Control Measures of Gypsy Moth and the Effect of STS Modeling in Canada

By

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ABSTRACT

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Gypsy moths are an introduced invasive species which causes decline in oak and maple in southern Ontario. In 1869 the moth was introduced into Massachusetts by Leopold Trouvelot, whose mission was to start a silk industry in America. The experiment was to breed European gypsy moths with the North American silkworms. During the experiment some European gypsy moths had escaped and an outbreak started shortly after. STS or "Slow The Spread" modeling which was used in the United states has proven to work and it should be implemented in Canada as well. It would cover 75 million Ha and would cost $15 million per year. Due to high populations and yearly potential for population increase it is extremely difficult to manage gypsy moths in urban areas. There are multiple biological, chemical, and mechanical control methods available for gypsy moth control, but they are expensive. Using pheromone traps has proven to be the most cost-effective method of capturing and controlling the populations. Slow the spread programs in the USA have proven to be successful in limiting the spread of gypsy moths.

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INTRODUCTION

The gypsy moth (*Lymantria dispar* L.) (Lepidoptera: Lymantriidae) was introduced to the United States in 1869 by Leopold Trouvelot. Trouvelot was born on December 16th, 1827 in Aisne, France. In 1851 his family fled France and came to America where they settled in the town of Medford, Massachusetts. From an early age, Trouvelot had an interest in entomology. During that period the United States was having a difficult time producing silk because the silk producing moths, the Asian silkworm (*Bombyx mori*) were being killed by diseases. Trouvelot had an interest in the Lepidoptera and decided to bring gypsy moth egg masses from Europe in the mid 1860's. The gypsy moth larvae were being raised in the forest behind his house but some larvae escaped and began to populate the forest. Following this incident, Trouvelot changed his mind and decided to study astronomy. He attempted to warn state officials about the outbreak, but he was not taken seriously. The problem became worse and by the time the state decided to control the moths it was too late and they began to spread faster.

Gypsy moths have spread as far as northern Ontario, southern Quebec, Massachusetts, Pennsylvania, and many surrounding states. In Canada, the gypsy Moth can mainly be found in Ontario, Quebec, Manitoba, Saskatchewan, and Alberta, with some sightings in British Columbia. Some provincial records are based on trapping males, but there are no established gypsy moth populations in the prairie provinces.

The Asian gypsy moths cause about $868 million annually in damages to trees and homeowners. Gypsy moth damage does not typically kill the tree unless defoliation occurs two years in a row or if it happens at the same time as a drought (Kille, 2012). There are many different control measures for the gypsy moth, but they are expensive, and the average homeowner is unable to afford to have their trees sprayed with chemicals. There are cheaper methods which will mitigate the spread of gypsy moth and decrease their population sizes. The objective of this thesis is to find a model for gypsy moth population control which is cost effective and available to the public. Finding a model that would be effective would result in a decrease in gypsy moth populations in Canada.

1.1 IDENTIFICTION AND LIFE CYCLE

Egg masses are laid by the female gypsy moth during the late summer. These egg masses are a light orange color (Figure 1) and can contain up to 500 – 1000 eggs within one mass. These eggs are 1 mm in size and are silver in color. These masses can be seen on trees under the branches and inside cracks between the months of August to May (Montgomery, 1988). The outside of the egg mass is fuzzy which protects the eggs from wasps and other small insects.

Figure 1: Gypsy Moth Egg Mass (Bugworld, 2017)

The gypsy moth caterpillars hatch in early May which is directly after bud flush (McManus, 1989). The caterpillars are very small in size and are only 5 mm long. These small, black caterpillars are very slow and will start climbing the tree to get to the leaves on top. The caterpillars are very light and will spin a small strand of silk which will carry the tiny caterpillar in the wind to nearby trees. This process is called ballooning and the caterpillar will be carried for about 1 mile (McManus, 1989). This is a very effective dispersal method which results in epidemic numbers of caterpillars on trees. The caterpillar grows extremely fast and can reach a size of 3 inches long in a matter of weeks. Within a few weeks' key identification features such as the yellowish body hairs and the red and blue symmetrical dots appear on its back (figure 2) (Bugword, 2017). The caterpillar will molt roughly 4 to 5 times before it reaches its mature size. The larvae will constantly eat day and night and can defoliate entire trees if there is a large population on the tree. After the 4th or 5th molt the caterpillars begin to behave differently and they only feed at night. During the day the caterpillar will walk down the tree to find a warm and dry spot to rest. They will continue to do this until they are ready to pupate. The larvae will pupate in the area which they have been using as the resting place during the day and that they know is safe. Once the caterpillar is ready to pupate it will make a cocoon, and within 7 to 14 days the adult moth will emerge (McManus, 1989).

Figure 2: Key Identification Features of a Gypsy Moth (Bugword, 2017)

The adult moth will emerge either as a male or a female. The adults are sexually dimorphic, meaning that they look very different. The female moths are large and white with black small specks on the wings (Figure 3). Another characteristic of the females are that they have dark legs. They also have a large tuft of fur on the head and a very large abdomen. The large abdomen is full of eggs which are fertilized by a male moth who locates the female (Bugword, 2017). The female moth is unable to fly so she climbs up a tree and then releases a chemical compound called a sex pheromone which disperses in the air for long distances and which the male moth can detect.

Figure 3: Female Gypsy Moth Laying Eggs (Bugword, 2017)

The male gypsy moth is much darker in color and is much smaller than the female. The male moth is a tan brown color and has dark zig zag markings on the wings (Figure 4) (Bugword, 2017). The antenna which they use to sense the female sex pheromone is large and has long hairs. The male flies upwind towards the pheromone source and locates the female and then mates with her. Then she lays her eggs on the tree close to the spot that she pupated (McManus, 1989).

Figure 4: Male Gypsy Moth

2.1 BIOLOGICAL CONTROL METHODS: INSECT PREDATORS AND PARASITOIDS

Natural enemies are the gypsy moth's main predators and these can cause high mortality to the population. Insects such as the fiery caterpillar hunter, or Calosoma beetle (*Calosoma sycophanta*), feed almost entirely on gypsy moth caterpillars during the beetle's life stages. The Calosoma beetle feeds on gypsy moth egg masses and caterpillars which makes it potentially a great control measure for gypsy moth. It was introduced into Michigan in the Great Lakes region as a long-term control method (McCullough, Raffa, & Williamson, 2001). The term parasitoid refers to a species of insect, such as a parasitic fly or wasp, that has a very specialized life cycle. These parasitoids proceed to lay their eggs by depositing them inside or on top of another host insect, such as a caterpillar (Figure 5). Once the egg has hatched, the parasitoid larva enters the body of the caterpillar and begins feeding on internal tissues, eventually killing it in the process.

Figure 5: Parasitoid fly laid a egg on a Caterpillar. Photo by Ron Weseloh

Ooencyrtus kuvanae is a small wasp that is a specialist that parasitizes the eggs of gypsy moths (McCullough, Raffa, & Williamson, 2001). This wasp was introduced into the United States as a biological control measure against gypsy Moth (McCullough, Raffa, & Williamson, 2001). The generation time of this wasp is unique since it can have three generations in the summer and fall after the egg masses are laid. When looking at a

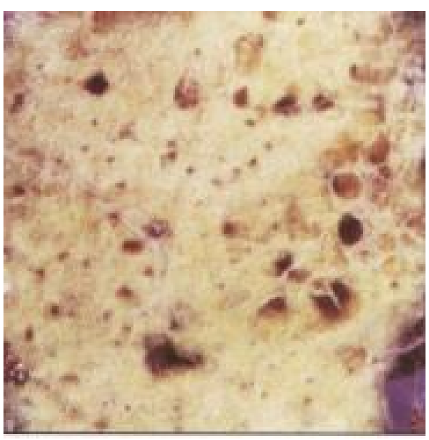

Figure 6: Holes in the gypsy moth egg mass where the wasp has emerged after becoming an adult. Photo by Michael Higgins

gypsy moth egg mass which has been ravaged by the wasp it is apparent that there are small holes where the adult wasps have emerged (Figure 6). Unfortunately, the wasp is very small and can only penetrate the mass's top layer of eggs, leaving the rest unharmed. Due to its small size and restricted access to all eggs in a mass, it is only able to kill 20% to 30% of the eggs in an egg mass (McCullough, Raffa, & Williamson, 2001).

2.2 BIOLOGICAL CONTROL METHODS: BIRDS

Many birds do not like gypsy moth adults as part of their diet due to the moth being large and hairy. There are a few species of bird which feed on the gypsy Moths eggs and larvae. These species include yellow-billed and black-billed cuckoos, blue jays, orioles, and rufous side towhees (McCullough, Raffa, & Williamson, 2001). Black-capped chickadee's also feed on gypsy moth eggs and can often cause high egg mortality.

2.3 BIOLOGICAL CONTROL METHODS: MAMMALS

There are native animals in Canada that feed on gypsy moths, including shrews, mice, voles, and other small mammals (McCullough, Raffa, & Williamson, 2001). These mammals prefer eating the female gypsy moths because they are bigger and cannot fly, making them easy prey. The male gypsy moths can fly and are about half the size when compared to a female which is unable to fly due to their heavy weight. Some animals like mice and shrews will bring the pupae underground and hoard them to be eaten at another time (Doane, 1981).

2.4 BIOLOGICAL CONTROL METHODS: PATHOGENS

Gypsy moths are affected by at least two pathogens; a virus and an entomopathogenic fungus, both of which are extremely important for controlling gypsy moth outbreaks. The virus that is helping control gypsy moth population expansion is NPV, or nuclearpolyhedrosic virus. NPV causes a disease that affects gypsy moth caterpillars Within a gypsy moth population NPV is endemic and can always be found (McCullough, Raffa, & Williamson, 2001). The method of spread is from the female moth to its offspring transovarially, or through the eggs. During an outbreak gypsy moths become very vulnerable because there is a lack of food and it is a high stress time for the caterpillars. NPV exists endemically and is triggered by overcrowding and stress in a population. It is a self-regulating population mechanism which is triggered at high population densities.

Within 1-2 years after an outbreak the disease will cause a massive die off. (McCullough, Raffa, & Williamson, 2001). Once the caterpillar is dead it will hang upside down in a V-shape and begin to liquify. The NPV pathogen is distributed annually by a federal agency which oversees the operation.

Gypsy moths are also very susceptible to *Entomophaga maimaiga* which is an entomopathogenic fungus that was introduced into North America 1910 from Japan. When it first arrived, it did not affect gypsy moths until the late 1980s when it began killing them. The fungus has been distributed by many states as a biocontrol measure for gypsy moth populations. The fungal spores overwinter in the soil and affect the caterpillars in the late springtime or early summer (D. Smitley, 1995). The spores land on the body of the caterpillar and their bodies will become a source of the fungus, and once the caterpillar dies the dead body will produce windblown spores. The caterpillars killed by the fungus will hang off the trunk of the tree facing the ground and the body will become dry and stiff (Figure 7). A few days after the caterpillar dies it falls off the trunk where the spores will overwinter in the soil (Doane, 1981).

Figure 7: dried and stiff body of a dead Gypsy moth killed by Entomophaga maimaiga. Photo by Lyle Buss

Bacillus thuringiensis kurstaki (Btk)is a biological insecticide that is extremely potent to gypsy moths. Btk crystals release a toxic protein which dissolves in the alkaline digestive system of the moth which leads to the caterpillar to stop feeding and dies within 5 days (Gov.Canada, 2013). This chemical does not affect other insects, mammals, birds, and aquatic life (Gov.Canada, 2013). Btk does not affect humans either; its sole purpose is to kill caterpillars. The Btk that is used in aerial sprays in cities like Toronto is comprised of 3% Btk bacteria, 75% water and 22% food grade inerts (Toronto, 2018). The term 'food grade inerts' refers to a mix of additives that help the chemical stick to foliage and gives the mix protection from ultraviolet light (Toronto, 2018). When Btk is sprayed in an area it last 3-7 days before it dissolves. Due to the fast dissolving time it is not feasible to spray before the caterpillar's hatch (BC, 2014).

2.5 INSECT GROWTH REGULATORS

Insect growth regulators are a method of insect population control that involves introducing chemicals into the environment that will prevent an insect from growing. In order to change the way an insect grows there must be a chemical which alters the physiology of the insect. Diflubenzuron is an insecticide which belongs to the benzoylurea class that inhibits the production of chitin which is used by insects to build an exoskeleton. This insecticide causes larvae to molt early and with a weak exoskeleton, ultimately leading to the death of the insect (Lensing, 2008). This insecticide is extremely effective against gypsy Moth larvae but also affects nontarget insects and also negatively affects other chitinous arthropods (Lensing, 2008).

2.6 BIOLOGICAL CONTROL MEASURES: MASS TRAPPING

Mass trapping is a control method that uses traps combined with artificial sex pheromones of the female gypsy Moth to attract the male moths. The female gypsy moths are unable to fly, making the spread of gypsy moths very slow. Triangular style pheromone traps (Figure 8) are baited with Disparlure (gypsy moth female pheromone) and are used all over the world for detection surveys; which are used to locate pockets of infestations (Lensing, 2008). When an area is located where there is a high number of moths the traps are placed at a density of 2–5 traps/km^2. Mass trapping works by capturing only male moths. Since the female moths are unable to fly they are harder to capture. Without the male moths the female moths will not be able to reproduce which means that they die without laying eggs.

Figure 8: Triangular Gypsy Moth Trap

Mass trapping is the most environmentally friendly way to kill gypsy Moths. It does not require any chemical sprays, introduction of new insect species, and does not affect any other insects.

3.1 GYPSY MOTH SPREAD

The gypsy moth was intentionally introduced to the United States in 1869 to create a silk industry in North America. From the beginning of the introduction of the gypsy moth it was destined to be an invasive species. Poor containment practices resulted in the spread of the gypsy moth. Between 1901 – 1922 the gypsy moth infested Rhode Island, New Hampshire, Connecticut, and Vermont. In 1912 the gypsy moth was introduced to British Columbia on young cedar trees being imported from Japan (Canada, 2015). In 1920 the gypsy moth was introduced once again to New Jersey on a shipment of blue spruce trees from the Netherlands. Later, the moths were introduced into New Brunswick, Nova Scotia, Ontario, and Quebec (TreesCanada, 2014).

The maps in Figure 9 show the spread of gypsy moths in relation to two different time periods; past and future. The spread of gypsy moths is very slow but can be accelerated when eggs are attached to firewood, trailers, or even on cars. This way the egg sacs are transported a long distance and can even cross provincial and state borders. Each egg mass has the potential of hatching 1000 caterpillars. The eggs in these egg masses will hatch and the caterpillars begin defoliating the tree it hatched on. The caterpillars can create a small strand of silk which will carry them with the wind to a new tree. It is estimated that forest damage from gypsy moth will go from 15% to more than 75% in Canada by the year 2050 (Regniere, Predicting insect continental distributions from species physiology, 2009). This model was created using a modeling application called BioSIM and is based on a conservative climate change scenario driven by a 1 percent per year increase in atmospheric CO_2 (Logan, Regniere and Powell, 2003)

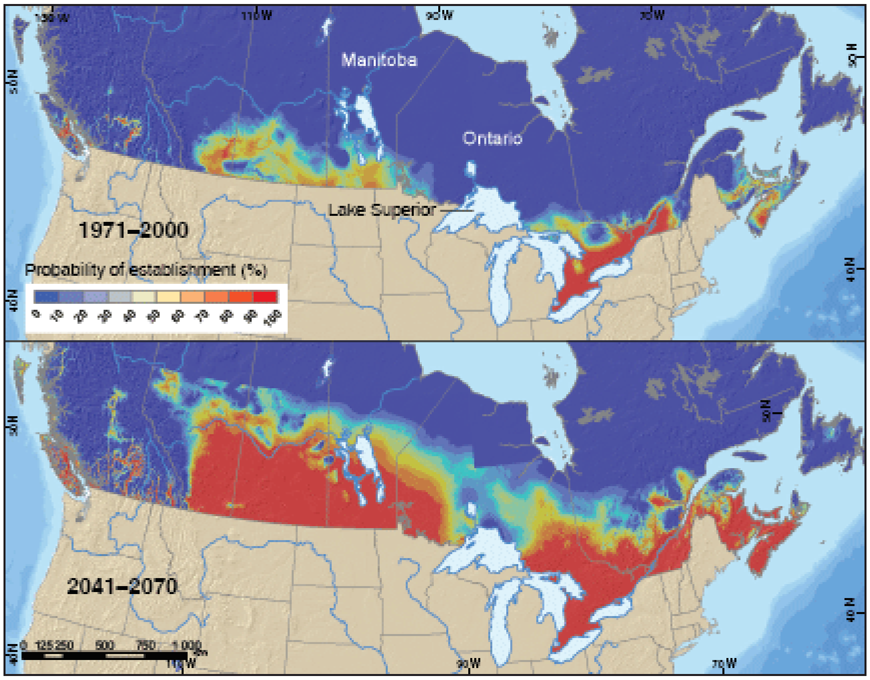

Figure 97: Past and future Spread of Gypsy Moth under current and predicted climate

Climate change is affecting the spread of the gypsy moth. It is very difficult to predict an insect's behavior or spread because climate change is extremely challenging to predict, and it is affecting every aspect of the environment. Modeling tools such as BioSIM (Regniere, BioSIM 9 User Manual, 2008) use current available data about the response of different insects and climate change data to predict future spread. Programs like this take into consideration factors that will determine whether it will survive the harsh winters typical of certain areas of Canada (Regniere, 2009). Models that are used mainly focus on the idea that the insect's main purpose is to complete its life cycle in a well-adapted seasonal pattern (Regniere, 2009). If an insect cannot successfully complete their generations then it means that it can no longer exist in that environment. Lake Superior is a geographic barrier to the gypsy moths due to the very harsh winters that occur there but, with climate change causing the Earth to become warmer, the range for the gypsy moths may eventually include the area around Thunder Bay.

METHODS AND MATERIALS

The information that was reviewed was obtained from many sources, including government websites, personal journals, articles, essays, reports, and trusted websites. The sources I used involved multiple cases and experiments with traps and other management techniques to control the spread of Gypsy Moth. I then used gypsy moth detection and modeling approaches that are used in the United States to create a similar gypsy moth detection and management program for Canada.

RESULTS AND DISCUSSION

Gypsy moths can spread at a rate of about 2.6 to 21.1 km/yr and they can exploit more than 300 host trees including *Quercus, Larix, Populus* and *Salix* (Tobin, 2008). The Slow the Spread (STS) program is a management strategy that is currently being implemented in North Carolina, Virginia, West Virginia, Kentucky, Ohio, Indiana, Illinois, Wisconsin, and Minnesota, in all covering nearly 40 million ha (Tobin, 2008). The STS program is based around setting 80,000 + traps/yr which are placed ahead of newly established gypsy moth infestations to predict the spread. The STS program is a very well-planned and effective program that can 'slow the spread' of gypsy moths and reduce the chance of it infesting new areas. This program had received federal funding between the years 2000 – 2007 which equated to $10 million USD.

This program implements 2 zones: (1) the evaluation zone which is where the moth has already infested and (2) the action zone which located outside the evaluation zone (Figure 10).

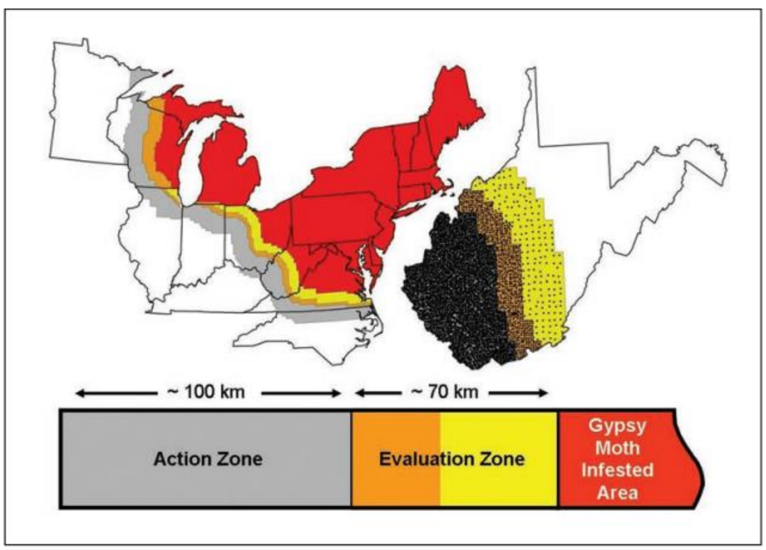

Figure 10: Map of STS Action and Evaluation Zones (Tobin, 2008)

The traps are places in both zones but at different grid intensities. In the evaluation zone the traps are placed 3 – 8 km apart, but in the action zone traps are spread 2 km apart from one another. Gypsy moth populations are rare in the action zone which is why a greater trap resolution is required (Tobin, 2008). If a new population is discovered in the action zone, then traps are placed 500 – 1000 m apart to better define the new population. This project also implements a spraying program which disrupts mating in such a way that the male moths are unable to detect the female pheromones. The chemicals that are used consist of Disrupt® II and BTK which is distributed by Hercon® Environmental. Mating disruption (chemical Spray) would only be used in areas where they find more than 17.5 moths/trap (Tobin, 2008).

Table 1: Breakdown of Chemical Mitigation (Tobin 2008)

Treatment option	Dose/acre × number of applications[a]	Cost/acre	Average acres treated/year
B. thuringiensis kurstaki	24 BIU × 1	$22.00	10,062
	24 BIU × 2	$44.00	68,984
	30 BIU × 1	$22.00	422
	30 BIU × 2	$44.00	1,988
	38 BIU × 1	$28.00	8,729
Mating disruption	6 g × 1	$8.34	273,741
	15 g × 1	$13.73	145,532
Dimilin®	1 oz × 1	$20.00	3,258
Gypchek®	5×10^{11} PIB × 1	$20.00	5,941

[a]BIU, billion international units. PIB, polyhedral inclusion bodies.

The mean overall cost of trapping in the evaluation zone is $28,138 USD for each 5 km of width and the action zone overall cost of trapping is $152,000 USD for every 5 km of width. (Tobin, 2008). Due to new colonies most likely infesting nearby areas it is important to place more traps near those colonies in the action zone. The funding for this program assumes 75% federal funding and 25% state contribution.

The size of the action zone is the deciding factor about the spread of the gypsy moth in this scenario. A smaller action zone is less costly but will result in a faster spread of the moth. A large action zone with more funding will slow the gypsy moth spread by more than 60%. Figure 11 shows the predicted spread of different action zones and funding costs for the years 2008 – 2025. It is apparent that a larger action zone will be more expensive but will more effectively slow down the spread of gypsy moth. A 40 km action zone will not sufficiently slow the moths down, leading to a higher spread rate of over 16 km/yr. With a 100 km action zone the rate of spread is reduced dramatically to only 2.2 km/yr. (Tobin, 2008)

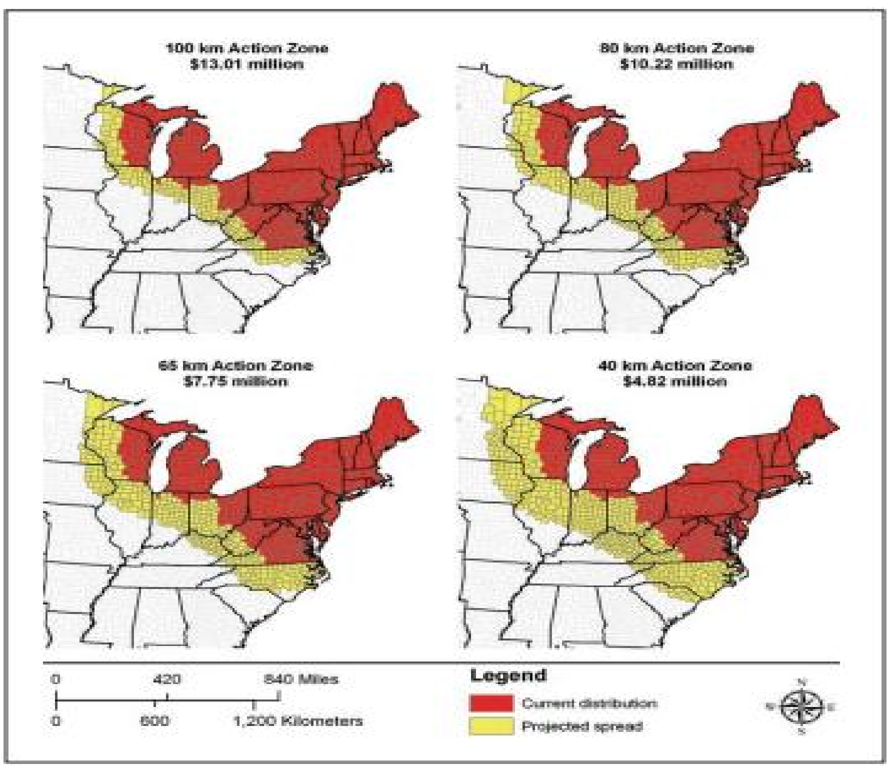

Figure 81: Predicted spread of Gypsy moth related to funding costs (Tobin 2008).

The STS program would be an essential factor in the slowing of the gypsy moths if it were to be used in Canada. If it were implemented in Canada, I would recommend using a very similar model to the STS program in the United States. I would create an action zone that would be very similar to the current spread seen in Figure 11. By implementing this program in Canada, the opportunity to slow the spread of gypsy moths is very high and the chances of preventing a drastic spread in the next 50 years towards a much larger distribution is decreased. I have mapped the STS program if I were to implement it in Canada (Figure 14).

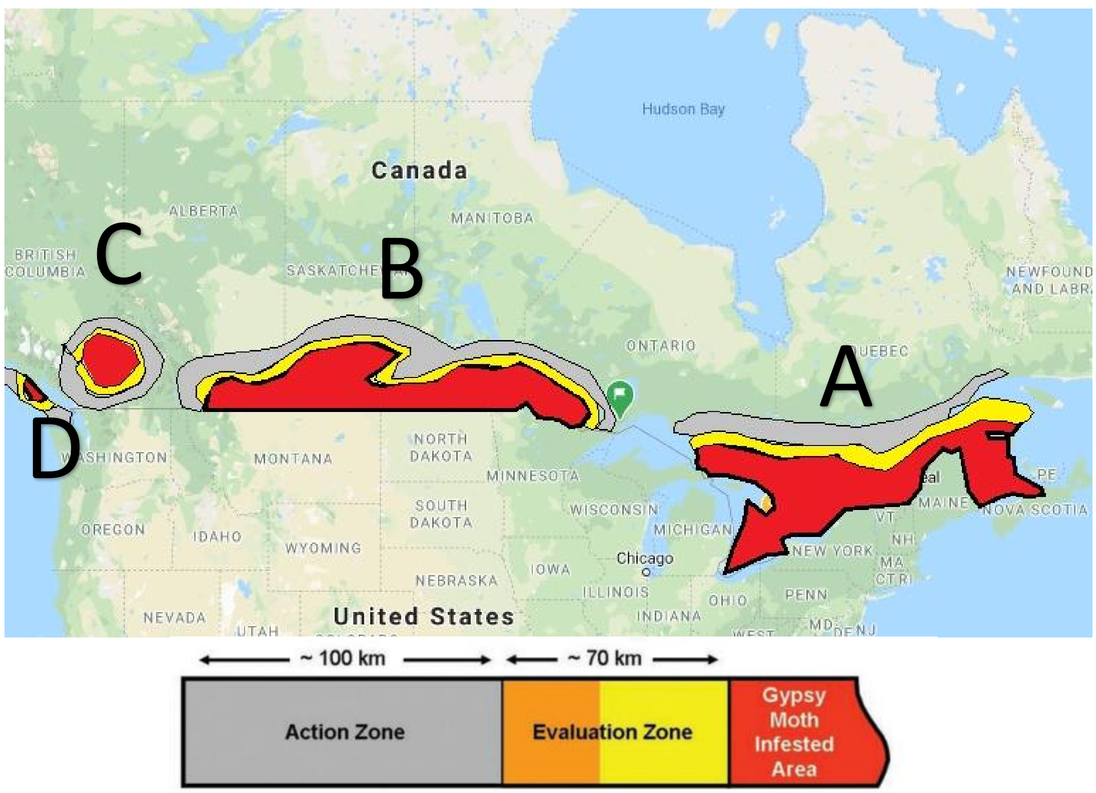

Figure 92: Model of Slow the Spread Program implementation in Canada

The main locations of spread at the moment are in southern Ontario, the prairie provinces, and parts of British Columbia. The total area in Canada infested by gypsy moth is estimated at 79 million ha. Placing traps in the action zone is extremely important and an estimated 30,500 traps should be placed. I used a 100 km action zone which will slow the spread of gypsy moths to about 2.2 km/yr. I chose to use the most expensive model because I believe that in order to prevent significant damage to the environment and our ecosystems, money should not be a factor. Table 2 Show the total traps in the action zone as per the STS model that was used in the states. The total action area will cover about 30,600,000 ha and require 36,600 traps.

Table 2:Total Hectares and area being treated

Zone	Area	Total Action area	Traps in Action zone
A	39,137,000 ha	13,000,000 ha	13,000
B	33,947,000 ha	12,000,000 ha	12,000
C	741,000 ha	600,000 ha	600
D	4,509,000 ha	5,000,000 ha	5,000

Many people are unaware of the problem and just see them as just another moth. From my own personal experinces with people in my neighbourhood in Toronto it is safe to say that even people who have gypsy moths currently infesting their trees are unaware of the problem. I have persoanally observed the gypsy moth slowly infest my neighbourhoood. I believe that there needs to be a large push for the public in large cities to learn about the insects that are infesting their trees. Without public education and participation it will be extremly difficult to prevent people from moving firewood and not protecting their trees.

Preventing further outbreaks of gypsy moth is extremly important and there are many things that homeowners can do to prevent their trees from becoming infested by this insect. Firstly, it is extremely important to keep your yard clean by removing dead branches, stumps, and other larger objects where a female gypsy moth can lay her eggs. Secondly, if an egg mas is spotted you should scrape it off into a bucket or cup and then incinerate, boil, or soak the egg mass in to ensure that the eggs are killed (GovernmentofCanada, 2013).

CONCLUSION

Gypsy moth is an invasive species that is very difficult to manage and, in large population outbreaks, they are extremely difficult to control. Due to its intense breeding and large egg sacs, each year the population can grow by 1000 %. A very large increase in gypsy moth populations in Canada may occur due to climate change. Implementing the ‘Slow the Spread’ program in Canada would benefit the health of Canada’s trees, and promote the control of such a destructive insect. The cost of the project would be about $15 million per year, but would be worth the expense to help preserve Canada’s oak and maple trees. This invasive insect must be eliminated, but the only way to do that is with proper funding, public participation, and public education.

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