rugged, and the enterprise was abandoned. Hay is still cut in one field.

Without grazing (but with annual mowing), the pastures at Normanskill Farm, which are dominated by orchard grass (*Dactylis glomerata*), have succeeded to a more wild community of forbs and grasses. Shrubs have also become increasingly abundant on the landscape. Invasive plants, including, purple loosestrife (*Lythrum salicaria*), Japanese honey suckle (*Lonicera japonica*) and multiflora rose (*Rosa multiflora*) were abundant throughout the former pastures. Other invasive species present in the pastures include garlic mustard (*Alliaria petiolata*), Japanese bittersweet (*Celastrus orbiculatus*) Canadian thistle (*Cirsium arvense)* and bull thistle (*Cirsium vulgare*).

3.2 Efficacy of sheep grazing an invasive shrub, *R. multiflora*

The IRTG grazing system used in 2011 consisted of eight, 0.1 ha enclosures (Figure 2). An ungrazed reference area was delineated adjacent to each grazing enclosure. The locations of enclosures were selected on the basis of *Rosa multiflora* density, as this was the invasive plant targeted for management on the Normanskill site. *R. multiflora* was the most abundant plant in seven of the experimental enclosures. Reference enclosures were selected after grazed enclosures were identified in locations adjacent to grazed enclosures and shared similar topography and plant community composition with the grazed enclosures. The other two experimental enclosures were dominated with *Lythrum salicaria*, and *Phalaris arundinacea*, respectively. The grazing enclosures were surrounded by Electro-Net® fencing (0.9 m high; Premier 1 Supplies). An Intellishock 20-B fence charger (Premier 1 Supplies), powered by a 12 A/12 V battery, and equipped with solar recharge, provided 5,000-8,000 Volts DC to the fence with an energy of 0.27 joules at a rate of 40 pulses min^{-1}. Only one fence was set up at a time.

This was moved around the study area during rotations. Thus, most of the time, most of the area was unfenced.

A flock of 13 sheep, obtained from local farms, was used during the first season. The sheep ranged in age from 2-13 years. On July 14, 2011, a 10-yr old ewe became moribund and was removed from the study. The sheep were stocked at an equivalent stocking density (SD) of approximately 9 tons ha^{-1}, about 4 times the SD typically used in conventional grazing systems. The flock was moved from one enclosure to the next at ca. 3-d intervals, an entire 8-enclosure cycle (plus an additional 1 enclosure not included in this study) requiring about 27-d to complete. The sheep were introduced into the enclosure system on May 23, 2011 and removed from the enclosure system on September 30, 2011.

Figure 2: Orthophotoquad (National Arial Photography Program) of Normanskill Farm, Albany, NY, with an overlay depicting the locations of grazed (black) and ungrazed (white) enclosures. The enclosures delineated by dashed circle did not contain any *R. multiflora*, but was still used during the rotation, and species richness data was collected there.

Shortly before dusk each evening, the sheep were moved into a barn to reduce the risk of predation. Each morning, at between 07:00 and 08:00 local time, the sheep were moved into the enclosure system with the aid of a border collie. The enclosures and the barn were supplied with fresh water, minerals and salt daily. Rye-straw was provided as bedding in the barn. A weekly health examination was performed on each sheep, to monitor flock health throughout the experiment (Appendix 1).

3.3 Data Collection and Analysis

Data were collected during three periods throughout the study, (i) prior to deployment of livestock in each enclosure (May 23- June 17), (ii) mid-season (July 23- Aug 13) and (iii) following removal of the sheep from the experimental enclosure system (September 1-30).

To evaluate the impact of grazing on *R. multiflora*, the photosynthetic surface area (PSA) of each plant in each enclosure was estimated. PSA was considered the surface area of the foliated portion of the plant. The shape of the canopy of a mature *R. multiflora* plant approximates a scalene hemi-ellipsoid. Thus, the PSA of each *R. multiflora* plant in each enclosure was estimated from length, width and height measurements by halving the approximation of Thomsen (2004) for the surface area of a scalene ellipsoid:

$$\mathbf{A \sim 2\pi\, (a^p b^p + a^p c^p + b^p c^p)^{1/p}} \qquad \mathbf{(1)}$$

$$\mathbf{PSA = A/2} \qquad \mathbf{(2)}$$

where A = surface area (m^2), a, b, and c = the lengths of the three hemi-axes and p = a constant, approximately 1.6075. The error associated with this approximation is $\pm$ 1.061% (Thomsen 2004). The foliated portion of a plant was defined conservatively, as stems containing more than 12 leaves m^{-1}. The length, width and height of the foliated portion of each plant were measured with a metered tape.

To determine the effect of grazing on species richness, S, of the vascular plant community, twelve 0.25 m^2 quadrats were randomly deployed in each grazed and ungrazed enclosure. Each plant in the quadrat was identified to the lowest taxonomic category, species where possible, and the number of species, whether identifiable or not, was estimated. This data was collected by Caroline Girard-Cartier (for full species list please contact her directly) Because many grasses are difficult to identify unless they are in flower, we likely underestimated the S.

Statistical analyses were performed with the Systat® 9.0 analytical software package. Within and between-treatment (grazed, ungrazed) differences in the estimated PSA of *R. multiflora* were assessed in relation to variability in time (sampling interval) and space (enclosure location) with a repeated measures ANOVA. Differences in species richness were assessed at two spatial scales – the quadrat scale (0.25 m^2; n=96) and the enclosure scale (0.1 ha; n=8). At the quadrat scale, the null hypothesis of no difference between means was assessed with Student's t-test without assuming equal variances (Systat 9.0). At the enclosure scale the null hypothesis of no difference between mean S in grazed and adjacent ungrazed enclosures was evaluated with the Student's t-test for paired samples (grazed, ungrazed).

3.4 Results

3.4.1. Changes in *R. multiflora* in grazed and ungrazed enclosures

Early in the 2011 season, the sheep did not seem to be grazing the *R. multiflora* plants, however by July 13th active grazing of *R. multiflora* by the flock was observed (Fig 3). In 2011, a total of 225 *R. multiflora* plants were monitored in the grazed enclosures and 221 plants in the ungrazed enclosures (Table 1). Prior to the beginning of the experiment, difference between the median size-frequency distributions of *R. multiflora* plants in the grazed and ungrazed enclosures was not significant (chi square goodness-of-fit test = 0.065; df = 3; $p > 0.05$). *R. multiflora* saplings and immature plants were heavily browsed, and were often completely defoliated by the end of the study. As a result, saplings and smaller plants were sometimes difficult to re-locate during mid- and post-season sampling. Large, mature plants were also heavily browsed. Not unexpectedly, most of the impact on large plants was evident on the lower portions of the shrubs (Figure 4).

Figure 3: Sheep actively grazing *R. multiflora*.

Table 1. Proportional median, minimum (Min) and maximum (Max) size-frequency distributions of *R. multiflora* in grazed and ungrazed enclosure in June 2012, prior to the onset of grazing. Chi Sq = 6.31 df = 4 p>0.05.

		Grazed % (N=225)			Ungrazed % (N=221)		
Category	Height (cm)	Median	Min	Max	Median	Min	Max
Large (2)	>120	0.35	0.29	0.48	0.25	0.11	0.39
Large (1)	120-80	0.18	0.03	0.52	0.25	0.08	0.28
Small	80-40	0.27	0.10	0.52	0.30	0.08	0.37
Sapling	<40	0.19	0.03	0.52	0.20	0.30	0.37

Figure 4: (a) A healthy *R. multiflora* plant prior to grazing (May 2011). (b) The same plant, partially defoliated, in September 2011, after the grazing season.

Prior to the deployment of sheep, the difference between mean ($\pm$SE) PSA of plants in grazed (18.01$\pm$7.83 m^2) and ungrazed (10.20$\pm$1.59 m^2) enclosures was not significant (Fig. 7; $t= 1.68$; $df = 211$; $p > 0.05$). The mean PSA in grazed enclosures declined by approximately 56.8% during the first year of the study, from 9.46 $\pm$ 3.27 m^2 in May-June to 5.41 $\pm$ 2.18 m^2 in September (Fig. 5). However, most of the decline occurred during the final third of the study. Mean PSA did not change significantly in the ungrazed enclosure over the same period of time. A repeated measures ANOVA was used to assess differences in PSA as a function of treatment (grazing), temporal (i.e., sampling interval) and spatial (enclosure location) variability. Over the entirety of the study, differences in PSA were due to enclosure location and time of sampling (pre-, mid-, post-season), but independent of treatment (Table 2a). However, in September, between-treatment differences were significant (Table 2b; $p < 0.01$). It should also be noted that prior to deploying the sheep into the grazing system, the difference in vitality of *R. multiflora* in grazed (Mean+SE=8.06 + 0.23) and ungrazed (Mean+SE=8.32+.22) enclosures was not significant (Student's t test; p>0.005). After grazing one season, the number of healthy *R. multiflora* plants in grazed enclosures had declined by 91% and the numbers of unhealthy and dead plants had increased by 205%. These results were not observed in ungrazed enclosures (Figure 11).

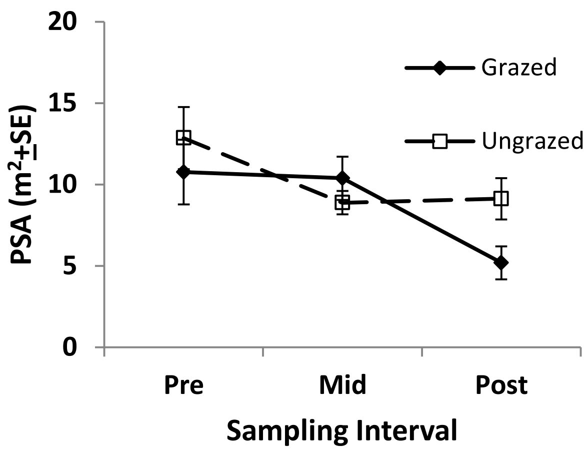

Figure 5: Changes in the photosynthetic surface area (PSA) of *R. multiflora* in grazed (squares) and ungrazed (triangles) enclosures at Normanskill Farm, Albany, NY, assessed three times during the 2011 grazing season: Pre (May 23; before livestock deployment), Mid (July 23; approximate midpoint of the season) and Post (September 30; after termination of grazing).

Table 2. Analysis of variance to detect changes in PSA as a function sampling time, treatment (grazed vs. ungrazed) and enclosure location.

Variable	F-ratio	df	p
a. Entire study			
Sampling Time	5.903	2	0.003
Treatment	1.907	1	0.168
Location	7.214	6	0.007

b. Post-season

Treatment	7.222	1	0.007
Location	1.005	6	0.421

3.4.2. Plant community species richness in grazed and ungrazed enclosures

Plant species distributions were patchy at the quadrat scale (0.25 m^2). The number of species varied from 1 to 19 per quadrat, with means ($\pm$ SE) of 9.24 $\pm$ 3.97 and 8.35 $\pm$ 3.85 in grazed and ungrazed portions of the landscape, respectively (Fig. 6). Coefficients of variation (= 100% x standard deviation/mean) in grazed and ungrazed portions of the landscape were 43% and 46%, respectively. The difference between mean species richness in grazed and ungrazed quadrats (0.25 m^2 scale) was not significant ($t = 1.57$; $df = 190$; $p > 0.05$).

Analysis was completed at the enclosure scale (i.e., 0.1 ha) by compiling all data points collected during specific times (pre, mid, and post treatment) in a given enclosure to eliminate patchiness of quadrat specific measurements, this adjustment in scaling revealed a different result (Fig. 7). Before deployment of the sheep, the difference between mean ($\pm$ SD) species richness in grazed (7.32 $\pm$ 3.26) and ungrazed (7.48 $\pm$ 2.09) enclosures was not significant ($t = 0.7$; $df = 8$; $p > 0.05$). After grazing operations concluded in September, the difference between mean S in grazed (9.28 $\pm$ 1.15) and ungrazed (8.37 $\pm$ 0.78) enclosures was highly significant (Student's $t = 5.76$; $df = 8$; $p < 0.001$).

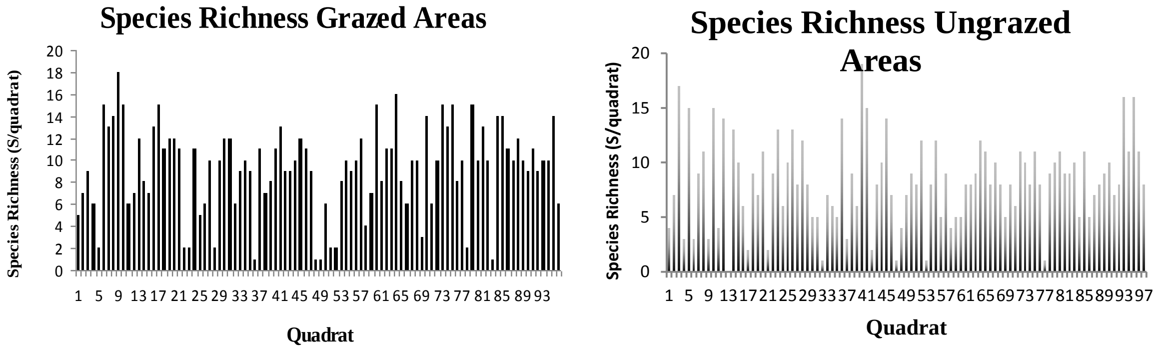

Figure 6: Mean species richness (S) in quadrats in grazed and ungrazed enclosures. S (grazed)= 9.24 + 3.97; S (ungrazed)= 8.35 + 3.85. Student's t=1.57; df=190; p>0 .05.

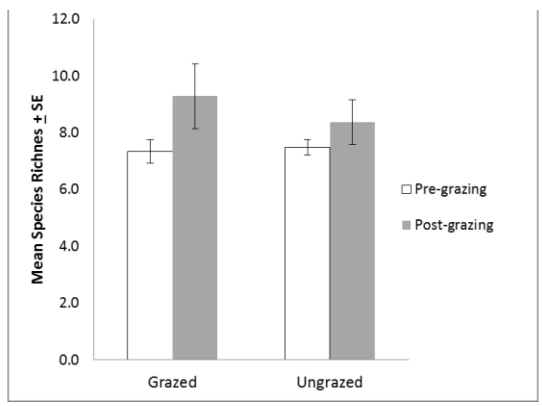

Figure 7: Mean species richness in grazed and ungrazed enclosures, prior to grazing (7.32 $\pm$ 3.26) and (7.48 $\pm$ 2.09) (Pre-grazing, May-June 2011) and after the grazing period (9.28 $\pm$ 1.15) and ungrazed (8.37 $\pm$ 0.78) (Post-grazing, September 2011) respectfully.

3.5 Discussion

The use of livestock to manage invasive plants communities is not new. In fact, the approach is quite common and is gaining in popularity as a means of replacing or supplementing the use of herbicides and energy-intensive mechanical approaches (Luginbuhl 2000; Tesauro 2001; Tesauro and Ehrenfeld 2007; Thorne 2001). Grazers and browsers have been used successfully to suppress cheatgrass (*Bromus tectorum;* Loeser et al. 2007), leafy spurge (*Euphorbia esula;* Rinella and Hileman 2009), kudzu (*Pueraria lobata;* Latshaw 2009), common reed (*Phragmites australis*; Kleppel et al. 2011), purple loosestrife (*Lythrum salicaria*; Kleppel and LaBarge 2011), mile-a-minute (*Persicaria perfoliata*; Girard 2011), giant hog weed (*Heracleum mantegazzianum*; Nielsen et al. 2005) and many others (*see*, Launchbaugh and Walker 2007). Caggiano and Kleppel (2010) reported on the local extirpation of *R. multiflora* from a pasture in New York's Hudson Valley by goats. The goats were not rotated and, while they suppressed the invasive, they severely overgrazed the landscape and required hay supplements to maintain their nutrition. Linginbuhl et al. (2000) also saw efficacy in grazing goats and goats with cattle on *R. multiflora* with the ability to decrease *R. multiflora* cover, open the canopy and enhance grazing tolerant plant composition.

The ITRG protocol appears to have had two effects on the plant communities in the landscape that we studied. First, we observed approximately a 51.81% decrease in the mean photosynthetic surface area in *R. multiflora* in grazed enclosures relative to plants in ungrazed areas. Second, we observed an average 27% increase in species richness, S, in grazed enclosures over the course of the experiment and a 10.7% higher S in grazed relative to ungrazed enclosures in the post-grazing analysis. This, we suggest, is not so much a function of the grazer species (goats versus sheep) as the management strategy (Savory 1983; Savory1999; Lunginbuhl et al. 2000; Fuhlendorf et al. 2001; Fuhlendorf et al. 2006). The high stocking density (9 tons ha^{-1}) and high rotation frequency (ca. every 3 d) of our IRTG protocol stands in clear contrast to the relatively low stocking density (2.4 tons ha^{-1}) and lack of any rotation of the goats by Caggiano and Kleppel (2010). This mimics the work Luginbuhl et al. (2000) saw when reducing *R. multiflora* cover from 2.5m2 to 0.4m2, however this study allowed grazers to remain on the landscape until the vegetation had been reduced to a height of 5cm or less prior to removal. Both Caggiano and Kleppel (2010) and Linginbuhl et al. (2000) utilized goats, but to prevent overgrazing Luginbuhl et al. (2000) removed goats and cattle from the landscape before overgrazing could occur causing increased biodiversity rather than degrading the landscape. One of the successes to the IRTG protocol is the visual management of the landscape and removal of livestock from the landscape prior to degradation similar to the success Luginbuhl et al. (2000) experienced.

It has long been known that wild ungulates, which generally have co-evolved with the plant community rarely overgraze (Milchunas 1988; Milchunas and Lauenroth 1993). These animals tend to aggregate densely in small portions of a landscape and to move constantly (Voisin 1959). These adaptations help to reduce predation and the re-ingestion of parasites. Intensive rotational grazing mimics these adaptations, and in agriculture has become recognized as a grazing management strategy that can improve pasture quality and livestock vigor (Savory 1999; DeGabriel et al. 2011). IRTG combines targeted grazing, i.e., the use of livestock to achieve specific vegetation management objectives, with intensive rotational grazing to both manage and improve the plant community (Kleppel et al. 2011). Rapid and substantial (25% - 53%) increases in S have been documented when IRG is used over the course of approximately 4-6 weeks, in ecosystems as diverse as wet meadows (Kleppel and LaBarge 2011), salt marshes (Ruifrok et al. 2014), upland parks and old fields (Girard 2011) and riparian zones (Kleppel et al. 2011). In the current study, the difference between S in grazed and ungrazed portions of the landscape was about 11%, somewhat smaller than observed previously. This may be due to the difference between the wilder landscapes, covered with herbaceous invasives in the earlier studies, and the present, pastoral site with shrubby invasives that are patchier in distribution and possibly less connected to the herbaceous components of the community. The relationship between the herbaceous and shrub components of the plant community in temperate pastoral systems remains to be clearly elucidated. Thus, we cannot quantify the extent to which grazing on *R. multiflora* directly contributed to the change in species richness in the vascular plant community.

The use of IRTG and other grazing strategies for vegetation management and particularly for controlling invasive plants should be thought of differently from other management approaches. Herbicide treatment, for instance, is often thought of (usually incorrectly) as a one-time treatment. Further treatment should not be necessary for a long time, if at all. IRTG is intended to be repeated regularly as a maintenance procedure, even if the invasive is completely removed. The repetition frequency depends on the extent of the infestation, the biology of the invasive species and the specific management goals of the project. One would predict that over time, the need for grazing for invasive suppression would decrease on a particular landscape, as the invasive is replaced by natives and less aggressive exotics. However, we suggest that grazing need not be halted. Rather, grazing can continue as an approach to maintaining the vitality of the plant community.

4.0 Rose Rosette Disease, *Rosa multiflora*, and landscape based IRTG treatment

During the 2011 field season it was noted that *R. multiflora* was exhibiting significant signs of stress, particularly in grazed enclosures. The signs of stress included stem elongation, clustering and loss of greenness in leaves (Figure 8). Regrown leaves on many grazed plants exhibited a red pigmentation. These symptoms are similar to those of plants infected with Rose Rosette Disease (RRD). As a result of these observations, the PSA was monitored throughout the 2012 field season and additional measurements were performed in grazed enclosures prior to ungulate deployment, mid-way through the study and after grazing had concluded.

Figure 8: Large *R. multiflora* displaying significant signs of stress.

4.1 Rose Rosette Disease

Rose Rosette Disease (RRD) was first identified in 1941 on populations of wild roses in Manitoba, Canada (Epstein and Hill 1995, Jesse et al. 2006). The disease is believed to be a membrane-bound virus-like particle, although the pathogen identity is unknown (Hindal and Wong 1988). RRD causes rose plants to exhibit specific symptoms: reduced leaf size, clustering of leaves, elongation of stems, increasing thorniness of stems, and reddening of regrowth each year, post infection (Jesse et al. 2006). RRD is fatal to *R. multiflora.* Typically the plant dies within 5 years of initial virus inoculation (Jesse et al. 2006).

RRD is transmitted by grafting of an infected plant to an uninfected plant, or via a mite vector, *Phylocoptes fructiphilus* (Allington et al. 1968; Doudrick et al. 1986; Epstein and Hill 1995; Thomas and Scott 1953). *P. fructiphilus* is known to overwinter on *R. multiflora* selectively and has been found to occur in high numbers on stems, buds, and bark of infected *R. multiflora* plants (Jesse et al. 2006). *P. fructiphilus* on *R. multiflora* plants exposed to full sun were observed to have higher numbers of mites than those in partial sun or shade (Jesse et al. 2006). The mite is known to have high proliferation rates and dispersal abilities (Jesse et al. 2006).

Many of the R. multiflora plants observed during the 2011 field season presented with what would be considered symptoms of RRD. During the 2012 field season the hypothesis was tested that RRD existed at Normanskill Farm by searching for the presence of the mite, *P. fructiphilus.* This would suggest that RRD was also contributing to the declining health of the *R. multiflora* population at Normanskill Farm.

4.2 Methods

In the 2012 season, the study shifted it's goals to testing a landscape based approach, per the sponsors' interest in how this technique be utilized on rough terrain. As a result, the previous smaller enclosures and their reference sites were absorbed into a larger 1.5 ha system consisting of six 0.25-ha enclosures, each of which were treated with the use IRTG grazing protocol (Figure 9). This eliminated the ability retain adjacent ungrazed locations as a means of comparison. The enclosures were made with semi-permanent fiber-rod posts (Premier 1 Supplies) configured to hold three strands of electric twine. Each enclosure was equipped with gates made with Electro-Net® fencing (0.9 m high; Premier 1 Supplies). The corners of the full 1.5 ha system were supported by wooden posts and support beams. These enclosures, unlike those used in the first year were not moved. Instead, they were meant to be semi-permanent. A Premier PRS 50 (Solar) Energizer Kit, powered by a 12 amp hour 12v sealed lead acid battery, and equipped with solar recharge, provided 5,000-8,000 Volts DC to the fence with a charge of 1 joule in 1.5 sec between pulses. The stocking density of sheep was comparable to that used in 2011. Sheep were moved in and out of the barn dusk and dawn to avoid predation.

Figure 9: Orthophotoquad (National Arial Photography Program) of Normanskill Farm, Albany, NY, with an overlay depicting the locations of grazed (white) enclosures 2012 study season.   Note: There was no reference site available this year of the study due to the expansion of the size in the grazed enclosures and change in study design.

4.3 Data collection and analysis

Vitality in *R. multiflora* was measured in the 2011field seasons. Each grazed plant was rated "dead," "healthy", with full, lush green foliage and no signs of stress, or "unhealthy" plant were the majority of the plant showing small red clustered leaves and little to no healthy green leaves. This assessment was made for every plant for which a PSA was recorded. All vitality estimates were made by the same observer as a means of keeping the scale consistent. Vitality was recorded prior to grazing, mid-way through each season, and after removal of grazers each season.

PSA data were collected from 86 plants in the enclosures during the 2012 field season to determine if a similar change in PSA was observed between 2011 and 2012 treatment areas was consistent. Values of length, width and height were collected and analyzed with the approximation of a hemi-scalene ellipsoid. Equal numbers of large, medium-sized, and small *R. multiflora* plants were monitored prior to deployment, mid-way through the season, and after sheep had been removed from the grazing areas.

Leaf samples (N=244) were collected to determine if there was a significant difference between the sizes of reddish and green *R. multiflora* leaves. Leaves were stored in zip lock bags, immediately placed onto ice in a cooler and transported to a freezer (-20^{o} C) for later analysis. To determine whether there was a mass difference between green leaves (healthy plants) and red leaves (stressed plants) (Figure 10), leaf samples were dried in an oven (50^{o}C) for a minimum of 24 hours, weighed, and the wet-dry weight difference was calculated.

Figure 10. Healthy green leaf and petiole *R. multiflora* sample as compared to unhealthy red leaf and petiole sample.

Additional leaf samples were taken (N=43) to determine if there was a significant difference between chlorophyll concentrations in leaves collected from healthy and unhealthy plants. These samples were collected at the beginning, middle, and end of the season. As soon as the leaf was collected it was placed in 90% acetone and then placed in a cooler and returned to the laboratory. The leaves were crushed with a mortar and pestle and the samples were extracted in 90% acetone at 5^{o} C for 24 hours. The extract was placed into a cuvette and decanted and its absorbance was measured at 700, 665, 645 and 630 nm with an Ultrospec 1000 spectrometer. The absorbance at 700 nm (used to detect noise) was subtracted from the aborbances measured at each of the other wavelengths. The amount of chlorophyll a in healthy (green) and unhealthy (red) leaf samples was quantified with the trichromatic equations of Strickland and Parsons (1972):

$$\mathbf{Ca = 11.6*E_{665} - 1.31*E_{645} - 0.14*E_{630},} \qquad \mathbf{(3)}$$

Where Ca = chlorophyll a (mg cm^{-2}), E_x = extinction coefficients at 650, 645 and 630 nm.

The Normalized Difference Vegetative Index (NDVI) was measured on individual red and green leaves or leaf clusters (N=47) with a Scout NDVI meter throughout the 2012 field season to assist in determining the relative health or stress of individual *R. multiflora* plants. NDVI is an indicator of the potential photosynthetic activity of the plant. In general, relatively high potential photosynthetic activity (i.e., relatively high NDVI) would be assumed indicative of a relatively healthy plant. Lower photosynthetic activity (low NDVI) should be indicative of stress (Wang et al. 2013).

$$\mathbf{NDVI = \frac{NIR-IR}{NIR+IR}} \qquad \mathbf{(4)}$$

To determine if the eriophyid mite *Phyllocoptes fructiphilus* was present on plants at Normanskill Farm, 61 leaf and stem samples were collected from unstressed and stressed *R. multiflora* as well as from the wool of five randomly selected sheep. It was observed that the sheep lay under the shade of *R. multiflora*, scratched against the branches and grazed on the invasive. Samples were transferred to 85% ethanol solution and stored at room temperature for later microscopic analysis.

4.4 Results

The vitality of *R. multiflora* in the grazed areas showed the percent of healthy *R. multiflora* decreased and both the unhealthy and dead *R. multiflora* increased (Figure 11). This trend was not observed in the ungrazed enclosures in the 2011 field season (Figure 11). Due to the sponsors request to determine how this protocol works in more rugged terrain, the reference sites were absorbed into locations with grazing treatment, eliminating the reference sites for the 2012 season. As noted in the 2011 IRTG treatment results, prior to deploying the sheep into the grazing system, the difference in vitality of *R. multiflora* in grazed (Mean±SE=8.06 ± 0.23) and ungrazed (Mean+SE=8.32 ±0.22) enclosures was not significant (Student's t test; $p>0.005$). One year after IRTG treatment, the number of healthy *R. multiflora* plants in grazed enclosures had declined by 91% and the numbers of unhealthy and dead plants had increased by 205%.

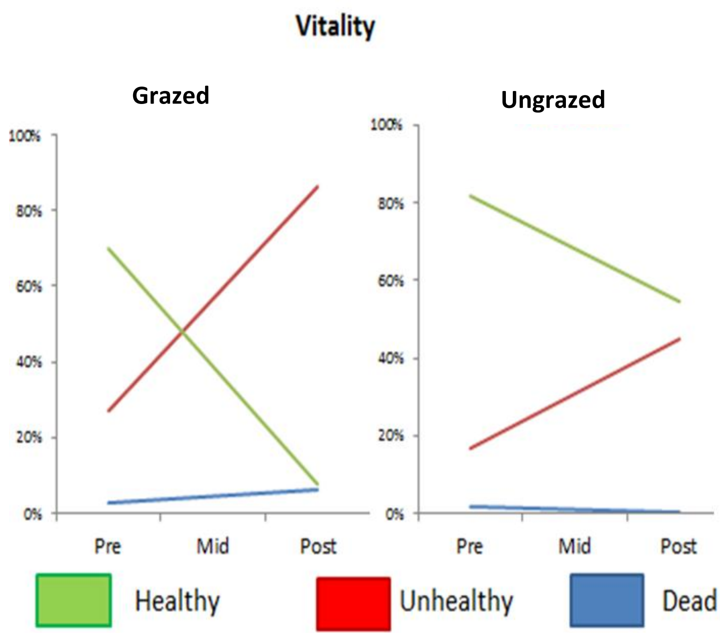

Figure 11: *R. multiflora* vitality measured over the duration of the 2011 field season.

PSA was recorded and observed in the 2012 field season. The decline in PSA in grazed enclosures from the start of the study to the conclusion during each field season was consistent (2011 – 56.8% decline and 2012 – 62.5% decline). Due to the landscape-based nature of the 2012 field season, no reference is available for direct comparison between grazed and ungrazed locations (Fig. 11).

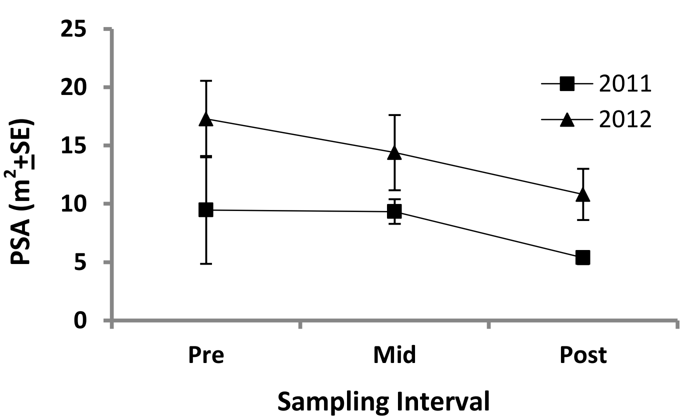

Figure 12: PSA pre, mid, and post grazing treatment in the 2011 and 2012 grazing season.

Analysis of green and red leaf chlorophyll, NDVI, and dry leaf mass measurements were performed to quantify the change in vitality as a function of grazing (Figure 13). A significant difference in the chlorophyll a concentration was observed (Student's t = 5.20, df=28, $p<0.001$) when comparing red (unhealthy) (Mean±Standard Deviation = 3.03 ±1.80) and green (healthy) (Mean ±Standard Deviation = 7.37 ±13.51) *R. multiflora* plants. There is also a significant difference in the NDVI in green (Mean ±Standard Deviation = 0.79 ±0.01) and red leaves (Mean ±Standard Deviation = 0.67 ±0.03) (Student's t = 2.76, df=32, $p<0.01$). Similarly, green leaves had a higher dry mass (Mean ±Standard Deviation = 0.021g ±0.014) than red leaves (Mean ±Standard Deviation = 0.004g ±0.003) did (Student's t =14.13, df=151, $p<0.001$).

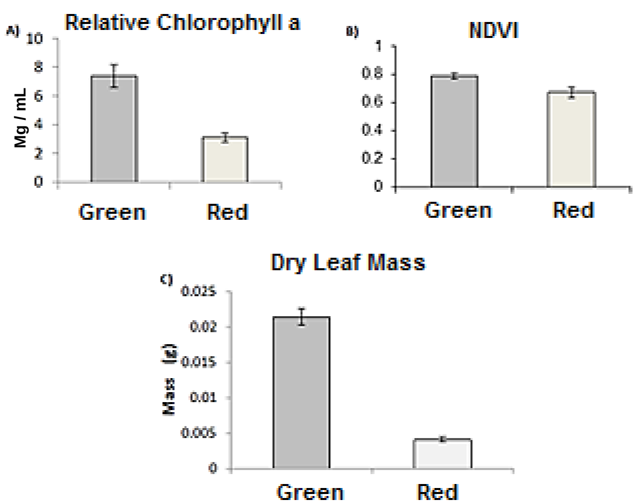

Figure 13: Physiological comparison of leaves from healthy (green) and unhealthy (red) plants. a) Relative chlorophyll a content of healthy (Mean+Standard Deviation = 7.37 ±13.51) and unhealthy (Mean+Standard Deviation = 3.03 ±1.80) samples T-Stat= 5.20, df=28, $p<0.001$. b) Normalized Difference Vegetative Index (NDVI) healthy (Mean+Standard Deviation = 0.79 ±0.01) and unhealthy (Mean+Standard Deviation = 0.67 ±0.03). c) Dry leaf mass of unhealthy (Mean+Standard Deviation = 0.004g ±0.003) and healthy (Mean+Standard Deviation = 0.021g ±0.014) samples.

RRD is typically found on *R. multiflora* plants with an abundance of *P. fructiphilus*. Very few mites were present in my samples (Table 3). The mean for all samples was 0.25 $\pm$ 0.65, which was unexpected. It should be noted however there were 4 mites found in all grazed samples and 3 in ungrazed samples. If these mites did carry the rose rosette disease, it is still possible that it was introduced into the population.

Table 3: *Phyllocoptes fructiphilus* counts

	Mean	SD	Min	Max	N (# samples)
Wool Sample	0.00	0.00	0.00	0.00	11
Unhealthy Ungrazed	0.00	0.81	0.00	3.00	66
Unhealthy Grazed	0.00	0.63	0.00	2.00	218
Healthy Grazed	0.00	0.59	0.00	2.00	130

4.5 Discussion

The 2011 field season lead me to question whether the decline in the health of *R. multiflora* was a result of grazing or RRD. There was a clear trend in grazed enclosures in both the 2011 field season that both the photosynthetic surface area of *R. multiflora* and the vitality of these plants decreased over time. This trend was not significant in the 2011 untreated enclosures. There was a decline in vitality in treated areas the 2011 field season, where the rate of decline in healthy plants was not as steep in the 2011 untreated locations. This was confirmed by chlorophyll analysis, the Normalized Difference Vegetative Index, and dry leaf mass analysis comparing green (healthy) and red (stressed) *R. multiflora* samples. The ANOVA, however, suggested that time and grazing were significant indicators of PSA changes; the longer the sheep were able to graze, the more significant the impact on PSA (Table 2). This study could not quantify the presence of the mite that transmits the RRD virus. There were some unhealthy *R. multiflora* plants in the untreated locations at Normanskill Farm. The untreated *R. multiflora* plants have not died off like those in the treated areas after returning to the site in 2015. Upon returning in spring 2015 to make casual observations at the site, most of the *R. multiflora* in the previously treated sites were dead, whereas in the previously untreated sites the plants were in budding.

P. *fructiphilus* was present in very low numbers; on average their presence was not different from zero. All signs and symptoms of RRD were apparent and became more pronounced in the second field season. Further research is needed to test for the presence of RRD virus at the research site. It appears that the thought that the sheep were acting as vectors for the virus has been negated.

The sheep frequently grazed near the bottom of the *R. multiflora* plants and then would sleep under the plants during hours of peak sun. Since one of the ways that *R. multiflora* grows is by re-rooting its stems into the ground, the sheep were effective in eliminating the vegetative spread of the invasive. IRTG treated *R. multiflora* plants were not showing signs of budding and were dead and brittle. *R. multiflora* outside the treated areas are not showing this pattern, they were budding and spreading vegetatively forming dense hedgerows. The number of healthy plants declined in both treated and untreated sites but at a steeper rate in the treated sites (Figure 11). This suggests that something was going on at the untreated sites. Further research would be required to determine if RRD be spread without mites. It is likely there were two stressors, IRTG and possibly RRD (though this hasn't been proven), at work in these treated sites.

5.0 Management Implications

The intensive rotational targeted grazing protocol can provide an alternative to many management techniques for invasive species management statewide. The IRTG protocol is a relatively inexpensive tool that can help provide jobs, boost the economy, manage state and private lands, and provide food in NYS. Farmers seeking to get a start who cannot afford land initially can graze their animals on special projects for the state. This allows management of state lands without tax dollar allocations, and in exchange the farmer can produce food and fiber to sell to the local community (Heitschmidt et al. 1990; Heitschmidt et al. 1991; Undersander et al. 2002). This technique has been formalized as a management strategy through a collaboration between the NYS Department of Environmental Conservation and the Biology Department of the University at Albany. The NYS Conservation Grazing Protocol (NYSCoG) is mutually beneficial to the state and to local agriculture. IRTG is not limited to NYS however; its techniques can be adapted to varying ecosystems and utilized for both invasive species suppression and general management large, naturalized landscapes. Private landowners can also adopt these techniques to manage their lands as grassland systems.

The protocol does have some limitations. The people managing the sites would need to be trained on livestock management. Site managers would also need to monitor and understand when the land has an increasing potential for overgrazing (Daubenmire 1940) due to heat, precipitation, and the availability of forage in the enclosures. This understanding is not particularly difficult to gain, but it does require some training prior to utilizing the protocol to ensure it is effective. If the land is not managed as the protocol indicates, degradation rather than restoration can occur.

Variation in fencing may be required if livestock other than sheep are utilized. Similarly, if working in a rugged terrain electronet may be unsuitable and electric twine more appropriate. Shelter or guardian animals would be required for grazers to remain onsite overnight. In this study, a semi-permanent fence and overnight shelter were available. Depending on the terrain, type of invasive targeted, and type of grazer being utilized during the treatment modifications may be necessary to the protocol explained in this study for successful implementation and similar results.

6.0 Conclusion

Overall, this study suggests the efficacy of using sheep to control a shrubby invasive. Previous studies by this lab have revealed the success this protocol on invasive forbes and grasses (Kleppel et al. 2011; Girard and Kleppel 2011; Kleppel and LaBarge 2011). The potential this protocol has in other regions and climates has yet to be tested.

The IRTG process is based on the work of Allan Savory (1983; 1999) in Africa, restoring deserts to grasslands with intensive rotational grazing practices. The science that backs Savory's process, however, is still not fully articulated. IRTG allows the science behind the rotational grazing practice to be implemented through the lens of invasive species management. Its implications, however, offer a much broader management approach that can be adapted for a variety of goals across mixed ecosystems.

The IRTG protocol can be used on a small patch of invaded land or on the landscape scale. It is a protocol that maintains the land while feeding livestock, whose excretions return nutrients to the soil, potentially feeding the plant community. This study shows that the IRTG protocol can be used effectively to suppress woody invasive after one year of treatment with a similar result after modifying the protocol the second year of the study. Further research on the long term effects of this study would be needed to determine if the IRTG protocol can have lasting impact on an invaded landscape after several years of treatment. Further research on the implications that other livestock managed with this protocol is needed. However as it stands, the technique is worthy of further consideration and development. It is relatively easy and inexpensive to implement and the land manager has greater control over the livestock than (s)he does with other management techniques (e.g., insect bio-control agents, that once released cannot be removed), but seems promising as the protocol leaves the land manager in charge of monitoring the landscape. If the grazers are overeating they can be moved.

The days of vast herd forming wild ungulates grazing in the landscape are past. If human processes which mimic former wild processes can be adopted, we can retain a closer, more sustainable connection with the environments we share with wildlife and retain the integrity of grasslands and forests alike. The use of the IRTG protocol merges agricultural productivity with conservation goals. It is sustainable and does not rely on fossil fuels, herbicides, or biocontrol agents that cannot be recovered once released. IRTG and programs like NYSCoG have the potential for state managed lands to be maintained in an eco-friendly, economically viable and ethically sound way; not to mention that it may save the tax dollars currently being invested in invasive management.

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Appendix 1: Sheep Weekly Health Assessment

	Date
	Examiner(s)
	Tag # **Sex** **Breed**
FAMACHA	**white pink red**
Limping/Lameness	**Y N**
Eyes	**Cloudy Clear**
Mucous	**Evident Not Evident**
Coughing	**Y N**
Breathing	**Labored Quiet**
Diarrhea	**Y N**
Bleeding/Abrasions/Lacerations	**Y N**
Spine (apparent nourishment)	**1 2 3 4 5** **Sickly = 1 Healthy = 3 Overweight= 5**
Hooves	**1 2 3** **Poor = 1 Good= 3**
Overall Physical Appearance	**1 2 3** **Poor = 1 Good= 3**
NOTES:	