THE IMPACT OF INVASIVE THISTLE SPECIES ON DYNAMICS OF CERCOPIDAE IN THE STIKINE-SKEENA REGION OF NORTHERN BRITISH COLUMBIA

by

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Photograph by J. Batters.

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ABSTRACT

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Keywords: alfalfa, Canada thistle, climate, crops, CO_2 levels, disturbance, economic expansion, invasive species, growth reduction, life cycle, meadow spittlebug, native flora, population growth, nymph, range expansion, spittle nesting, Stikine-Skeena, xylem-siphoning

During the Summer of 2019 I worked on suppressing invasive species spread in the Stikine-Skeena region of Northern British Columbia. I frequently observed invasive thistle species of the genus Cirsium hosting abundant individuals of the introduced meadow spittlebug, Philaneus spumarius, more so than other surrounding native flora. My own observations, as well as the scientific literature, point to the meadow spittlebug potentially preferring invasive thistle species due to reasons such as nymph development synchronization. Interpreting information provided by a number of sources, it is shown that invasive thistle species will continue to spread throughout the Stikine-Skeena from factors such as climate change, increased human development in the north, and the general invasive nature of thistle species. This paper suggests that this invasive thistle spread could benefit the population and ranges of P. spumarius as well. Assessing the destructive impacts of meadow spittlebugs on a vast number of crop species and native flora points to their additive spread only amplifying the severity of damage that comes with the spread of invasive thistle species like Cirsium arvense. This potential synergistic relationship may hold significant impacts on the economy and environment of the Stikine-Skeena region as climate change and human expansion continue to unfold.

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INTRODUCTION

During the Summer of 2019 I worked on suppressing invasive species spread in the Stikine-Skeena region of Northern British Columbia. I frequently observed invasive thistle species of the genus *Cirsium* hosting abundant individuals of the introduced meadow spittlebug. The observed spittlebug species, *Philaenus spumarius* L., has a global distribution and is non-native to North America. This species is considered an agricultural pest and are known to feed on over 400 species of plants. This vast diet includes valuable crops like alfalfa, wheat, oats, strawberries and corn, all of which can experience substantial yield reductions through spittlebug predation by both nymphs and adults (Cornara et al. 2018, Farms, 2019). Scientific literature shows that the meadow spittlebug shows a preference for invasive thistle species (Everly 1956, Gregg et al. 1989, Grant et al. 1996, 1998). Such a preference could indicate that invasive thistle species positively impact meadow spittlebug populations and that the population growth of the meadow spittlebug could benefit from the continued spread of invasive thistles throughout the Stikine-Skeena region of British Columbia.

If the environmentally and economically noxious Canada thistle (*Cirsium arvense* L.) contributes to a positive impact on meadow spittle bug populations, negative impacts may be seen in the native ecosystems and economy of the Stikine-Skeena region of British Columbia. The severity of these impacts could be potentially exacerbated from climate change and increased human development in the region.

My thesis will seek to see if a potential population increase of the meadow spittlebug is possible due to invasive thistle spread, and if such an increase will be more relevant to our economy and environment as time passes. The objective of this thesis is to examine the potential population response of meadow spittlebug populations to the spread of the invasive Canada thistle. If we see a positive host relationship between invasive thistle species and spittlebugs, then we can expect to see a spittlebug population increase as invasive thistle species continue to spread throughout Canada.

LITERATURE REVIEW

SPITTLEBUG ECOLOGY

Spittlebugs, also known as froghoppers, are hemimetabolous insects that belong to the family Cercopidae, in the order Homoptera (Hamilton 1982). The term "spittlebug" derives from the spit-like mass produced by nymphs and uses as a shelter (Hamilton 1982, Yurtsever 1999). The Cercopidae have been extensively studied by biologists over the past few decades due to their large habitat diversity, economic importance, global distribution, and unique ecological and polymorphic traits exhibited by many of its species (Whittaker, 1976, Yurtsever, 1999).

Most newly hatched spittlebugs quickly find themselves a suitable vegetative host from the random crevices, bark, or leaf sheaths they emerged from. Individual nymphs have been shown to move considerable distances if a suitable host is not in proximity (Hamilton 1982). Once a host is found, the nymph will insert its beak into the hostplant and proceed to draw xylem sap from the plant (Hamilton 1982, Hoffman & Mcevoy 1986). The excess water cycled through the nymph during this feeding is produced into spittle by the anus which is used to encapsulate the nymph, the sap sticking to its body and the plant (Wiegert 1964). The spittlebug can breathe in these spittle structures, and it allows them to remain in the artificial habitat for the entirety of the spittlebug's instars (generally around 5) providing the host plant specimen provides enough sap. These spittle masses provide excellent shelters against extreme environmental conditions and predators, allowing a very high percentage of spittlebug nymphs to reach the adult stage. Reaching maturity takes about 1-3 months after the nymph has hatched, depending on climate. (Hamilton 1982, Whittaker 1976, Yurtsever 1999). Adults, while indolent, are much more mobile than their nymphal stage. They do not reside in the spittle masses but instead move from host to host, feeding on large quantities of sap that can cause a severe loss of vigor for the hostplant (Hamilton 1982). Adults are long lived and can survive for up to 6 months in some climates. Death usually occurs with the onset of cold weather in late fall, although some have been observed alive until severe freezing occurs (King & Weaver, 1954). The reproductive cycle largely depends on the species of spittlebug, with some species producing 1-3 broods during the warm season (Hamilton 1982).

Spittlebugs in general have been shown to cause significant damage to native plants and crops (Hamilton 1982). Damage not only comes from the rapid sap feeding from adults, but the exposure of wounds from beak punctures and deposit of salivary toxins which can cause deformed leaves, form galls, defoliate branches, prevent proper formation of fruit and seeds, and in resinous plants may cause the formation of resin-filled pockets in the sapwood which can kill the whole tree (Hamilton 1982, Hoffman & Mcevoy 1986, Cornara et al. 2018).

THE MEADOW SPITTLEBUG

Philaenus spumarius, also known as the "meadow spittlebug" is an insect species belonging to the family Cercopidae, in the order Homoptera (King and Weaver 1954). The species is credited with eurytopic properties, that is it can thrive and tolerate a wide variety of environments, greatly assisting in the species wide global distribution. The species has been introduced to many areas and is reported to occur in Europe, Asia, Africa, Japan, and North and South America (King and Weaver 1954, Yurtsever 1999, Cornara et al. 2018).

Within this large habitable range, the meadow spittlebug occurs in most terrestrial habitats such as meadows, forests, marshlands, gardens, roadsides, and cultivated fields that provide sufficient host moisture to keep early nymphal stages alive (Yurtsever 1999, Farms 2019). Due to the characteristic spittle nesting of the family though, rather low humidity levels can be tolerated once a nest has been built thanks to the artificial environment it provides. The adult stage seems much less sensitive to humidity levels, however, with adults surviving into late fall, and as late as January in the northern United States (King & Weaver 1954).

When a meadow spittlebug hatches from its egg varies with climate, but always occurs in the period of early spring to early summer (Wiegert 1964). Depending on temperature, observed nymphal development times can take between 33 – 70 days to complete (Whittaker 1976, King & Weaver 1954). In North America egg-laying is a timely process for *P. spumarius*, with fully developed eggs not commonly found in mature adults until late September. The number of eggs laid can vary from 5- 50, which is rather low compared to other insect species, but is accounted for in that *P. spumarius* has a very low predation rate, like other species of the family Cercopidae (Hamilton 1982, Whittaker 1976, King & Weaver 1954, Yurtsever 1999). Unlike some other species of the family Cercopidae, it is generally agreed that *P. spumarius* is a univoltine species, producing only one generation in a summer and laying its eggs in fall (the overwintering stage), although there are some reports that the species is partly bivoltine in certain parts of Greece. (King & Weaver 1954, Wiegert 1964, Yurtsever, 1999).

Philaenus spumarius is thought to have the greatest cold tolerance amongst spittlebugs in the Cercopidae, being the only species observed past the 800-degree-day zone (Hamilton, 1982). This makes the climate of Canada hospitable for this invasive insect, including the Stikine-Skeena region of British Columbia (Cornara et al. 2018). This introduced species has been found in abundance on the eastern and western coasts as far north as Alaska, with the highest population density occurring within a 500 km radius of major ports (Figure 1) (Wiegert 1964, Hamilton 1982).

Figure 1. High density localities of *Philaenus spumarius*. The dashed circles represent the 500 km radius from Major ports. Source: Hamilton 1982

P. SPUMARIUS AS A NOXIOUS PEST

The habitat adaptability of *P. spumarius* is equally matched with its vast host range and voracious appetite (Everly 1956). It has been recorded as feeding on over 400 species of plants, including many ecologically important plants like the Genus *Solidago,* and many important economic crops, such as alfalfa, wheat, oats, strawberries and corn (Story 1985, Meyer & Root 1993, Yurtsever 1999, Farms 2019). Through rapid xylem sap ingestion in both nymphs and adults, significant host deterioration can be exhibited in localities with high densities of *P. spumarius*, so much so that crop yields can decrease up to 50 percent (Farms, 2019; Meyer & Whitlow, 1992).

Multiple studies were conducted by Meyer & Whitlow (1992) on the impacts of herbivorous insect predation on the goldenrod species, *Solidago altissima*. In both studies, the xylem feeding *P. spumarius* was compared to two other herbivorous insects, the leaf-chewing *Trirhabda* spp., and the phloem-sap feeding *Uroleucon caligatum*. Both studies found that the xylem sucking method of *P. spumarius* was, by far, the most detrimental of herbivores to the overall health of the greenhouse controlled *Solidago altissima* specimens. The recorded results were from goldenrod individuals that had about 20 spittle bug nymphs placed onto them for approximately two weeks. *Philaenus spumarius*-infested individuals were observed to have their leaf area and dry weight reduced by 27% and 37%, respectively, an internal increase in $C0^2$ levels, a 17% decrease in overall photosynthesis levels of the plant, and a growth rate decrease of 33%. Additionally, while new leaf production rates weren't slowed while the plant was infested, the area of newly produced leaves was, with a reduction of 63% in its total surface area (Meyer & Whitlow 1992). After *P. spumarius* was removed from the plants, a symptom recovery lag was exhibited and area of new leaf produced was still reduced in the following days, and the stunted individual still had not recovered in height up to 17 days after the removal of the spittle bugs, leaving many still stunted at the time of harvest. In high fertility soils, delayed flowering and reduced total seed biomass was also observed (Meyer & Whitlow 1992, Meyer & Root 1993). These detrimental effects were the consequence of two weeks of feeding by 20 spittlebug nymphs per individual goldenrod. With *P. spumarius* densities observed in the wild reaching 406 nymphs per m^2, these impacts can be amplified to extreme levels, especially when left untreated (Meyer & Whitlow 1992).

These high feeding densities and consequential health impacts to hostplants are not only witnessed on goldenrod but also, as previously stated, are exhibited in many plant species (Hamilton 1982). Alfalfa, a valuable crop species, has been seen to be a highly preferred host for *P. spumarius* as well, especially in their first year of growth, where densities reached 1280 nymphs/m^2 in a small alfalfa field (Wiegert 1964). A study of *P. spumarius* predation on *Erigeron glaucus*, otherwise known as beach aster, demonstrated the effects of feeding on the reproductive parts of this plant species; significantly less flower heads were produced by infested individuals, and a decrease in overall seed production was observed at the end of the season. The lag effect was again seen in this plant species as well, with a reduction in flower head production still seen three years after the spittlebug was removed (Karban & Strauss 1993). Although the exact detrimental impacts of *P. spumarius* varies between study and species, the consequences are still strong enough to exhibit negative consequences to the ecological fitness of the hostplant species at low densities of *P. spumarius*, and serious yield and reproductive impacts at large densities (Hamilton 1982, Meyer & Root 1993, Karban & Strauss 1993, Farms 2019).

Mass migrations of high-density populations of *P. spumarius* can occur if their feeding environments are disturbed. In the common scenario involving one of their preferred "juicy" hosts, such as the alfalfa crop being harvested or disturbed, the majority of the feeding nymphs and adults will migrate into the surrounding environment. The success of *P. spumarius* in the environment into which it newly migrated varied greatly, but these fleeing insect masses could constitute more than 50% of the above ground insect fauna biomass of their new habitats (Wiegert 1964, Hamilton, 1982, Hoffman & Mcevoy, 1986).

THE RELATIONSHIP BETWEEN THE INVASIVE THISTLES OF CANADA AND *P. SPUMARIUS*

Two studies conducted by Grant et al. (1996, 1998) involved the apparent high occupancy by *P. spumarius* on the invasive musk thistle (*Carduus nutans* L.). The musk thistle has overtaken many roadsides, pastures, and disturbed lands in Tennessee. During the peak of infestation in early to mid-April, 50-90% of the plants were infested with spittle masses. This level of infestation for a single hostplant species was not common and was of additional interest due to the invasive status of the musk thistle. The study selected 4 separate sites where high infestations were observed, one-half located in middle Tennessee, and the other half in the eastern region of Tennessee.

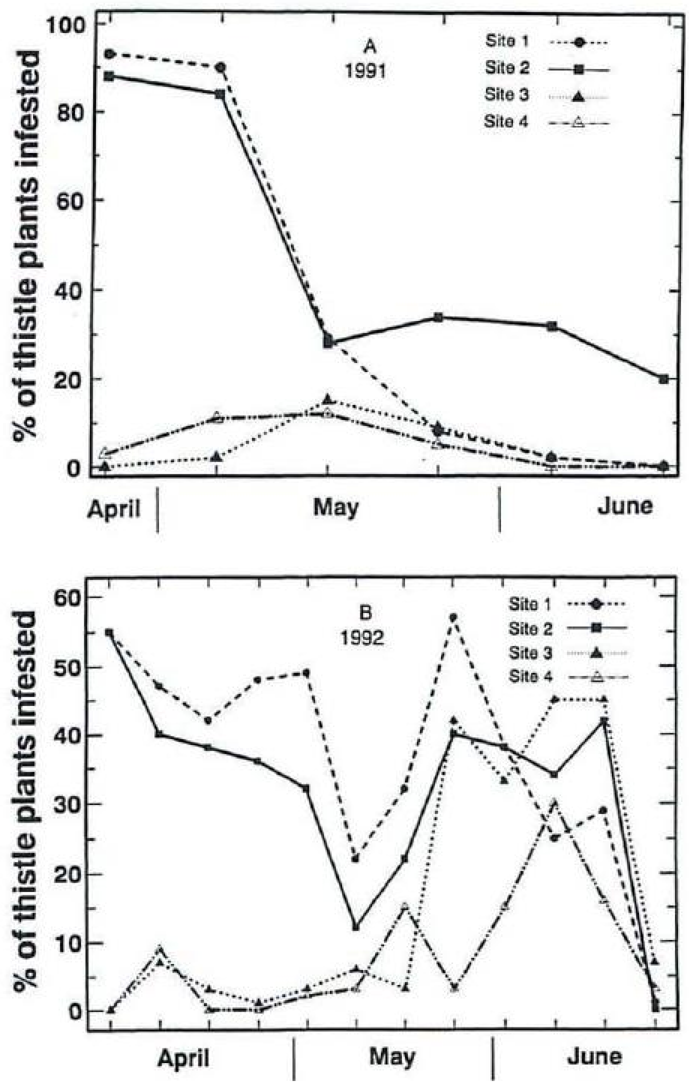

Figure 2: The percent of musk thistle plants infested by *P. spumarius* at four sites in Tennessee during active months of study for the years 1991 and 1992. Source: Grant et al. (1998)

As seen from Figure 2, infestation rates varied greatly between both study years and all four sites, but the study provided no conclusive explanation as to why any of these fluctuations occurred (Grant et al. 1998). Height of the hostplant species also fluctuated greatly; in 1991 musk thistles in eastern and middle Tennessee had an average height of 66.8 and 51.8 cm, respectively. In 1992 both sites saw an approximate decrease of 40% in their average heights, in which seasonal variation in environmental conditions was the posited explanation. The average number of spittle masses per musk thistle for eastern Tennessee peaked at four. The spittle masses were found to hold between 1-10 individuals, but the overall seasonal average between both sites was 1.5 nymphs per spittle nest. Consistent between both sites was the locational preference of the spittle masses, with 60-80% of them located between the leaf internodes (Grant et al. 1998).

A drastic decrease in the number of recorded individuals for both sites and years was found at the end of June. The paper suggested that the decrease in habitation occurs once a thistle has reached maturation, whereupon *P. spumarius* adults seek out more succulent hosts that are available in the surrounding vegetation, such as valuable crop species like alfalfa (Grant et al. 1996). The authors highlighted how musk thistle development synchronized well with the nymphal populations of the meadow spittlebug. The plants' early to mid-April development may provide the meadow spittlebug an important reservoir host during their nymphal development stage, whereas later on in development more plant species are available for sap intake (Grant et al. 1998). This observed high infestation rate of musk thistle in Tennessee was also documented in 1989 and 1990 (Grant et al. 1996).

Story (1985) studied the different impacts that phytophagous insects commonly found on the invasive Canada thistle (*Cirsium arvense*) would have on that species growth. Canada thistle is one of the most destructive plants in Montana, and the group had a high incentive to find a herbivore species that could potentially halt the spread of this highly successful and destructive invasive plant species (Story 1985). One of the common species they found nesting on the plant species was to *P. spumarius*. The spittlebug in the paper was described as "very abundant on *C. arvense* in a variety of habitats but had little noticeable effect on the plant" (Story 1985).

As seen from Table 1, *P. spumarius* was one of the most common insects detected on musk thistle in the Grant et al. (1996) study.

Table 1. Plant structural stratification of selected arthropod taxa found on musk thistle in Tennessee for the combined years of 1989 and 1990 (Grant et al. 1996).

Arthropod Taxa	n	Percent found on: Stem	Leaf	Bud	Flower	Seed head
Mordellidae	13	15.4[a]	0.0	0.0	84.6	0.0
Diabrotica undecimpunctata howardi Barber	10	20.0	0.0	0.0	80.0	0.0
Chauligonathus pennsylvanicus (DeGeer)	27	7.4	22.2	3.7	66.6	0.0
Grasshoppers	41	39.0	29.3	4.9	9.8	17.1
Orius insidiosus (Say)	36	0.0	0.0	0.0	100.0	0.0
Pentatomidae	19	21.1	0.0	10.5	21.1	47.4
Lygus lineolaris (Beauvois)	14	14.3	7.1	28.6	50.0	0.0
Philaenus spumarius (L.) (Adult)	237	44.7	42.6	9.3	2.9	0.4
Philaenus spumarius (L.) (Nymph)	206	69.9	26.2	3.4	0.5	0.0
Aphids	20	60.0	0.0	0.0	30.0	10.0
Ants	213	35.2	16.9	12.2	30.0	5.6
Thrips	1260	0.0	0.0	1.6	98.4	0.0
Spiders	49	24.5	8.2	0.0	49.0	18.4

[a] Percent of all individuals collected from musk thistle.

In Table 1, High numbers of *P. spumarius* were observed in their nymph stage and even higher numbers were observed in their adult stage (Grant et al. 1996). The study was able to quantify adult sightings and does indeed state that the adults still hold a significant presence on musk thistle, although these densities greatly decreased as the growing season progressed (Grant et al. 1996). This density decrease in the later months means that the adults of *P. spumarius* are either dying or migrating to other species, with migration being the likely explanation supported by other sources. (Hamilton 1982 , Wiegert 1964, Grant et al. 1998).

Another study (Wood 2018) surveyed the spittle nesting quantities on 31 infested plant species on Kent Island, New Brunswick, Canada. It was found that there was a very high discrepancy in spittlebug nesting selection by hostplant species. Goldenrod and the invasive Canada thistle (*Cirsium arvense*) hosted the majority of the spittlebug nests. While no concrete reasons were given in this paper as to why these plant species were selected, goldenrod species have been shown to be a preferred species of *P. spumarius* in other literature (Wood 2018, Meyer & Root 1993). Other sources have further supported the observation of high numbers of meadow spittlebug nymphs on *Cirsium arvense*, bull thistle (*Cirsium vulgare*), and other thistle species (Everly 1956, Henderson 1989, Crews et al. 1998). The research literature suggests that thistle species all share similar morphological traits of spiked stems and leafs, high density flower heads, and thick succulent stalks, and that many are highly invasive in Canada (Invasive species council of BC, 2019). This may be why multiple species of the genus *Cirsium* are noted as a highly preferred host for the meadow spittlebug.

SPREAD OF INVASIVE THISTLE SPECIES AND THEIR RELATIONSHIP WITH CLIMATE CHANGE

Invasive thistle species have been a serious concern in agriculture not only in Canada, but also globally (Guggisberg et al 2012). The invasive thistle, *Cirsium arvense*, originated from temperate regions of Eurasia where, even as a native plant, it is considered the third most harmful agricultural weed in that region (Guggisberg et al 2012). It has also been classified as one of the most invasive plants world-wide, overtaking niches of many native plant species as the dominant rangeland weed in all four continents it has been introduced to. It was thought to have been introduced to North America during the 17th century and had spread quickly due to its massive seed heads and seed counts, a consistent characteristic of *Cirsium* species. Its rapid spread is also attributed to the ability of *C. arvense* to spread vegetatively through its rhizomes (Guggisberg et al 2012, Craig 1894). This has made this species, and many other invasive thistle species very difficult to control through just mechanical removal; many requiring the use of herbicides such as glyphosate to completely eradicate. The aggressive spread of *Cirsium* species, their resistance to removal efforts, and the wide range of niche's occupied by *Cirsium* species allows them to outcompete and displace much of Canada's native vegetation and heavily impede crop growth; one such crop production of particular issue being that of alfalfa, with yield losses as high as 48% due to Canada thistle (Craig 1894, Invasive species council of BC 2019, Mesbah & Miller 2005).

Figure 3 shows the distributional range of *Cirsium arvense* in 2012 and the predicted range of spread based on native occurrence data.

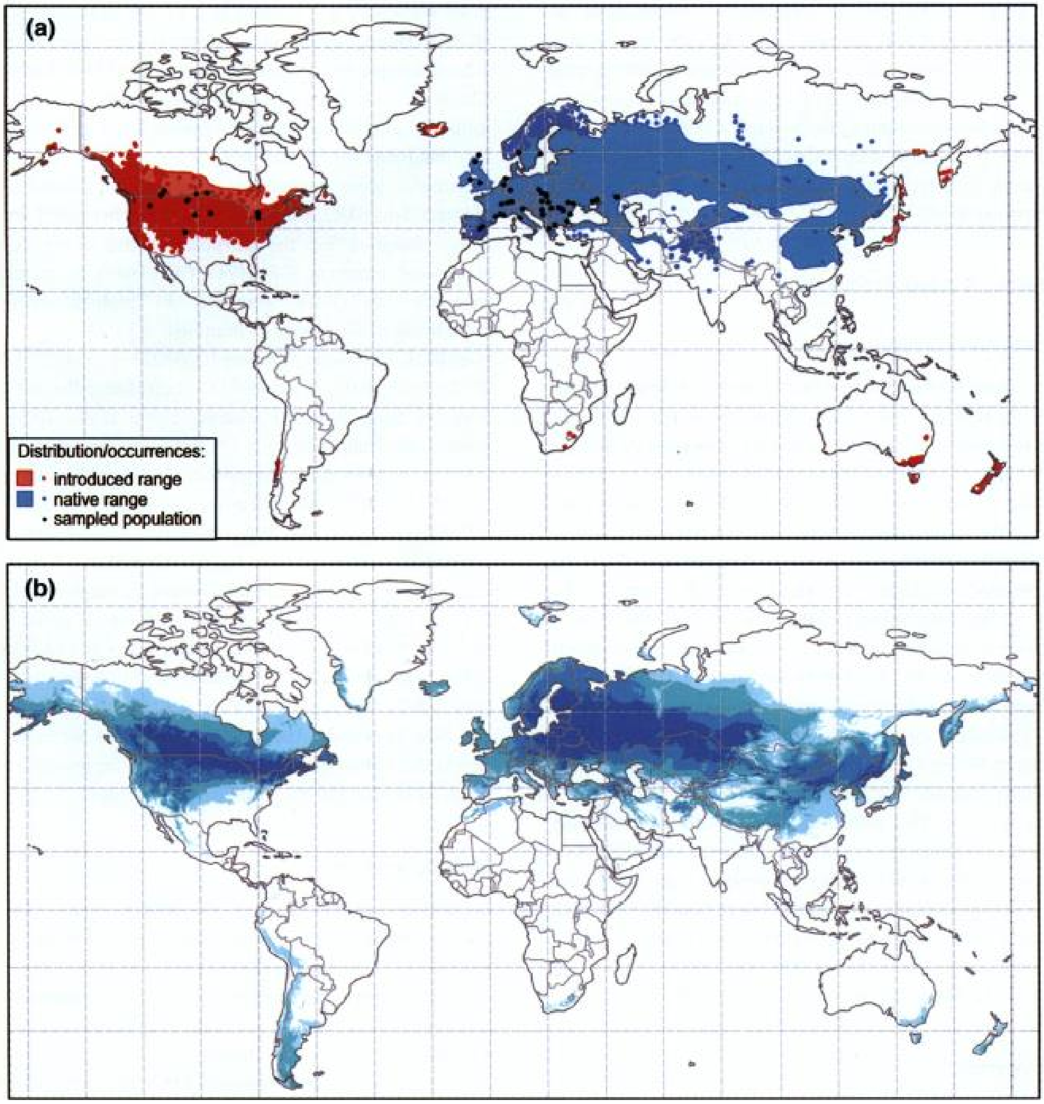

Figure 3. (a) The distributional range of *Cirsium arvense* in 2012 and (b) the predicted distribution of the species based on the native occurrence data at the time, with areas of higher climate suitability for the species highlighted in darker shades of blue. Source: Guggisberg et al. 2012

As seen from Figure 3 (b), the spread of Canada thistle is predicted to continue both northwards and southwards at every location of infestation based only on native occurrence data (Guggisberg et al. 2012). (These models, however, do not account for the global changing climate (Guggisberg et al. 2012); multiple studies suggest that climate change will most likely heighten the severity of this spread.

It has been emphasized in the literature that in a changing environment phenotypic plasticity, and general climate tolerance is a strong indicator for future success (Ditommaso & Lelements 2010, Walther 2009). As stable ecosystems continue to be affected by unusual climatic events, the niche species that compose the ecosystem and its constituent communities may experience less stability, lowering their future populations. These situations can leave ecosystems that once were filled with niche-occupied native vegetation vulnerable to more generalist invasive species that can flourish in a changing climate (Ditommaso & Lelements 2010, Walther 2009). Thistle species, especially Canada thistle, are categorized as such generalist species, and many have already outcompeted many native plant species on introduced continents such as North America. (Craig 1894, Guggisberg et al 2012 , Invasive species council of BC 2019).

There are some specific aspects of climate change that seem to benefit the growth and spread of thistle species. Multiple studies have looked into increasing CO_2 levels from human fossil fuel consumption and its impact on thistle species. One study conducted by Ziska (2003) involved six invasive species that were exposed to different historical and projected levels of carbon dioxide. His study reported Canada thistle as having the most extreme reaction by far to the varying levels of CO_2. As Ziska (2003) stated: “The average stimulation of plant biomass among invasive species from current to future [CO_2] averaged 46%, with the largest response (+72%) observed for Canada thistle. However, the growth response among these species to the recent [CO_2] increase during the 20th century was significantly higher, averaging 110%, with Canada thistle again (+180%) showing the largest response. Overall, the CO_2-induced stimulation of growth for these species during the 20th century (285±382 mmol mol±1) was about 33 times greater than for any species examined previously". The study also reported increases in leaf spine number and length, and most of the increased mass being allocated to both root and shoot growth (Ziska 2003). This study suggests that these extreme reactions to increases in CO_2 may already be a substantial reason towards the historic success in the spread of Canada thistle in North America and other continents over the past century. The results suggest that the increased CO_2 levels projected over the 21st century will continue to play a crucial role in the increasing success and spread of this species (Runion et al. 2008, Ziska 2003).

A study by Ziska (2004) reported that these increases in Canada thistle biomass have directly influenced their ressistance to one of the most popular chemical control methods for this invasive species, the herbicide glyphosate. Necrotic biomass damage above ground from the application of glyphosate showed no difference between CO_2 controlled plants, but belowground biomass was shown to be less damaged for enriched CO_2 specimens. This effect is due to better dilution of the herbicide due to a larger biomass in the enriched CO_2 specimens. This implies that more glyphosate would have to be administered to Canada thistle specimens as CO_2 levels increase their total biomass, therfore increasing the amount of total glyphosate needed to completely kill the plant (Ziska 2004).

METHODS AND MATERIALS

The foundation of this paper is based primarily on a literature review of previously published works. However, observational data from the field was the motivation towards crafting this thesis. Visual observations were noted, and pictures of insect interactions with invasive species were collected in the Stikine-Skeena region of British Columbia, Canada from May to August of 2019. This observational data was used to correlate previous literature findings to my observed relationship between P. spumarius and invasive thistle species in British Columbia. Because of the high number of plants infested with spittlebugs and work time restraints, few of the infestations were photographed or quantitatively documented. The few cases that were documented were photographed with an LG G6 phone and had the host species as well as the suspected spittlebug species identified. Documenting the invasive species composition of our management sites in Microsoft Excel was required for my work at the company Spectrum Resources. With this requirement, I was given access to the 2015 to 2019 invasive thistle species survey data. This information surveyed the flora composition of hundreds of Stikine-Skeena region sites. This information was in Excel tables provided by Spectrum Resources, and included the site number and time observed, and gave measurements in hectares of invasive thistle observed for active sites. I have analyzed this provided data to highlight its relevant information in this studies results.

RESULTS

This results section contains the accumulated observational photos of Cercopidae species interacting with invasive thistle species during the Spring and Summer of 2019 in the Stikine-Skeena region. Thistle species hosting spittlebugs was a common sight, so a select few photos are provided here to demonstrate the typical interaction I observed between the species. Many of these interactions were noted outside of Prince Rupert, Terrace, Kitwanaga, and Port Edward, on street sides, public paths, and gravel pits. Interactions of the spittlebug were documented on Cirsium vulgare (bull thistle), Cirsium arvense (Canada thistle), and Cirsium palustre (marsh plume). In many of these environments the spittlebug seemed to dominantly favor the thistle species as a host, whereas surrounding vegetation, both native and invasive, such as Hieracium caespitosum (Yellow hawkweed), Castilleja indivisa (Indian paintbrush), and Polypodium glycyrrhiza (licorice fern) were far-less common to be hosting any spittlebugs. In monoculture stands of thistle species, it was not uncommon to see more than one spittle mass on each thistle plant, whereas nearby surrounding patches of other flora would often be entirely devoid of any evident spittle nesting (Figure 4-6). The overall health of the thistle species observed hosting spittlebug specimens did not appear to deviate from other thistle plants devoid of nesting spittlebugs.

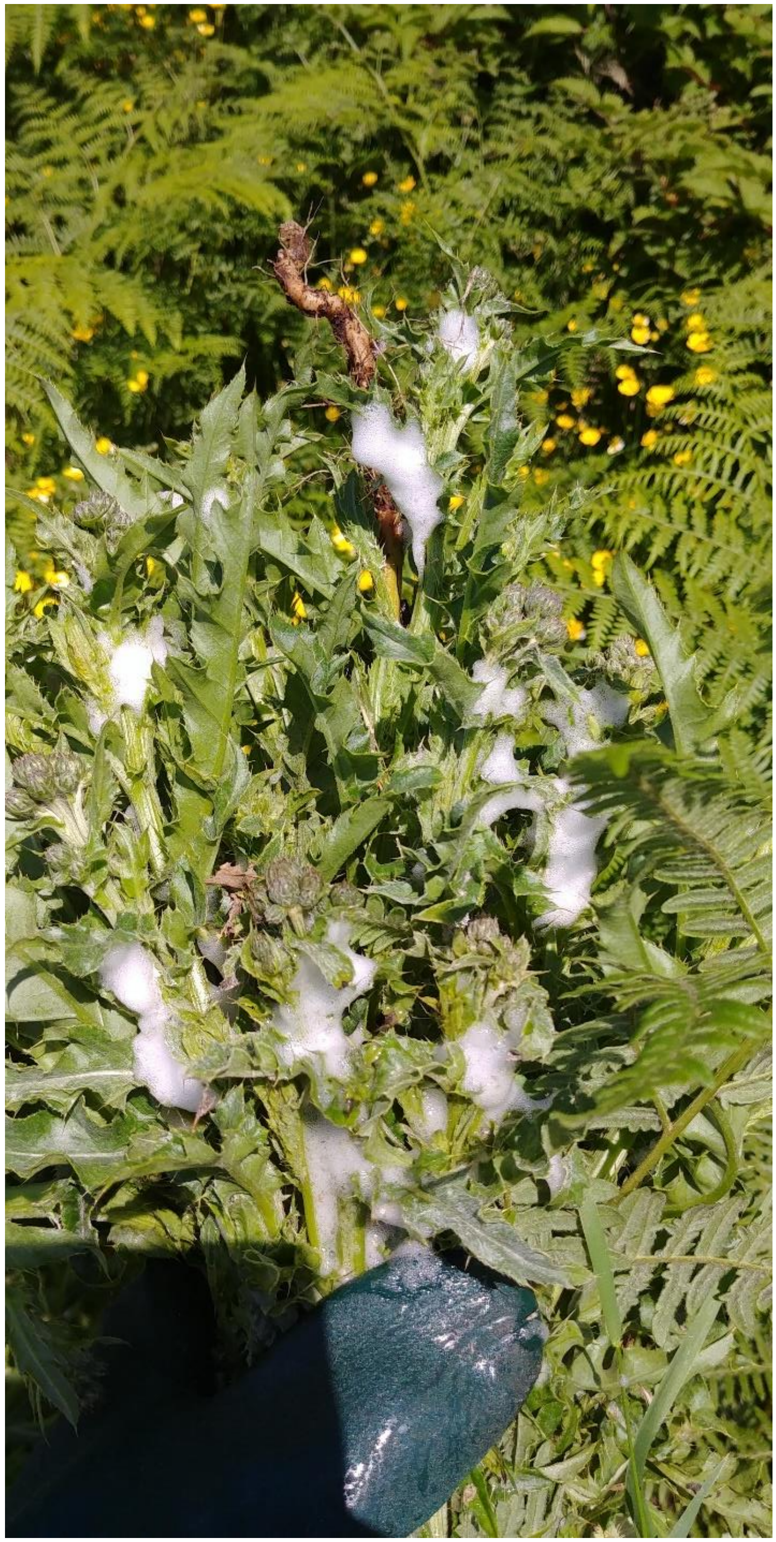

Figure 4. Multiple meadow spittlebug specimens nesting on a single *Cirsium vulgare* specimen. Photograph by J. Batters.

Figure 5. A grouping of *Cirsium vulgare* individuals exhibiting high infestation rates of the meadow spittle bug. Photograph by J. Batters.

Figure 6. A disturbed meadow spittlebug (underneath the flower buds) removed from its nesting on a *Cirsium vulgare* specimen. Photograph by J. Batters.

Survey data of observed invasive thistle species from 2015-2019 in the Stikine-Skeena region was additionally provided by Spectrum Resources. This data has been summarized and presented in Excel graphs and Google Earth imaging to help visualize the past and present density, range, and thistle species distribution over Stikine-Skeena region of British Columbia. Table 2 and Table

Table 2. The number of active invasive thistle sites by species and year from 2015- 2019

	Active Annual site #				
Invasive thistle species	2015	2016	2017	2018	2019
Cirsium vulgare	49	62	97	79	85
Cirsium arvense	44	104	120	117	117
Cirsium Palustre	39	40	54	48	54
Sonchus spp.	11	41	58	48	55

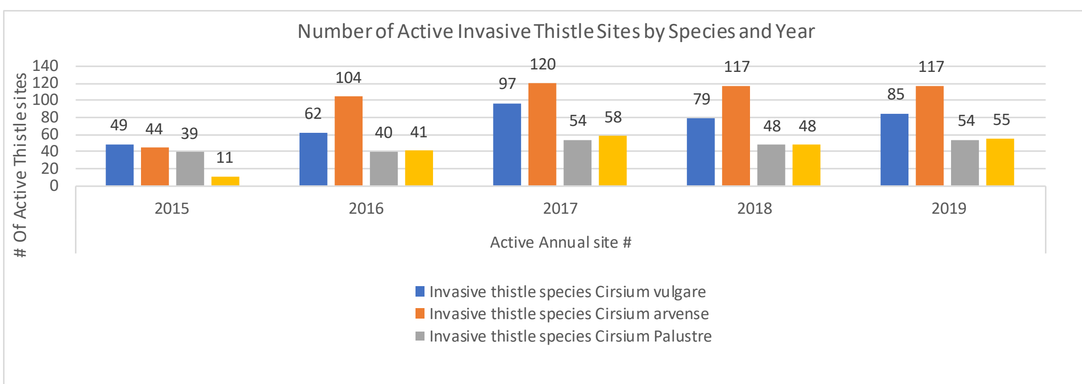

Figure 7. The number distribution of active invasive thistle species sites by species from year 2015-2019.

Looking at Table 2 and Figure 7, it is apparent that Canada thistle and bull thistle are the most abundant invasive thistle species surveyed in the Stikine-Skeena region, with Canada thistle having the highest number of active sites by a large margin in 2016 and onwards. A drastic increase in surveyed sites is seen from 2015 to 2016. This is likely due to higher budgeting provided to Spectrum Resources for surveying and increased public attention in the Stikine-Skeena region. From 2017-2019 we see active invasive sites level off with little to no changes in their quantity. However, Table 2 and Figure 7 do not record sites that were previously active with invasive thistle species. As Spectrum Resource group specializes in invasive species removal through mechanical and chemical means, many invasive thistles are removed from sites entirely for years on end, thus removing them from the active site count. The lack of either a drastic increase or decrease from 2017-2019 indicates that thistle-eradicated sites are being replaced by new active sites from invasive thistle spread.

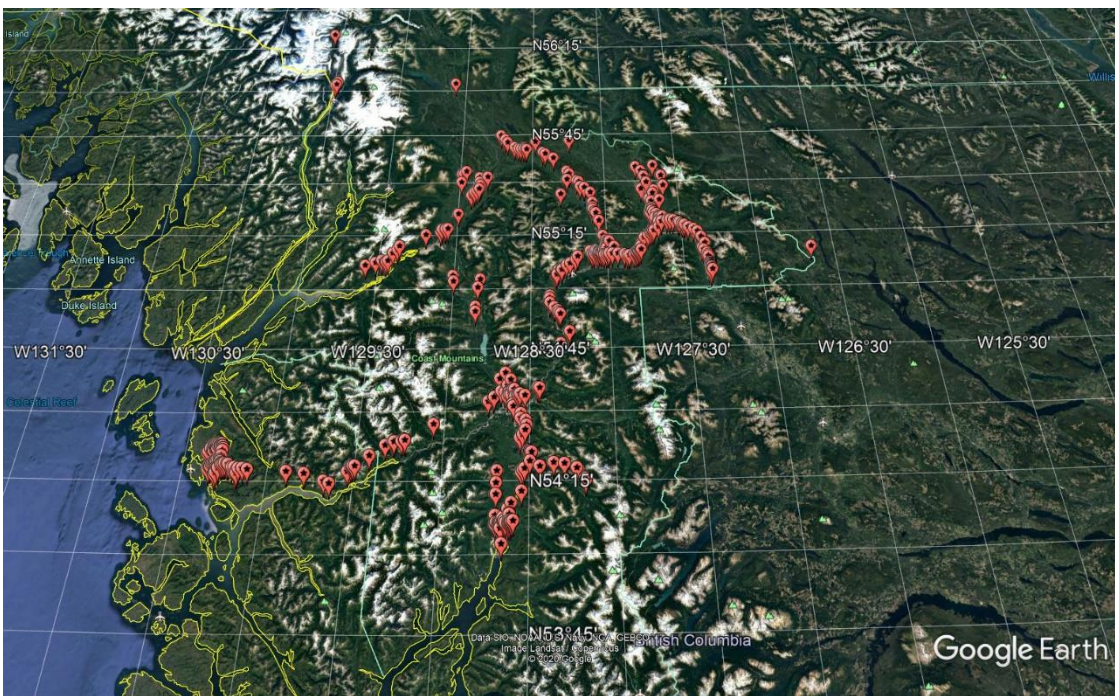

Figure 8. A Google Earth image displaying all sites that hosted an invasive thistle species during any year between 2015-2019 in the Stikine-Skeena region. Source: Google Earth.

Figure 8 shows the layout pattern that invasive thistle species have taken within the Stikine-Skeena region. We see the groupings with the highest density of active sites are that of major cities like Prince Rupert and Terrace, and that most of the other marked points exactly follow the major highways present in the region. Overall the range shown from Figure 8 tells of an expansive reach on the Stikine-Skeena region, with thistle presence as high as above N56 °15’.

DISCUSSION

The spittlebug family Cercopidae has shown itself to be an adaptable family of insects, with members like the meadow spittlebug, P. spumarius, having an incredibly wide global range and voracious appetite for a vast diversity of plant species (Yurtsever 1999). The species has been observed in the Stikine-Skeena region in both the past literature and from my own observations (see Figures 1 and 6). In this region the meadow spittlebug has access to many native species that typically grow in open fields and as roadside vegetation. Some of this integral native flora, like the goldenrod genus, Solidago, have been referenced as preferred host plants for the meadow spittle bug, and this insect has been reported to have extensive negative impacts on hostplant species through significant decreases in leaf area, dry weight, photosynthetic capabilities and overall growth rate (Meyer & Whitlow 1992). While the goldenrod population density tapers off at higher altitudes, these same negative impacts on host flora has been shown to impact a wide variety of flora species, which could influence both native and invasive species dynamics (Invasive species council of BC, 2019).

Qualitative observations of hundreds of roadside sites scattered throughout the Stikine-Skeena region showed the common occurrence of the meadow spittlebug nesting on invasive thistle species. Such thistle species the spittle bug was observed feeding on were *Cirsium vulgare*, *C. arvense*, and *C. palustre*. In many of these environments the spittlebug seemed to dominantly favor the thistle species as a host. Monoculture stands of thistle species commonly had more than one spittle mass on each thistle plant whereas surrounding patches of other flora like grasses, Indian paintbrush, and licorice fern would often devoid of spittle nesting. Literature documenting *P. spumarius* host preference of multiple thistle species, as well as this thesis study's own qualitative observations, lead me to believe that general shared traits among the thistle families are beneficial to meadow spittlebug populations, and that this spittlebug host preference could be exhibited in most thistle species.

The reasons why the meadow spittlebug may prefer thistle species is unknown but, unlike other plant species mentioned in the literature, thistle species do not seem to experience any consistent negative impacts from hosting moderate spittlebug populations (Grant et al. 1998, story 1985). Without negative impacts to their reproduction and growth from the spittlebug and other native plant species, invasive species like Canada thistle can flourish in open environments where native vegetation cannot compete, allowing the species to develop monodominant stands of pure thistle. These monocultures were commonly seen throughout my observational sites and could be even more beneficial to meadow spittlebug populations with access to an abundance of one of their seemingly preferred species.

Interestingly, the past literature notes that spittlebug nymphs and adults feeding on musk thistle migrated to other surrounding plant species as the thistle species reached maturation near the end of June (Grant et al. 1996). It was found that musk thistle acted as an important reservoir for the meadow spittlebug earlier in the season, whereas later in development more plant species were available for food intake (Grant et al. 1996). This synchronization of development between Canada thistle and the meadow spittlebug may be seen with other thistle species present in the Stikine-Skeena region, and may hint to the possibility of some form of co-evolution having occurred between the two species. This synchronization also may imply that surrounding native flora would experience the majority of the detrimental meadow spittlebug feeding impacts later in the season, after the thistle species has matured. The adult stage of spittlebugs often move from host to host and may bring even more potent detrimental impacts to native flora as the season progresses (Andrew. 1982, Hamilton 1982).

The research literature and my own data show that invasive thistle species like *Cirsium arvense* are continuously expanding throughout the Stikine-Skeena region and the rest of Canada . These range expansions have been induced by the invasive/generalist nature of these thistle species succeeding in highly disturbed areas, as well as rising CO_2 levels that are increasing vegetative biomass of Canada thistle far more than surrounding flora. As seen from Figure 8, the areas where invasive thistle species seems to flourish the most is along major highways and within cities, areas that experience frequent environmental disturbance through urban expansion and plant clearing. These locations are also where public reports of invasive thistle species are high (especially in cities), and the means of accidental invasive spread through vehicular transportation would be very likely.

With rising temperatures brought about by climate change, we can expect to see a gradual increase in agricultural productivity in northwestern areas of British Columbia like the Stikine-Skeena region with shorter, milder winters, and longer, hotter summers (Cline, 2008). Because of this, already popular crops in British Columbia like alfalfa and wheat could become more common in these northern regions (Cline, 2008). This would increase suitable conditions for both *Cirsium arvense* and *Philaenus spumarius*. Canada thistle grows well in open monoculture crop fields like alfalfa and can decrease yields as high as 48% in such fields. The meadow spittlebug has also been shown to highly favor crop species like alfalfa and wheat, which has led to huge spittlebug populations feeding on these crop species and resulting in yield decreases as high as 50% (Farms 2019, Mesbah & Miller 2005, Wiegert 1964).

Again, the apparent mutualism between the meadow spittlebug species and Canada thistle may lead to even greater crop yield losses and higher preventive management costs in the form of herbicides (Ziska 2004).. If economic expansion accelerates in northern British Columbia due to a favorably changed climate, we could also expect to see increased road infrastructure and transportation. This will only create more open disturbed environments for Canada thistle to flourish in and more transportation to pick up its seeds and promote its spread. As seen from Figure 8, these disturbed environments are where invasive thistle species best flourish. Such a positive impact for thistle species that leads to a larger population range and density could therefore also lead to a larger population range and density for the meadow spittlebug as well.

Zones of disturbance could allow mass migrations of spittlebugs into the surrounding environments if it follows the spread of invasive thistle, causing more damage to the surrounding environment (Karban & Strauss, 1993). Monoculture crops and roadsides experience regular floral disturbance through harvest and mowing at a certain point of growth. These disturbances can cause mass migrations of spittlebug nymphs and adults into the surrounding environment. Potentially composing more than 50% of above ground insect biomass of these newly migrated habitats, such migrations could have significant impacts towards surrounding forest and open field ecosystems (Wiegert 1964, Hoffman & Mcevoy, 1986, Hamilton, 1982).

As climate change continues to worsen and CO_2 levels continue to rise, Canada thistle will most likely continue to benefit and expand its range (Ziska 2004). As the scientific literature and my own observations suggest, if invasive thistle species act as a highly beneficial and preferred host to meadow spittlebug species, then we can infer that the range and populations of the meadow spittlebug will increase with the continued success of invasive thistle species. Such a species relationship will only amplify the severity of damage that their invasive spread will bring to both native ecosystems and crops, which could prove a hinderance to economic development and ecosystem preservation in the Stikine-Skeena region.

CONCLUSION

My observational data, as well as previous scientific literature, point to the meadow spittle bug having a strong preference for multiple thistle species, especially *Cirsium arvense*. These preferences could indicate that thistle species positively impact meadow spittlebug populations by providing suitable and well synchronized habitats for nymphal development. Invasive thistle species will continue to spread throughout the Stikine-Skeena region as a result of climate change, increased human development in the north, and the general invasive nature of thistle species. This invasive thistle spread could therefore potentially benefit the population and ranges of *P. spumarius* as well. With the recorded destructive impacts meadow spittlebugs hold on a vast number of crop species and native flora, their additive spread will only amplify the severity of damage that comes with spread of invasive thistle species like *Cirsium arvense.* This potential synergistic relationship may hold significant impacts on the economy and environment of the Stikine-Skeena region as climate change and human expansion continue to manifest. It is suggested that more in-depth research occur on the relationship dynamics between *P. spumarius* and invasive thistle species, as well as the impacts *P. spumarius* has on surrounding native flora in the Stikine-Skeena region.

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