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SPRUCE BUDWORM POPULATION CHANGES IN SUMMER 2016 IN NEW BRUNSWICK

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Title
Spruce Budworm Population Changes in Summer 2016 in New Brunswick

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Abstract

The aim of this thesis is to research and analyze spruce budworm moth numbers and distribution in the province of New Brunswick in Canada. Spruce budworm is a forest pest and has caused large forest damages in the eastern Canada. It is important to know by monitoring, where budworms are located and where populations are rising. This information helps to control spruce budworm populations and to prevent forest damages. Used research material is from a citizen science project and volunteers, who participated the project, collected samples during summer 2016. Budworm moth tracking season was 12 weeks long and volunteers used pheromone traps to capture budworm moths. After the tracking period, samples were processed in the laboratory of Natural Resources Canada and data was gathered in Excel form for future research use.

Research was done by analyzing citizen science data, and the results were presented with graphs and a written analyze. Research results show that there are regional differences in budworm moth distribution. Reason to these findings are moth migration or raised population. Next research will determine are the captured moths' migrants or locals by using DNA analyze.

Language	Pages 37
English	Appendice 0

Keywords

Eastern spruce budworm, Choristoneura fumiferana, New Brunswick, citizen science

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Tekijä
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Nimeke
Choristoneura fumiferana -kannan muutokset New Brunswickin provinssissa kesällä 2016

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Tiivistelmä

Opinnäytetyössä on tutkittu Kanadassa suuria metsätuhoja aiheuttaneen metsätuholaisen Choristoneura fumiferana -hyönteisen kannan määriä ja maantieteellistä levittäytymistä New Brunswickissa. Tuhohyönteisen kannan kasvun ja sijainnin määrittäminen ovat tärkeitä, jotta levittäytymistä pystytään kontrolloimaan ja ehkäisemään ennalta metsätuhoja. Tutkimuksen tilaajana oli Kanadan luonnonvarakeskus, joka hyödyntää tuloksia jatkotutkimuksissa.

Tutkimuksessa käytetty materiaali on vapaaehtoisprojektiin osallistuneiden paikallisten keräämää tietoa hyönteisten esiintymisestä kesällä 2016. Projektiin osallistuneet vapaaehtoiset pyydystivät Choristoneura fumiferenaa käyttäen feromoniansoja. Tutkimusjakso kesti yhteensä 12 viikkoa. Tutkimusjakson jälkeen kerätyt näytteet laskettiin ja tunnistettiin Kanadan luonnonvarakeskuksessa. Tuloksista koottiin tilastotiedostot tarkempaa tutkimuskäyttöä varten.

Tämä tutkimus on toteutettu tarkastelemalla koottuja tilastotiedostoja. Tilastosta tuotettiin kuvaajia sekä sanallinen analyysi. Tutkimuksen tuloksista selviää, että pyydystettyjen metsätuholaisen määrissä on suuria alueellisia eroja. Alueellisten erojen syynä on hyönteisen muuttaminen tai paikallinen kannan kasvu. Jatkotutkimuksena pyydystettyjen hyönteisten alkuperä määritetään DNA:n avulla sekä lisätään kannan seurantaa alueilla, joilla hyönteiset ovat lisääntyneet merkittävästi.

Kieli	Sivuja 37
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Asiasanat

Choristoneura fumiferana, New Brunswick, kansalaistiede

Content

1 Introduction

Forests pests cause millions of hectares of forest damage every year across Canada. Eastern spruce budworm is the most widely distributed forest pest and causes most forest damages in eastern Canada. It causes economic and ecological losses especially in forestry dependent provinces like New Brunswick. Spruce budworm outbreaks every 25 to 40 years and scientist have not found certain reasons to this variation. Last severe outbreak in 1970’s caused over 50-million-hectare forest damage across eastern Canada and caused millions of dollars of economic losses in forestry sector. Recent outbreak started in Quebec in 2006 and nearby provinces are afraid that the outbreak will spread.

Government, scientists and forest sector have tried to find effective and environmentally safety ways to prevent budworm forest damages and control populations for decades. Monitoring budworm populations tells where budworms are if the populations are rising. This helps targeting and timing prevention acts to right areas. Canada is the second largest country in the world and monitoring spruce budworm populations is expensive and time-consuming in large areas. Solution to this was a citizen science project which use volunteers to help monitoring budworm populations in the eastern North America.

The aim of this thesis was analyze of caught spruce budworm moths from citizen science project in New Brunswick. Forest industry has a strong influence to province economy and that is why this province was chosen for more precise research. The aim was to find and explain reasons for possible regional differences in population distribution, and detect areas where populations are higher.

2 Eastern spruce budworm, Choristoneura fumiferana (Clemens)

2.1 Biology

Eastern spruce budworm, Choristoneura fumiferana (Clemens) is an insect which larva prefers balsam fir (Abies balsamea) needles, buds and cones on its nutrition. White (Picea glauca), red (Picea rubens) and black spruce (Picea mariana) are also suitable host trees. It is native to North America and has been found in Canada and the United States. (Healthy Forest Partnership, 2014a.)

Picture 1. Spruce budworm moth (Picture by Joris Wiersinga).

The eastern spruce budworm population has normally one-year life cycle, but two-year life cycle is also possible in western North America. Spruce budworm larva has six stages before pupae stage (Morris 1963, 12.) Adult moths emerge from pupal cases in mid-July to early August. Within one to one and a half week after emerge, adults mate and female lays approximately 200 eggs on the underside of conifer needles and then die. Spruce budworm adult moths are about 12 mm long and their wingspread is 22 mm to 28 mm. Both sexes are similar in appearance; forewings are gray or brown and banded or streaked and each sex have a white dot on the wing margin. (Morris 1963, 13-14.)

Picture 2. Spruce budworm eggs on branch and single needle (Picture by Enna Siikavirta).

The egg stage ranges from 10 to 12 days. Eggs are green, oval shaped and about 1.2 mm long. First instar larvae emerge by mid-August and the larvae are tended to move toward light so they tend to move toward the branch tips. Larvae do not feed itself but they spin hibernacula within which they moult to the second instar. Hibernacula is moisture-dependent and that is why it prefers balsam fir, bark scales, flower scars and lichen on the branches or on the tree pole to overwinter. (Morris 1963, 13-14.)

In the early May of the following year larvae emerge from hibernacula. Larvae response to light and move towards branch tips to feed themselves. Second stage larvae prefer flowers for food. If these are not available, the larvae use either new buds or one- and two-year old foliage. When the population is high, the current year shoots may be consumed completely and larvae might be forced to feed on older foliage. Larvae moult to the third-instar after it has mined only one needle. From the third-instar to sixth-instar larval period lasts from early June to early July. Larvae become full grown after 30 days and leave their overwintering place. (Morris 1963, 13-14.)

Picture 3. Spruce budworm fifth stage larva (Picture by Joris Wiersinga).

The first stage larvae are yellow- brown with brown heads and during their next three stages they have orange- brown bodies and black head. The bodies of the fifth stage larvae are olive- brown and with small whitish spots. Heads are dark brown. In the six stage, mature larvae are 18 to 24 mm long with dark brown heads and olive- or reddish- brown bodies. The head width average of sixth-instar larvae is 1.6 mm for male and 1.8 mm for female. Bodies have also cream colored spots and areas. (Morris 1963, 13-14.)

Picture 4. Spruce budworm pupa (Picture by Joris Wiersinga).

The pupal stage is in mid- July and it lasts about 8 to 12 days. Pupation normally takes place in feeding site or sixth-instar larvae may move toward the center of the branch to pupate. Pupae are about 15 mm long and they are broad from the end and are narrowed towards the tail. The color is green or yellow at first and then it turns into dark brown. (Morris 1963, 13-14.)

2.2 History and damages

Budworm has a long history in the Eastern Canada and macrofossil studies proves that there have been spruce budworms as far as 6800 years ago. There have been at least eight outbreak cycles since 1700 and that includes three outbreaks (1910's, 1940's and 1970's) during the last century. Current eastern spruce budworm outbreak started in Quebec in 2006, and it is not showing any signs of recession. (Pureswaran, Johns, Heard & Quiring 2016, 5.) Spruce budworm epidemics last several years and then subside naturally and occur approximately every 25 to 40 years as spruce budworm population outbreaks (Pureswaran et al. 2016, 5).

Spruce budworms have been a target of intensive research for more than 65 years. There are numerous long-term studies and published articles but scientists still are not sure which ecological factors effect to the beginning and the end of the outbreak. Scientists have hypotheses explaining budworm outbreaking population dynamics which have been shifting through the decades and there have been three main hypotheses. Silvicultural Hypothesis in 1920's explained that forest management practices favoring softwood species were reason to budworm outbreaks. In 1960's, Multiple Equilibria Hypothesis proposed that warm weather conditions release low density budworm populations from the control of natural enemies as parasitoids and birds. (Pureswaran et al. 2016, 2-14.) The third hypothesis in 1980's named Oscillatory Hypothesis proposed that "budworm population dynamics were governed by a second-order density-dependent process, with oscillations being driven by natural enemy-victim interactions." Recent researches which have tried to explain spruce budworm dynamics, have supported components of all three hypotheses. (Pureswaran et al. 2016, 2.)

Eastern spruce budworm causes most damage of any insect in the eastern North America (Morin, Jardon & Gagnon 2009, 556). The level of forest damages depends on the severity and length of an outbreak (MacLean 1996, 399). At 1970's spruce budworm outbreak lasted about 20 years and damaged 52 million hectares of forest only in Eastern Canada. (Pureswaran et al. 2016, 5.) To comparison, Finland's total land area is 39 million hectares and 25 million hectares is covered with forest (Tilastokeskus 2016). Last outbreak started in 2006 when spruce budworm population started to increase in province of Quebec and since then a 6000-hectare outbreak has grown up to 6,3 million hectares (in 2015) in Quebec area (Pureswaran et al. 2016, 5). In New Brunswick budworm populations are rising and it is feared that the outbreak will spread from Quebec to New Brunswick and elsewhere in eastern Canada.

Picture 5. Locations where current outbreak started in Quebec (Picture: Google maps).

Feeding by the budworm larvae causes defoliation to trees which slows down or even stops tree growth and after several years of defoliation it can cause top kill and tree mortality (Natural Resources Canada 2016a). Tree mortality is consistently higher in balsam fir than in spruce stands and higher in mature than young stands. This is because of spruce budworm prefers balsam fir, the proportion of balsam fir in stands remains high and older trees are more vulnerable to defoliation damages. (Morin et al. 2009, 558.) Damaged trees are also more vulnerable to other insects and diseases.

Picture 6. Damaged forest (Picture by Joris Wiersinga).

In eastern Canada spruce budworm has a strong economic impact on softwood pulp and lumber industry and on boreal forest (Pureswaran et al. 2016, 4). In eastern Canada softwood species (coniferous) are harvested almost two times more than hardwood (broadleaves) species (National forestry database 2014). Therefore, severe budworm outbreak reduces productivity of forest and wood supply, drops harvesting levels and has strong impacts on forestry sector. It is estimated that in the whole Canada insects and disease pests have cost hundreds of millions of dollars over the years in revenue losses and prevention and control investments. Last outbreak which started 1970's, destroyed in mid-1980's over 10 million cubic meters of softwood only in Quebec. (Natural Resources Canada 2017.)

Spruce budworm has an ecological role in boreal forest (Natural Resources Canada 2016b). Boreal forests span from North America and Asia to parts of Europe, and forests are coniferous, and contain large amounts of evergreen trees (Boreal forest facts 2014). In eastern parts of Canada Ontario, Quebec and Newfoundland have boreal forest (Natural Resources Canada 2016c).

Budworm outbreaks are part of natural forest dynamics and have a role in forest renewal, nutrient cycle and in food web. When outbreak is severe, it has also negative impacts on nature when it comes to and concerns tree species composition, tree age class distribution and tree density changes. Fast changing forest affects lives of plants and animals, some species benefit and another species do not. (Natural Resources Canada 2016b.) Also, defoliated and dead trees reduce landscapes aesthetic values and stands killed by budworm are more vulnerable to forest fires (Natural Resources Canada 2012, 7).

Spruce budworm outbreaks have an effect to carbon balance. Severe outbreaks cause tree mortality and reduce tree growth in large areas which temporarily reduce carbon uptake from the atmosphere and increase leaf litter which releases carbon through decomposition. Carbon balance returns slowly when dead stands are replaced with young growing stands which can absorb carbon from the atmosphere. (Gray & McKinnon 2011, 550.)

2.3 Weather and climate change

Weather is an important factor to budworm population dynamics but there is no consensus how it influences to the beginning or the end of outbreak (Natural Resources Canada 2016a). All insects, including spruce budworm are cold-blooded and their development depends on the temperature where they develop (Owens & Johns 2016, 3) and as well food availability (Luonnonvarakeskus 2014). Emerging time of larva in the spring and budworm development time from larva to adult moth depends on spring and summer temperatures. Scientists have researched that in optimal temperatures spruce budworm develops faster, and larvae mortality rate is lower when summer is warm and dry compared to wet and cool summer which can contribute population to grow. Therefore, emerging time of larvae and moths can vary from year to year. (Ives 1974, 1-9.)

Threshold temperature, when second stage budworm larva can emerge is 5,6 Celsius degrees (Royama 1984, 439). Spruce budworm development stages can be estimated by using heat units (Ives 1974, 1-9.) Estimating development stages is useful in timing of treatments and tracking adult budworm moths.

Weather has also other effect to budworms. Regional climate hazards, like late frost, can cause budworm larva mortality (Royama 1984, 451.) Warm weather conditions can cause updrafts and pull up spruce budworm moths and carry them hundreds of kilometers away (CBC News 2016).

In New Brunswick growing season starts when ten days average daily temperature is over 5 Celsius degrees and ends when minimum daily temperature is 0 Celsius degrees or October 31st. Effective growing degree days (GDD) in New Brunswick with calculated long-term averages in 1971-2001 were between 900 and 1600. Future GDD based on climate change scenario for years 2010-2039 are 1200 to over 1800. Scenario predicts that average monthly temperature will rise one to two Celsius degrees (Agriculture and Agri-Food Canada 2014.)

There is variation in growing degree days in New Brunswick because of northern part of province has high elevation areas, where it is normally cooler than in low areas in the middle part of the province. In coast-line areas where there is lower GDD, is because of effect of cold ocean water (Hassan, Bourque, Meng & Richards 2007, 8.) The start of growing season determines when trees can start to grow and produce flowers and new buds. Emerged spruce budworm larva needs these to its nutrition. Temperature variations regionally in New Brunswick affect to spruce budworm development. In warmer areas budworm larvae and adult moths will emerge earlier than in cooler areas. (Royama 1984, 439.)

Climate change is a long-term change in earth’s climate and it rises the atmospheric temperature in the earth, and increase regional weather changes like droughts, heat waves and rainfall (Nasa 2011). In Canada, annual temperature has warmed 1.6 Celsius degrees over the period of 1948 to 2013. Warming trend is strongest in the far north. (Climatechange.gc.ca 2015.) It is expected that warming climate will change tree species composition in eastern North America. Heat waves and drought will increase forest fires and weaken trees to be more vulnerable to forest pest infestation. Climate change has a positive influence to survival and life cycle of forest pests, and alters their geographical distribution. Winter temperatures normally limit several pests but rising winter temperatures will likely increase pest outbreaks. (Government of Canada 2014, 71-72,166.)

Over the past decades, growing seasons have lengthened (Government of Canada 2014, 73). Scientist have predicted that warmer climate and longer growing season will increase severity and length of budworm outbreaks in northern latitudes. Already, current out-break in the north shore of the St. Lawrence River in Quebec began in unusually far north where the impact of spruce budworm is normally mild. Scientist models have predicted that warmer climate may change budworm distribution, increase length of outbreak, change ecosystem and disrupt matching of budworm with it parasitoids. Effect of climate change to spruce budworm needs more research and monitoring before getting any certain results. (Pureswaran et al. 2016, 19-20.)

2.4 Prevention

In eastern Canada and the United States scientists, stake holders, industry, academics and government have formed a four-year research initiative (2014-2017) Healthy Forest Partnership which tries proactively monitor, treat, protect and test new treatment options and technologies to fight against spruce budworm (Natural Resources Canada 2016d). Between outbreaks budworm populations remain so slow that they are difficult to detect. Monitoring budworm population is the most important way to know when and where populations are rising. Knowing where the budworms are active helps researchers, government and forest sector to use right forest management practices. (Pureswaran et al. 2016, 6-7.)

There are three spruce budworm management strategies which use treatments and silviculture to control budworm damages (Pureswaran et al. 2016, 7.) The idea of early intervention strategy is to identify hot spots and areas where spruce budworm populations are rising, and then use different methods, like treatments, to drive population back to low level (Natural Resources Canada 2016d). Hot spots are areas where there are favorable conditions for budworm population to grow and in these places budworm densities rise faster. The idea of foliage protection strategy is to prevent tree mortality and growth losses by using insecticides to kill spruce budworm larvae. This has been the most used strategy to control budworm. Foliage protection strategy is normally used in high value forests and forests which have high budworm insertion. Silviculture is used to prevent spruce budworm forest damages and to proactively limit forest susceptibility risk. (Pureswaran et al. 2016, 7, 17.)

There are three used treatments against spruce budworm: Foray 76B (Btk), Mimic 240LV (tebufenozide) and Disrupt Bio-Flake SBW. All treatment products are federally registered and do not cause harm for the environment or humans (Healthy Forest Partnership 2014b) and all these products are used in New Brunswick. Btk and Mimic are used when larvae are fourth to fifth instar (Pureswaran et al. 2016, 17) because sixth instar larva cause most defoliation (MacLean 1984, 274). Pheromones are used to adult spruce budworm moths (Healthy Forest Partnership 2014c).

Foray 76B, better known as Btk (Bacillus thuringiensis var. kustaki), is biological insecticide and naturally occurring soil bacteria which kill spruce budworm larvae (Government of Newfoundland and Labrador 2015). Btk is aerial sprayed from plane to forest canopy, and after budworm larvae ingested Btk, it affects the gut lining and larvae stop eating and die in a day or two (Healthy Forest Partnership 2014c). Btk is the most used tool to control spruce budworm populations because it is safe for the environment (Natural Resources Canada 2016e). It has been used since 1977 when previous outbreak occurred (Government of Newfoundland and Labrador 2015) and between 1980 and 2014, Btk was used on 8 million hectares of budworm infested forest (Lacey 2017, 323).

Mimic 240LV is an insecticide and its active ingredient is tebufenozide. Mimic imitates an insect’s natural growth hormone. After budworm larva has consumed mimic it causes premature skin molting and larva stops feeding and dies (Valent Bio Sciences Corporation 2014) Mimic is spread aerial by plane like Btk. Btk treated areas are sprayed once or twice but Mimic can only be sprayed once because of the law (Owens 2017). Both Btk and Mimic affect also to other insects. Btk is toxic only to lepidopteran insects like spruce budworm (Natural Resources Canada 2016e) but Mimic has an effect to gypsy moths, tent caterpillars, tussock moths and loopers (Natural Resources Canada 2016f). Disrupt

Bio-Flake SBW is pheromone which affects only to spruce budworm male moths. Pheromone disturbs male moths to find female moths and mate. (Healthy Forest Partnership 2014c.) In 2016, about 60 000 hectares of forest were treated with Mimic and Btk in northern New Brunswick and 500 hectares was treated with pheromone (Healthy Forest Partnership 2016).

Btk and Mimic are both cost effective ways to prevent tree damages. Costs per hectare in both insecticides are 45 dollars (Brett & Cooke 2013), application costs are 130 dollars per hectare (Johns, Martel & Pureswaran 2015). Weather is the only challenge when insecticides and (pheromones) are spread. Rain and strong wind makes budworm larvae more difficult to feed themselves with sprayed insecticide drops and moths don’t fly in rainy weather (Healthy Forest Partnership 2015).

Spruce budworm prefers mature, even aged, balsam fir stands and firs have higher mortality comparing to spruce species. (Morin et al. 2009, 558.) Therefore, decreasing mature even aged fir forest and changing forest structure from even aged to uneven aged, and increasing spruce and hardwood species composition will increase stand resistance and reduce defoliation (MacLean 1996, 400). Hardwood mix can also increase natural enemies of budworms and have impact on budworm populations. (Pureswaran et al. 2016, 11). During severe spruce budworm outbreak, proactive cuttings in high risk mature fir and spruce stands will reduce economical losses (MacLean 1996, 403).

3 Citizen science: a budworm tracker program

3.1 Citizen science

Citizen science use non- professional volunteers in ecological research. Volunteers can help in various tasks as data collection and observation. Ecological citizen science projects collect important data and it allows cost-effective data collection over large geographic regions and private lands. Citizen Science projects range from local to global and can monitor different kind of living organism as plants, animals, insects and fishes. Citizen science projects are increasing and playing important role in research of environmental crisis and changes. (Dickinson, Zuckenberg & Boner 2010, 149-154, 165-166.)

History of citizen science goes back in 1749 when amateurs helped scientist with bird monitoring. Amateurs helped collect data on timing of when birds' migration began in Finland. For science, amateurs' observations have been important for centuries, and last decade numbers of citizen science projects have risen and scientist can get more easily large scales of data. Citizen science projects are affective way to track species spreading, track invasions and migration, finding rare species and help conservation (Dickinson et al. 2010, 149-154.)

Volunteers participation in ecological projects gives them access to learning materials, protocols, social media and gather data and enter them to online into a database. Participation on citizen science projects offers to public scientific education, personal research and learning experiences and it creates dialogue between scientists and citizens (Dickinson, Shirk, Bonter, Bonney, Crain, Martin, Phillips & Purcell 2012, 295.) When people from different backgrounds work together towards a common goal it has influence to public opinions, it creates better understanding of nature and can affect policy making, and new innovations and inventions are more likely to arise (Johns 2016).

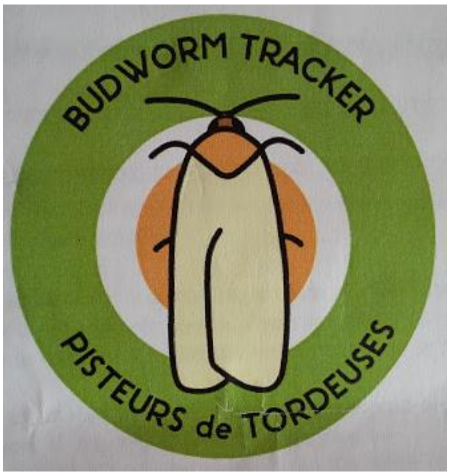
Because of the citizen science projects educational meaning, many of the projects have received funding. Funding enable creation of good education materials, which includes background material and in long time projects annual report. Scientists contact to volunteers normally via phone, email and postal service because it is easiest and fastest way in bigger projects. Also, citizen science projects use social network groups like Facebook, blogs, newsletters and local and national media to get word out to public and to create communication between scientist and volunteers and it help to connect community and share new information. Real time information keeps volunteers updated and motivated. (Dickinson et al. 2012, 295-296).

Citizen science projects use internet, geographic information systems (GIS) and smart phone applications to help volunteers to collect location-based ecological data. Online data systems enable data collecting to be inexpensive, initiate projects quickly and gives online data information during the project (Dickinson et al. 2012, 291.) Still traditional way, sending samples via mail to scientist is still used. Citizen science data collection and data processing have some challenges. Citizen science volunteers' skills to collect data properly and identify species are not same than professional scientist. This affects to data quality and makes data processing more difficult and can lead to sampling error. (Dickinson et al. 2010, 161-162.)

Easy to read and informative protocol, background information, where and how volunteers can find species, are the requirements for citizen science volunteers training before the project starts. It improves volunteers' data collection and observation skills, and helps them to understand why gathering accurate data is important. Scientists can also choose already educated volunteers and have partnership between scientists and specialized hobbyist for example bird watchers. Also one way to improve data accuracy is to test volunteer's species identification skills with quiz before participation, and this way ensure that volunteers know how to identify species. Also, long time citizen science projects have observed that volunteers become better data collectors during the project when they gain more identification experience and come more familiar with the protocols (Dickinson et al. 2010, 161-162.)

3.2 A budworm tracker program

Budworm tracker program is led by Natural Resources Canada (NRC). Program aim is to engage public to help NRC scientists to collect data on spruce budworm moth migrations and spread during budworm outbreak in the eastern Canada and the northeast United States. The aim is to better understand spruce budworm migration during the outbreak, and to monitor where the budworm populations are most active. (Natural Resources Canada 2016g.) This helps to target treatments and other research projects as overwintering larvae surveys in the fall (Owens & Johns 2016, 3). Program have trackers in six Canadian provinces and one state in the United States, provinces are Ontario, Quebec, New Brunswick, Nova Scotia, Newfoundland and Prince Edward Island and the one state is Maine. Program started in 2015 and it will last probably through the outbreak. For the budworm research, program received roughly 500 000 dollars funding from the Atlantic Innovation Fund grant. (Johns 2016.)



Picture 7. A budworm tracker program logo (Picture by Emily Owens).

Citizens who have participated to program use pheromone traps to catch adult spruce budworm moths. Pheromones are naturally produced behavior modifying chemicals. Synthetic pheromones are placed into the traps to lure and detect insects. (Natural Resources Canada 2016d.) A budworm tracker program pheromone trap includes pheromone lure which attract only male spruce budworm moths. Male moths fly into the trap, insecticidal strip kills them, and volunteers collect these moths for the further research.

In 2014, Natural Resources Canada had 12 pheromone traps only in New Brunswick to monitor spruce budworm populations. NRC crew tried to check traps three times a week but only 75 percent of traps were checked that often. This way costs and spent time to check traps were too high. To monitor spruce budworm, a citizen science program was more cost effective and better solution to collect data from larger region. (Owens 2016.) In 2015, budworm tracker program got 284 pheromone trackers in the eastern Canada and 90 percent of traps were successfully checked and data was returned to NRC (Owens &

Johns 2016, 3). In 2016, Program got 394 trackers and 75 percent of traps were successfully checked (Heustis 2017a).

Budworm tracker program advantages are low data collection costs, easier way to collect data in large geographical scale, and more frequently checked traps, which gives valuable information to determine when moths are active and to suggest are the moths locals or migrants. (New Brunswick Department of Environment and Natural Resources etc. 2016, 4.) Using of citizen scientist program data, scientist can develop an effective and an efficient budworm management programs, and can target treatments, and further research to high density budworm areas (Owens & Johns 2016). To public program offers education and offers an entry point to discussion, how and when the outbreak should be managed (New Brunswick Department of Environment and Natural Resources etc. 2016, 4).

3.3 Budworm tracker volunteers and data collection

Natural Resources Canada finds new volunteers to new budworm tracking season in the fall and in the spring. Volunteers who are interested to take part to the program have tried to outreach via social media, radio and TV interviews. Also, volunteers are tried to find with direct contact to local professional organizations as forestry companies, woodlot associations, conservation and park groups, schools, and municipal, provincial and state governments. (New Brunswick Department of Environment and Natural Resources etc. 2016, 5.) Forestry organizations are good source for volunteers because of the eastern spruce budworm affects most strongly to their living (Dickinson et al. 2012, 291). Interested volunteers can sign in to program in budworm tracker website.

After the volunteers network spread, Natural Resources Canada employees try to target people through smaller local medias, and try to reach people who can take part to the program, and focus to fill in the gaps in areas where are not yet any volunteers. The aim is to have trackers spread uniformity through the tracking region. Volunteers who have taken part to the program in previous summer, and have informed that they want to take part to the program in next tracking season, are contacted directly by phone and email to confirm they participation (New Brunswick Department of Environment and Natural Resources etc. 2016, 5.)

Before the NRC starts to send free start up package to volunteers, all volunteers are contacted by phone and email to confirm their contact information where the trap will be send. Startup package includes a pheromone trap with unique identity number, pheromone lure, insecticidal strips, 40 paper bags for the samples, freezer bag, vinyl gloves, wooden stick, pencil, contact information and data collection sheets, return envelope and protocol with the easy instructions where and how to set up the trap. Volunteers who participated previous summer and have kept their pheromone trap to take part to the program next year, will be send refill kit which includes everything else but pheromone trap (New Brunswick Department of Environment and Natural Resources etc. 2016, 5).

Data collection happened the same way in 2015 and 2016, only the tracking season was different. In 2015 trap needed to be set up before June 11th to September 2nd (Owens 2017) and in 2016 before June 12th to August 31st (Natural Resources Canada 2016h, 3). Trap needed to be placed in wooded area, at least five meters into the tree line, away from overnight lights and hung on fir or spruce tree at eye level. Trackers needed to check their trap at least once per week and mark checking date and number of moths or just checking mark if tracker did not want to count moths or there was not any, to sample sheet. Moths or other insects found in the trap, were emptied in labeled paper bag. Bag needed to be placed into freezer as soon as possible because moth’s DNA breaks down if it is left too long time in warm conditions. (Natural Resources Canada 2016h, 3.)

Picture 8. Pheromone traps (Picture by Emily Owens).

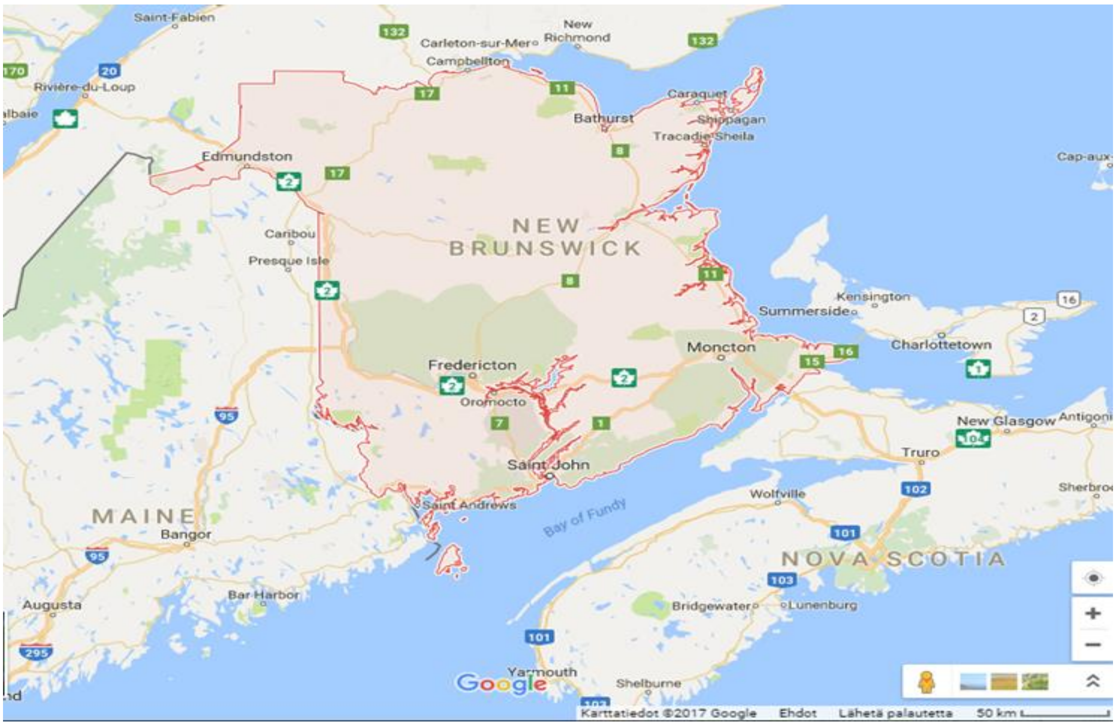
Trackers have possibility to use Budworm Tracker App or register on budworm tracker website. This is an optional way to register trap and update sample information online. Every trap has QR code and it takes registered tracker directly to his or her account on the website. Still, volunteers who are using app or website need to write their sample information on sample sheet, just to make sure that the information doesn’t get lost. (Natural Resources Canada 2016h, 3.)

End of the tracking season all trackers sent their sample bags, filled sample sheets and contact information back to Natural Resources Canada in prepaid return envelope. If tracker decided to participate next summer, he or she needs to store the trap until next year tracking season. Trackers who decided not to participate again sent their traps back to NRC for free (Natural Resources Canada 2016h, 4).

NRC counted and identified moths and saved this data to excel form. Excel form includes unique trap ID, province where trap was placed, trap location city name and coordinates, sample date when the sample was collected and number of moths on that collection day. Excel form includes also failure reason and failure notes. Failure reasons were that data wasn't collected in accurate way for example all tracking season samples were in same bag. Failure notes includes reasons why volunteers did not check traps at all or less than once a week. These notes are based on volunteer's own information what they gave to Natural Resources Canada. (Heustis 2017b.) After all data have been processed, NRC writes annual program report. Annual program report has overview from previous tracking season, what new information trap catches have given and improvements and plans for the upcoming tracking season. It is available for everyone in budworm tracker program website.

4 New Brunswick

New Brunswick is a province in eastern Canada and the largest of three Maritime provinces (other two are Prince Edward Island and Nova Scotia). It is located under Quebec Gaspé Peninsula and the western boundary is with the United States state Maine. The east is located Gulf of Saint Lawrence and Northumberland Strait boundary is entirely coastal and the southern New Brunswick is connected to Nova Scotia Peninsula and rest of the southern boundary is coastline of Bay of Fundy. (Government of New Brunswick Canada 2017.) It is only bilingual province and its population is about 755 000 (Natural Resources Canada 2016i). The total land area is 73 440 square kilometers (7,344 million hectares) (Historica Canada 2015) and about 6 million hectares (80 percent) of it is covered with forest (Owens & Johns 2016).



Picture 9. Map of New Brunswick (Picture: Google maps)

In New Brunswick, forestry is the largest industry (Department of Natural Resources 2016, 8) and in 2014 the province forest sector, generated revenues over 3,3 billion Canadian dollars (Natural Resources Canada 2016i). Forest sector account about five percent of New Brunswick gross domestic product Department of Natural Resources 2016, 8) and employs in the province directly almost 12 000 people (Natural Resources Canada 2016i). Little bit over half of the provinces forest is public owned and rest is private lands. Parks and protected lands covers 223 000 hectares. (Province of New Brunswick 2014). New Brunswick annual softwood wood supply has been about 5,7 million cubic meters and hardwood 3,3 million cubic meters (National Forestry Database 2014).

Previous outbreak in New Brunswick in 1970's caused defoliation to 3,6 million hectares and had impact to next decades' wood supply. It has been estimated that uncontrolled outbreak can cause loss of jobs and cause in 30 to 40 years 4 to 6 billion dollars economic losses and decrease yearly softwood supply over one million cubic meter. (Healthy Forest Partnership 2014d.) Resent spruce budworm outbreak in Quebec had caused over six million hectares of defoliated forest in 10 years, which is equate to whole New Brunswick forest area. Because of the importance of the forest industry, in New Brunswick forest industry, academics, government and stake holders founded Healthy Forest Partnership to monitor and find ways to prevent spruce budworm infestation to happen again in the province. Public is also engaged through active information sharing and a citizen science project.

5 Materials and methods

5.1 Aim and purpose

Current spruce budworm outbreak started in 2006 in Quebec. It is feared that outbreak will spread to New Brunswick. Forest industry is the province biggest industry and new severe budworm outbreak could cause huge economic losses for years. To prevent new outbreak to happen, Natural Resources Canada is leading budworm tracker program to monitor and to detect spruce budworm populations in the eastern Canada, including New Brunswick.

This thesis used budworm tracker program pheromone trap moth catches and trap coordinates. Research used only data collected from New Brunswick in summer 2016. Research focused only to the province of New Brunswick because this province industry is dependent on forest and budworm damages have strong impact to its economy. Also researcher did her internship in New Brunswick and was part of the citizen science: a budworm tracker program, and spruce budworm research group. Using this data, researcher aim was to observe spruce budworm moth numbers and compare were there any regional differences.

Thesis have two research questions: Where spruce budworm populations are located? Are there regional differences? To answer these questions, researcher analyzed citizen science data and determined areas where spruce budworm moth populations are high, and observed were there regional differences, and tried to explain found observations. Knowing where the budworms are, gives scientist information where in the future focus monitoring, treatments and it gives other research projects information where to collect samples. Monitoring, spruce budworm population levels and locations, helps budworm prevention treatments to be targeted in right areas and keep populations in control.

Thesis topic is current and interesting because spruce budworm damages have far reaching influence on the economy and the nature. Influence of climate change and rising temperatures can spread budworms to new areas or even new countries, and enable more frequent and severe outbreaks. Forest pests are not only risk to forests health in Canada. In Finland forests are mainly pure spruce or pine stands and because of it, more vulnerable to forest pests.

5.2 Realization and data processing

Natural Resources Canada started to find volunteers to budworm tracker program in the fall 2015 and in the spring 2016. Volunteers who participated to budworm tracker program used the pheromone trap to catch spruce budworm moths. Traps were sent to volunteers on mid-June (week 23). Tracking season was 12 weeks long (June 13th to August 31$^{st)}$, volunteers were instructed to check their traps at least once a week and collect found moths to bags. Each day's catches needed to be placed to separate bags, mark collection date, trap number and freeze bags. This way trap findings can be later accurately processed. End of the tracking season volunteers sent their samples to the Natural Resources Canada.

Between September 2016 and February 2017 NRC laboratory workers counted and identified moths. Counted moth numbers, collection dates, unique trap numbers, trap coordinates and information of possible sample collection failures, were saved to excel form. For this thesis researcher used only New Brunswick data from summer 2016. In New Brunswick were total of 128 traps, and for this thesis data from 84 traps were used and data from 44 traps were removed.

Traps which were not checked every month (June, July and August), and traps with missing coordinates were removed. Trap needed to be checked at least once per month that it data was taken to this research. Data was processed using pivot program in excel and my maps in google. Outcomes are presented with graphs, maps and written analyze.

5.3 Research method and data accuracy

This thesis research method is quantitative. Quantitative research method use only numerical data and analyze and observe it using mathematical and statistical methods (Thomas 2003, 2). Quantitative research try to examine correlations and changes between different data's (Heikkilä 2014). All data which was used in this thesis was in numerical Excel form and was analyzed by Excel, and statistical program spss to make graphs. Therefore, choose of research method was clear.

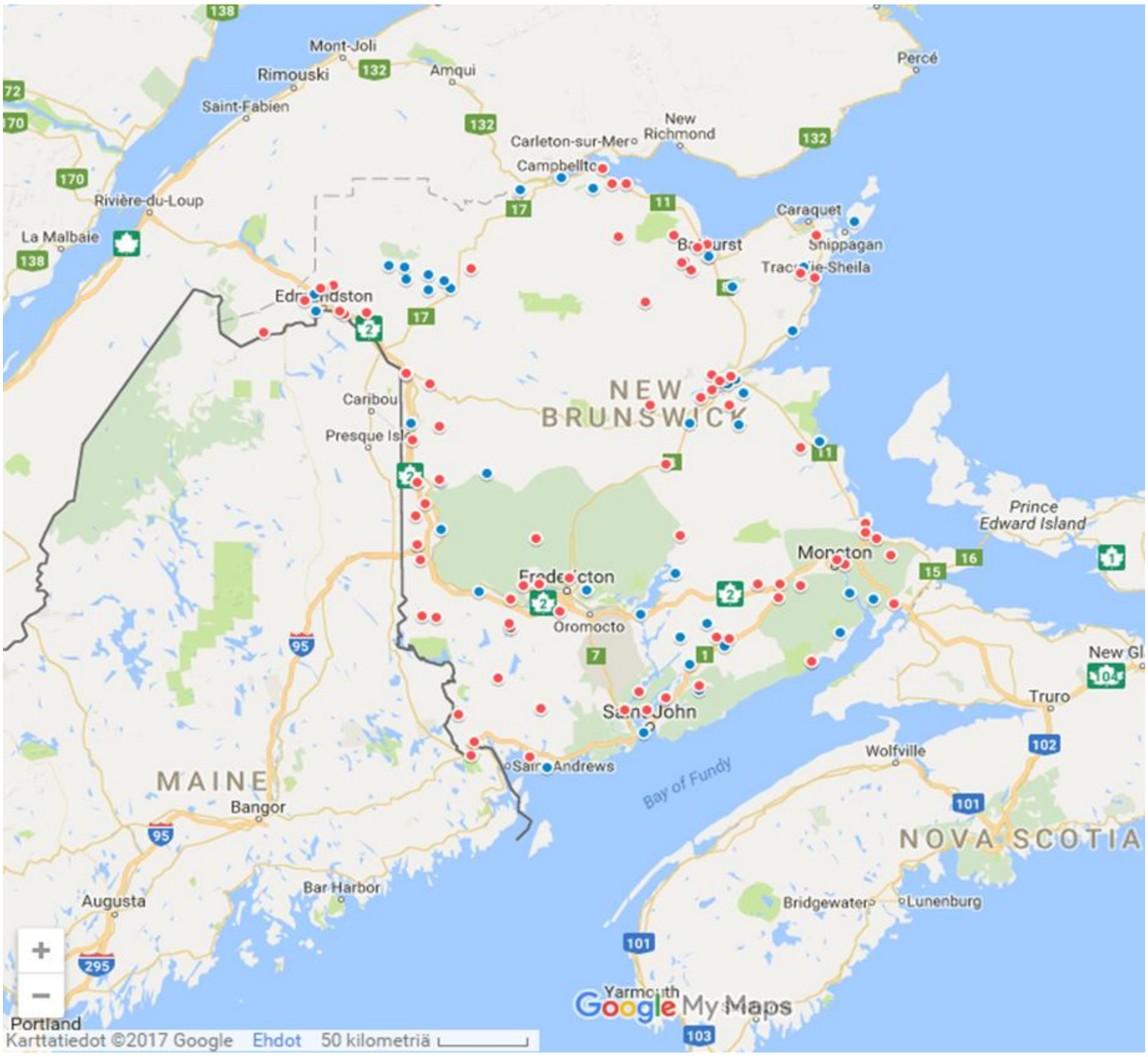
To achieve scientifically accurate research results, number of collected samples need to be large enough and collected correctly. This decrease chance of data error (Heikkilä 2014). In citizen science projects where volunteers collect samples, data quality is not always same compared it with data collected by scientist. Volunteers might not follow the instructions and check their traps infrequently, for example collect all samples to same bag or store them incorrectly. (Dickinson et al. 2010, 161-162.) Partial and incorrectly collected data increase change of mistakes when data is processed, or make samples even unusable. When sample sizes are very large, its lessen chance to sampling error. (Dickinson et al. 2010, 161-162.)

In 2016, 394 traps were sent to volunteers and samples from 297 were returned successfully (75 percent) (Heustis 2017b). All traps were not checked regularly every week, traps were checked different days and tracking season was started or ended earlier. This made data processing more challenging and distorted results. Irregularly checked traps distort the possibility to have accurate weekly moth numbers. For example, if trap is set up begin of the tracking season and first checked end of the month, it is possible that trap includes moths from several weeks. During processing and identifying moth samples, chance of wrong identify and wrong moth count has been possible. Chance of mistakes during putting data to Excel form has also been possible.

6 Results

6.1 Trap distribution and coverage

Map below shows trap distribution and coverage in New Brunswick. Successful traps (84 pieces) are marked with red dots and unsuccessful or removed traps (44 pieces) are marked with blue dots. Trap coverage was good in south, west and southeast of province. Northern and central part of the province were almost without traps. One explanation to this is that in the central part of province are no big cities and it is mostly rural area. Most traps were located around cities. In the southern part of province around Saint John, Fredericton and Moncton, and in the northern part around Bathurst, Edmundston and Miramichi. Possible reason for this is bigger number of inhabitants. In the west was also good trap coverage following the New Brunswick-Maine border line.



Picture 10. Successful traps are marked with red dots, and removed and unsuccessful traps with blue (Picture from Google my maps).

If data from removed traps could be used, it would give better regional information from the northwest of New Brunswick. Monitoring spruce budworm populations especially in the northern part of province is important because of the current outbreak in Quebec is not far from the New Brunswick-Quebec border. Better trap distribution would give more realistic results how widely spruce budworms were or were not spread. Now received spruce budworm distribution results are incomplete because there were no data from central part of province and in the northern part have also gap.

6.2 Population development and statistical analysis

Spruce budworm population development in summer 2016 followed normal life cycle as figure one shows. Adult moths normally emerge on mid-July to early August. After they have emerged they mate and live one to one and half week and then die.

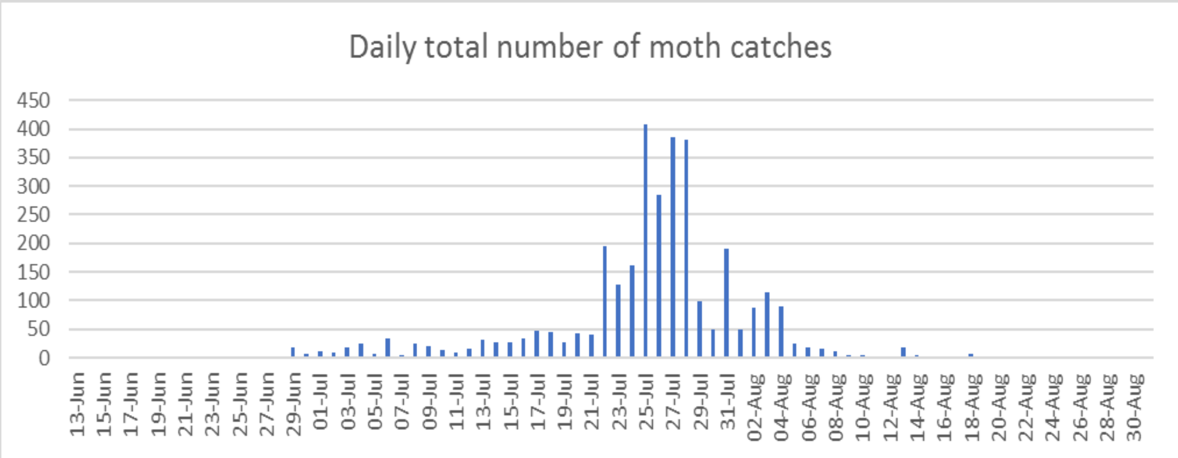


Figure 11. Daily moth catches in New Brunswick (Picture from Excel).

As figure 11 shows, single moths were found on June and early July but moth numbers started to rise after 13th of July. Highest peak was between July 22nd and July 28th and moth founds remained high until fourth of August. After first week of August moth founds declined steadily and after mid-August there were only single moth captures.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Määrä is the same across categories of Alue.	Independent-Samples Mann-Whitney U Test	,153	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Picture 12. Mann Whitney U test summary, where Määrä is number of moths and Alue is latitudes (Picture from spss program).

Mann Whitney U test was done with statistical program spss. The Mann-Whitney U test is a nonparametric test, that allows two groups to be compared without assuming that values are normally distributed (Social science statistics 2017). The aim was to find were there any differences in caught moth numbers between the north and the south part of New Brunswick. Traps were in 40 different latitudes and those were split to two equal groups. The splitting line was on latitude 46.35. Result was that between those two areas average of moth numbers did not have difference in five percent confidence level as the picture 12 show.

6.3 Regional differences

Figure 13 below shows that the average number of spruce budworm moth catches rise when latitude rise and location is more in the up north. One peak in middle of the figure was because of there was one trap near border of Maine with over 100 moth catches. This rose that latitude average.

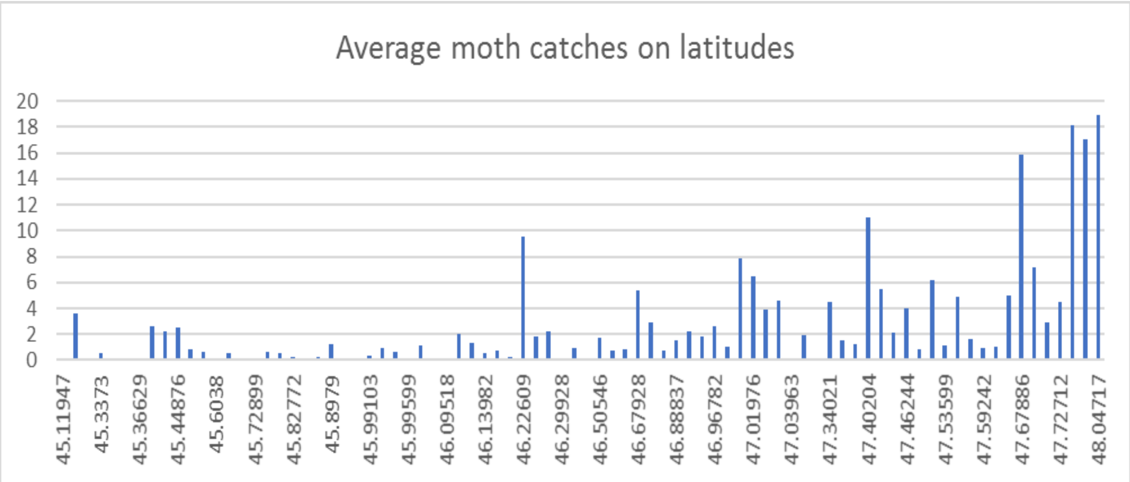
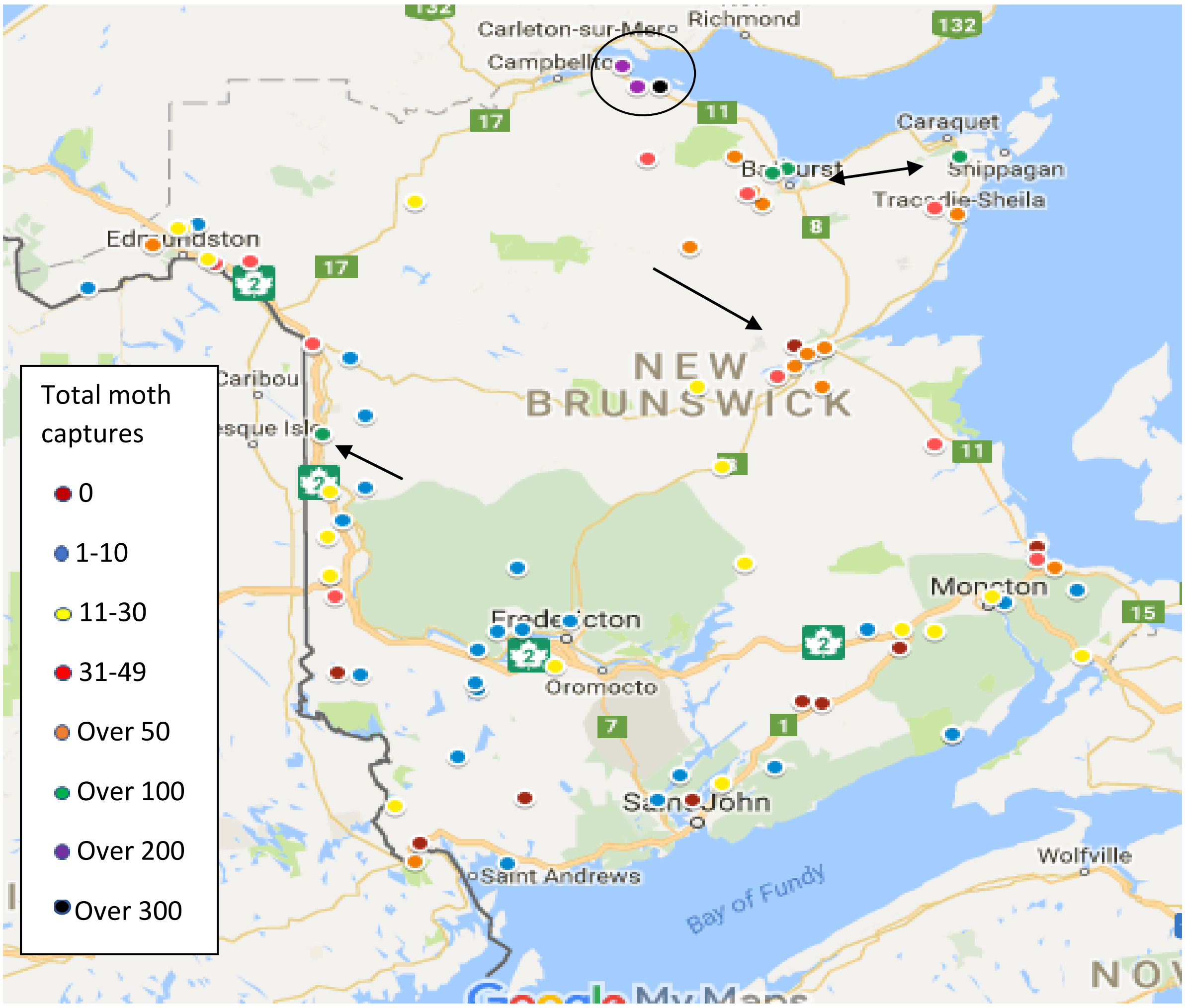


Figure 13. Average moth catches on latitudes in New Brunswick (Figure from Excel).

Total number of captured moths in 84 traps were 3280. Map below shows total number of moth catches in each trap. Traps located in the north and in the northeast had the highest moth catches as the figure 13 show. In the north, near Dalhousie area (circled) one trap had total moths over 300 and two traps had over 200 moth captures. Four traps had over 100 moth catches, two traps located in northeast near Bathurst, one in Village-Blanchard and one trap in west, near Maine border. Around Miramichi moth catches were between 50 and 99 and it is likely that the spruce budworm population is on the rise on this area. Edmundston area in northwest had single trap with over 50 moth catches and all other traps in the area had also moth catches but still low densities.



Picture 14. Total moth captures on each trap (Picture from google my maps).

The southern part of province, around and between, cities of Fredericton, Moncton and Saint John had low moth numbers. Most of the traps had caught moths less than 30 and eight of the nine zero traps were in this area. Only in the northeast from Moncton and in the northwest from Saint Andrews had single traps with 50 plus moth caught. For the next summer, it would be good to have more volunteer budworm trackers in these areas to see how widely budworms have spread.

From 84 traps, there were three traps where were over 100 moths in one check and one trap with 285 moths around Dalhousie and Bathurst. Over 50 caught moths in one check were found in three traps located in Miramichi, northeast from Moncton and southwest from Bathurst. These single time trap captures were clearly higher than in any other traps. All traps in Dalhousie-Bathurst area were checked between July 26th and July 31st. Other high caught moths were found between July 23rd and August 4th.

7 Discussion

The results show, that there are no statistical differences in spruce budworm moth numbers between the northern and southern part of the province. However, traps with high one time check findings were all located in the north and in the northeast of the province. Budworm levels are still in low densities in the province when comparing to Quebec's outbreak areas where total moth catches have been over thousand. Detecting areas with rising budworm populations and using treatments (btk and mimic) to these areas, province can keep spruce budworm levels low and, thus, prevent forest damages.

Around Miramichi there were areas where trap catches were higher, between 50 and 99 and Edmundston area had moth founds in every trap. Those areas populations are likely rising and needs monitoring in coming summers to determine which direction populations are going. In the southern part, moth catches were lower, and most of the traps with zero or less than ten moth catches were located around Fredericton and the western and the southern part of province. This was expected because it is likely that outbreak in Quebec will spread from the north to the south. In the north and the northeast part of province were seven traps with over 100 of total moth catches, which is the limit when Natural Resources Canada is looking defoliation in those areas (Owens & Johns 2016. If there are no visible defoliation on the trees that tells to scientist that caught moths are most likely migrated.

In this research, total of 100 plus and over 100 moth catches in one time check, in the northern part of province were more likely or at least partly migrated from

Quebec. This presumption cannot be proved without DNA analyze, but it is possible because of the spruce budworm mass migration in end of July in Campbellton-Dalhousie area. Moth migration was so massive that it was possible to see moths moving down from the north in the weather radars. (CBC 2016). Starting July 25th millions of moths migrated from Quebec to the northern part of New Brunswick and these moths were both male and female. Highest moth catches were found in Dalhousie and Bathurst area between July 26th and July 31st. Timing of mass migration, and timing of all 100 plus moth catches support the presumption that those moths were partly or entirely migrated. Trap near Maine border with over 100 moth catches is more likely area where spruce budworm population is rising and area needs future monitoring. That location is far from mass migration areas, so it is likely that moths are endemic.

Picture 15. Because of mass migration, spruce budworm moths at the parking lot in Campbellton (Picture by Natural Resources Canada).

Things which distort this thesis research result were trap distribution and data accuracy. Trap distribution was incomplete, and therefore available data from the central part of province and up in the north, near the Quebec border had gaps. Gaps in trap distribution means that it was impossible to have full information about the locations and densities of budworm populations in the province. Trap distribution need to be improved in the future to receive overall data from the province. Data accuracy is always problem in the citizen science projects. In this research data with clear mistakes, like all tracking season moths were collected in one bag, or trap was checked only once or couple times, were removed. Only way to improve data accuracy is education and clear and easy instructions. Ways to achieve this are protocols and other instructions like videos and social media updates, which gives volunteers clear instructions how and when to collect samples and how to store them properly. Volunteers who are committed and take part to program several years are normally best data collectors because their previous years' experience.

There are multiple further research options after this research. One research would be DNA analyze to determine spruce budworm moth's origin and research are moths mated. This could give important information are the populations really rising or just migrated and have the migrated moths mated. Another further research could be comparing different years' moth catches to see how populations are developing. Comparing multiple years' data, gives more precise results what are directions in spruce budworm populations, and how well treatments have worked in treated areas.

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