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Perceptions of Spruce Budworm Monitoring, Management, and Remote Sensing Technology in Maine's Forest Sector

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Cover Page Footnote

We would like to thank the Cooperative Forestry Research Unit and all of the survey participants who shared their perspectives regarding spruce budworm monitoring, management, and remote sensing practices. Funding for this project was provided by the National Science Foundation Grant No. 1828466.

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by Allison Foster, Adam Daigneualt, Parinaz Rahimzadeh-Bajgiran, and Aaron Weiskittel

INTRODUCTION

Eastern spruce budworm (*Choristoneura fumiferana* Clem; SBW) is a native forest pest in the northeastern United States and Canada that has cyclic outbreaks every 30 to 60 years. The larval stage of spruce budworm is a caterpillar that feeds on the needles of balsam fir (*Abies balsamea*) and spruce (*Picea* spp.) trees. Year after year of heavy defoliation during an outbreak can increase tree mortality (Virgin et al. 2017). Spruce budworm devastated Maine's forests in the 1970s and 1980s, resulting in the defoliation of more than 50 million hectares of spruce-fir forests at the peak of the outbreak (MacLean et al. 2019). This outbreak had both ecological and economic effects and resulted in hundreds of millions dollars of lost revenue from Maine's forest-based economy (Wagner et al. 2015).

According to the *2023 Spruce Budworm Annual Review & Outlook Report,* "Historic data tell us that Maine is due for another [spruce budworm] outbreak and monitoring efforts illustrate that over roughly the last decade, [spruce budworm] population levels appear to have left the endemic or 'stable' phase experienced between outbreak events" (Parisio 2024:1). Outbreaks of spruce budworm are detected and monitored through pheromone trapping, overwintering larval sampling, and aerial and ground surveying. The pheromone trap network consists of approximately 350 traps across the state, which provide information about male moths and their movements. Overwintering larval sampling is a coordinated effort from forest managers and the University of Maine Spruce Budworm lab, where branch samples are examined for the presence of spruce budworm larvae. The Maine Forest Service performs annual aerial surveys to look for insect and disease issues in Maine forests, which includes looking for spruce budworm defoliation. Maine Forest Service also evaluates defoliation at sites in Aroostook County using a ground-based survey.

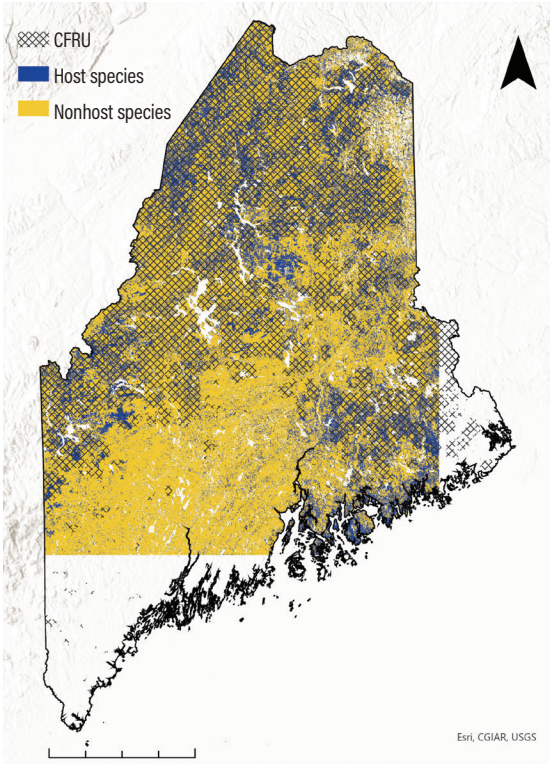
In addition to the monitoring methods described in the previous paragraph, the use of remote sensing to monitor forest health has become more common in the past 20 years. It has many benefits including being more cost effective and less labor intensive than other techniques (Rahimzadeh-Bajgiran et al. 2018). Freely available data like Landsat and Sentinel-2 imagery can help forest managers detect spruce budworm defoliation and further inform management actions (Bhattarai et al. 2020). Remote sensing can supplement monitoring by providing a better understanding of where and to what extent the defoliation damage is occurring (Hanavan et al. 2022). The use of remote sensing, however, does depend on the organization's personnel capacity, i.e., the number of staff and their skill levels and the amount of time required by the task (Mjema 2002). Although the use of remote sensing can save time, it does requires additional technical skills, which can be a burden on the organization.

The goal of the research reported here was to understand forest managers' perceptions of spruce budworm monitoring and management and the use of remote sensing for forest health monitoring. To achieve this, we surveyed Maine's large forest owners and managers. By understanding forest managers' perspectives on current forest monitoring and management practices, we can inform future priorities for the state of Maine.

MATERIALS AND METHODS

We administered an online survey via Qualtrics to members of the University of Maine's Cooperative Forestry Research Unit (CFRU) between April and June 2023.[1] The CFRU consists of 33 member organizations representing more than 50 percent of Maine forest lands. Members include foresters and land managers in Maine with backgrounds in forest products, government, and research on forest ecology, management, and operations. The survey instrument consisted of 31 questions and focused on participants' perspectives on the following topics: spruce budworm monitoring and detection approaches, management activities, remote sensing

FIGURE 1: **Map of Maine with Spruce Budworm Host Species**



Note: Host species = balsam fir and spruce. Nonhost species = broadleaf and conifer. The crosshatch represents CFRU land ownership.

TABLE 1: **Survey Respondent Roles within Their Organizations**

Role in organization	% Total	N
Biologist	7.7	2
Forester	38.5	10
Government official	3.8	1
Land manager	11.5	3
Planner	19.2	5
Researcher	3.8	1
Executive	3.8	1
Science director	3.8	1
Did not indicate	7.7	2
Total		26

technology, and forest health challenges. The survey consisted largely of five-point Likert-scale questions to judge levels of concern about forest pests and likelihood to use specific management and monitoring approaches (Kreye et al. 2019). All Likert scale questions had the same baseline scale of not at all, slightly, moderately, very, and extremely.

The survey design corresponds with a survey of CFRU members administered in 2010 (Foster et al. 2010). Our survey, however, included questions on remote sensing. Comparisons from 2010 and 2023 (when available) are available in the supplemental materials. A literature review and conversations with forest industry professionals helped develop the additional survey questions.[2]

A total of 26 CFRU members completed the survey for a response rate of 78 percent (n = 26). Out of 26 total participants, 24 provided information about their role in their organization (Table 1). Forest organizations reported managing a variety of land sizes: from a high of 6.8 million acres (encompassing forestland in Maine and Canada) to a low of 500 acres, with an average of 1,051,965 acres. The median was 750,000 acres. Across the respondents of this survey, the total amount of forestland represented is 24,195,203 acres. Our sample size is representative of the ownership of managers that are susceptible to a spruce budworm outbreak (Figure 1).

RESULTS

Forest Health and Industry Perceptions

The survey had several questions designed to elicit respondents' perceptions on forest health. For example, we learned that spruce budworm is the forest pest in Maine with the greatest average level of concern, and spongy moth was the pest of least concern (Figure 2).

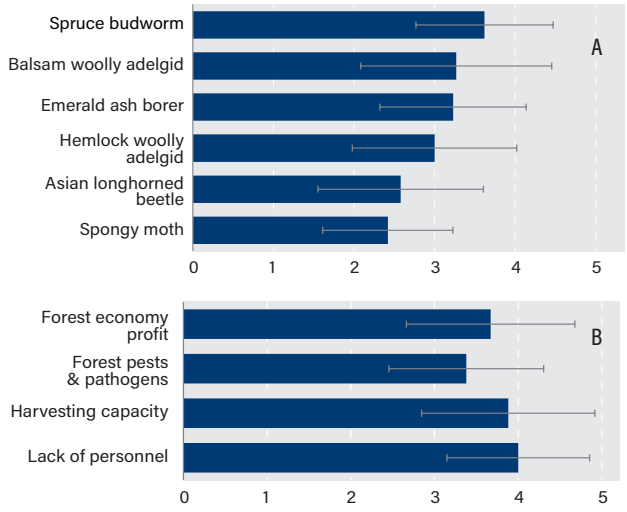
For spruce budworm in particular, forest managers are most likely to use pheromone trapping as a monitoring approach and silvicultural control as the management approach. Similarly, forest managers were least likely to not take any monitoring or management actions for spruce budworm outbreaks (Figure 3). Reducing timber loss was the most common reason cited by respondents for managing forests during a spruce budworm outbreak in Maine and the least common reason was encouragement from neighbors (Figure 4).

Looking at general forest health concerns currently and in the future, climate change was the most concerning factor for forest managers in Maine followed by forest pests and forest pathogens (Table 2). Climate change was listed as the top current forest health issue and as the top concern for 20–30 years from now.

Remote Sensing Perceptions

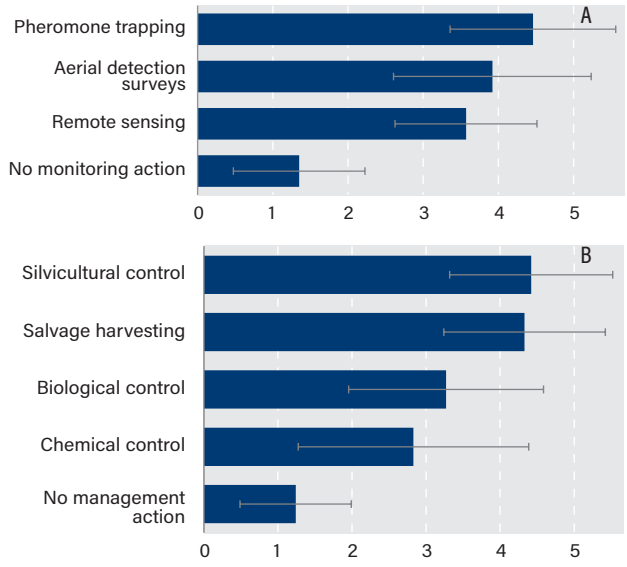
Approximately 54 percent (n = 14) of respondents mentioned their organizations currently use remote sensing products or technologies for forest health applications. Six respondents provided more information about their use of remote sensing, and of those respondents, 67 percent used light detection and ranging (LiDAR) data. Other answers included imagery such as National Agriculture Imagery Program (NAIP), unmanned aerial vehicle (UAV)

FIGURE 2: **Concern for (A) Forest Pests and (B) Forest Sector Challenges in Maine**



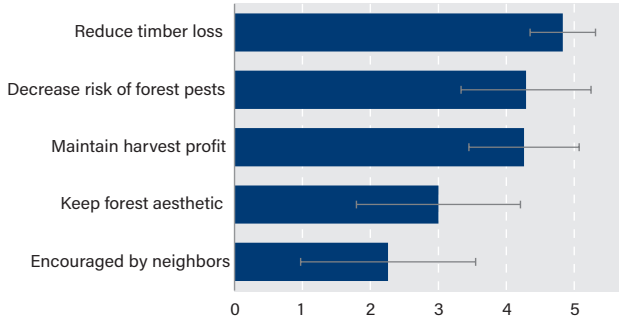
Notes: (A, n = 26; B, n = 24) Likert scale ranging from 1 = not at all concerned, 2 = slightly concerned, 3 = moderately concerned, 4 = very concerned, 5 = extremely concerned. The error bars represent standard deviation.

FIGURE 3: **Preferred (A) Monitoring and (B) Management Approaches for Spruce Budworm Outbreaks**



Note: (n = 24). Likert scale ranging from 1 = not at all likely, 2 = slightly likely, 3 = moderately likely, 4 = very likely, 5 = extremely likely. The error bars represent standard deviation.

FIGURE 4: **Reasons for Managing Forestland during a Spruce Budworm Outbreak**



Note: Likert scale ranging from 1 = strongly disagree, 2 = slightly disagree, 3 = neutral, 4 = slightly agree, 5 = strongly agree. Error bars represent standard deviation.

TABLE 2: **Forest Health Issues Concern Now and in 20-30 Years**

Forest health issue	Current mean	20-30 year mean	P-value
Climate change	3.88	4.29	< 0.001
Forest pests	3.87	4.00	0.15
Forest pathogens	3.33	3.75	< 0.05
Drought	2.79	3.33	< 0.01
Frost	2.26	2.52	< 0.001

technology, and near infrared cameras. When asked about remote-sensing applications, the respondents were most interested in forest health monitoring and forest composition maps (Table 3). Among remote-sensing applications for spruce budworm monitoring, forest managers were most interested in the application of remote sensing to identify hotspots by integrating remote sensing data with overwintering larval sampling.

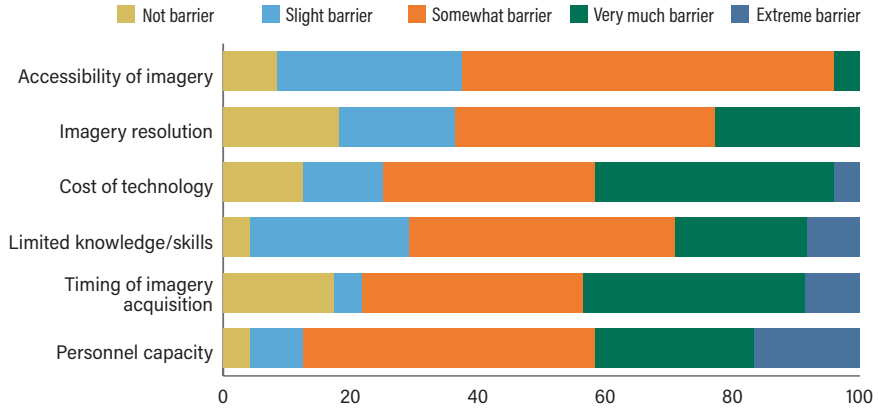
Respondents indicated personnel capacity was the biggest barrier to the use of remote sensing technology, and the ability to access the imagery was the least likely barrier (Figure 5).[3] Some respondents felt that the cost of the technology would be the major barrier; the cost of technology can be related drones, computer software, and satellite imagery, among other things.

Forest managers were also asked to rank five different forest pest detection attributes from most important to least important (speed, landscape coverage, accuracy, cost-effectiveness, and safeness). The accuracy of the detection approach was the most important attribute, with 35 percent of forest managers selecting it as their first choice (Figure

TABLE 3: **Willingness to Invest in Remote Sensing Applications**

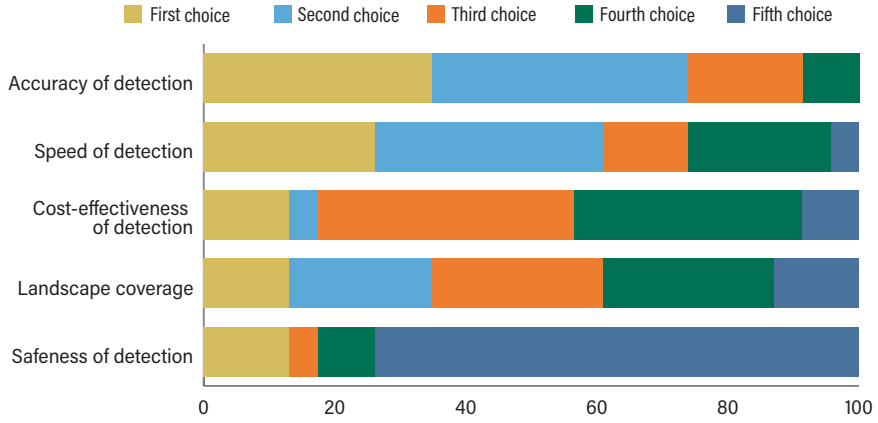
Remote sensing application	% Total	N
Forest health monitoring	91.6	11
Forest composition maps	75	9
Land use land cover maps	33.3	4
Other: change detection	16.7	2
Total		12

FIGURE 5: **Perceptions of Barriers to Using Remote Sensing Technology and Satellite Imagery**



Note: (N = 24).

FIGURE 6: **Rankings of Preferred Remote Sensing Detection Attributes**



Notes: (N = 23).

6). The speed of detection was also important, with 26 percent of forest managers selecting it as the most important, and 35 percent selecting it as the second most important. Safety was the least important attribute to forest managers when considering a detection approach, with all other attributes being significantly more important.

DISCUSSION

Forest Health and Industry Concern

We can use the results of this study to glean important insight into forest managers' perceptions of spruce budworm and general forest management techniques. Understanding forest managers' preference to use silvicultural management techniques, which can include precommercial thinning and salvage harvesting, for managing spruce budworm outbreaks can help the Spruce Budworm Task Force when they propose management actions for landowners. Additionally, recognizing that forest management modeling tools have become much more sophisticated since the last outbreak, we understand that forest managers have a greater ability to assess the outbreak and its impacts. The survey results also showed that forest managers are concerned about profitability (Figure 2). Since spruce budworm and other forest health challenges pose severe threats to Maine's forest economy (Ranco et al. 2012), policymakers should prioritize forest health issues when designing forest management policy. Furthermore, as shown in Table 3, the significant relationships between items of concern now and predictions of items of concern 20 years from now indicates a need to start addressing these problems soon because respondents feel that the issues will persist.

Remote Sensing Perceptions

Prior to our study, there was no baseline of information on the use of remote sensing for forest health monitoring in the state of Maine. While the state of Maine has well-established spruce budworm monitoring programs, remote sensing has the potential to be used for fine-scale annual defoliation detection as well as mapping spruce budworm host species distribution and

susceptibility based on stand type and maturity (Bhattarai et al. 2020, 2021, 2022). Decision-makers in Maine should be aware of the approaches already being implemented, while they actively work towards the integration of remote sensing technologies, specifically for challenges like forest health monitoring. Remote sensing data is most effectively used when there's a clear and specific understanding of its application, which is often the case in forest health monitoring (Fassnacht et al. 2024).

As there is a positive correlation between personnel capacity and limited knowledge or skills to use remote sensing, it is important to provide forest managers with the tools so they can use this technology and information themselves (Carter et al. 2021). One of the task force's priorities is to facilitate communication between monitoring efforts and research needs, specifically between forest managers and academia. However, there is a great diversity of forest managers in Maine, which can sometimes pose communication challenges (Soucy et al. 2022). There can be a knowledge gap between foresters working in the field and researchers working on the technical aspects of remote sensing applications (Palumbo et al. 2016). It will be crucial to overcome that gap when discussing remote sensing specifics.

While our study did not ask about data fusion techniques of remote sensing such as multi-sensor data fusion, combining data sources is common as outlined in several published studies (e.g., Heckel et al. 2000; Wolter and Townsend, 2011). Sources can be remote sensing data (i.e., multispectral, LiDAR) or information found via other monitoring approaches. For example, New Brunswick has both a citizen-science-based monitoring program and conventional monitoring programs for spruce budworm, so the province reaps the benefits of both (Owens et al. 2021). For Maine to continue as a leader in sustainable forest management and integrated pest management, the state must use all options available for forest monitoring, including both field surveys and remote sensing technology.

When choosing a detection approach, accuracy and speed of detection were both highly important to forest managers. Defoliation caused by spruce budworm was detected, accurately and quickly, using satellite imagery in the past including Landsat (Rahimzadeh-Bajgiran et al. 2018) and Sentinel-2 (Bhattarai et al. 2020) imagery. With continuous improvement in satellite data quality and availability and advancement in artificial intelligence and machine-learning approaches for data analysis, any issues relating to data quality and availability can be expected to decrease in the near future. In addition, integrating data from remote sensing and field (e.g., the pheromone trapping network) will help forest managers to respond to spruce budworm outbreaks in their forests.

Barriers and Constraints

We found that forest managers' biggest barrier to using remote sensing technology and satellite imagery was personnel capacity. Most forest managers expressed high levels of concern about a lack of personnel in Maine's forest industry (Figure 2),[4] and 40 percent stated that personnel capacity is a barrier to using remote sensing technology (Figure 5). To increase capacity in Maine's forest community, we propose three recommendations. First, focus on partnership development and strengthening collaborations. Second, hire a remote sensing specialist for the Maine Forest Service to support these efforts. Third, use networking and collaboration platforms to advance remote sensing capabilities. Using collaborative platforms allows users to learn about different tools and generally leads to greater knowledge and skill development (Martin and Gareces 2023).

While monitoring and management efforts have been coordinated by the Maine Forest Service in the past, during the current outbreak the responsibility will fall on private landowners. There needs to be leadership in these collaborative efforts, and the Maine Spruce Budworm Task Force should discuss next steps and lead these collaborative efforts.

Communication and engagement can be challenging when the audiences range from forest managers to the general public; however, that does not mean that public communications should be dismissed. The Maine Forest Service, Bureau of Pesticides Control, Cooperative Forestry Research Unit, and Spruce Budworm Task Force need to use clear language in their communication materials. ArcGIS story maps that show spruce budworm population numbers over time, for example, can be a useful tool to reach an audience beyond forest managers (Budowle et al. 2022). Communication between forest managers and the Maine Legislature should also be facilitated, especially considering issues of management policy during an outbreak.

Clear communication between decision-makers and forest managers will aid in management efforts that protect Maine's forests, both ecologically and economically. The Maine Spruce Budworm Task Force and other partnerships need to emphasize the importance of social contracts in collaborative forest management. While Maine has a number of organizations that bring foresters together, we must ensure that these groups have productive and

proactive conversations about the needs of the forest industry in Maine.

Future Research Efforts

Survey results highlight that we need more research to show how remote sensing can integrate with existing field sampling techniques and on defoliation detection by remote sensing technology. Additionally, Maine's forest community needs a more information about the cost-effectiveness of remote sensing. Beyond spruce budworm, forest managers need more research on how remote sensing can aid in other forest health monitoring efforts, especially for pests such as hemlock wooly adelgid and brown tail moth.

Similarly, more efforts need to be made to reduce the barriers to adoption of remote sensing caused by personnel capacity and the lack of knowledge and skills. As the use of remote sensing in forestry applications continues to grow, it will be critical to develop effective ways to communicate and engage with foresters across the state. The state needs training programs aimed specifically at enhancing the skills and knowledge relating to remote sensing in forestry. Following these recommendations can help strengthen Maine's forest community in the event of a spruce budworm outbreak.

CONCLUSION

With a spruce budworm outbreak threatening the state's spruce-fir forests, Maine's forest community must work together and use all available tools to mitigate the loss of these trees. Strengthening forest health monitoring programs in Maine will promote proactive forest management and reduce the economic loss of timber and other forest products. Ensuring effective monitoring through the use of clear policies and collaboration between organizations will prepare Maine's forest managers for the spruce budworm outbreak and other challenges.

We need to be aware that forest health issues and biophysical stressors such as climate change are of high concern to forest managers in Maine in order to determine what future policy directives we need to work towards. The high level of concern for lack of personnel capacity in the forest industry in general and for remote sensing technology in specific is something that decision-makers in Maine should be aware of, especially given the high level of interest in remote sensing applications found in our survey. Gradual integration of remote sensing technologies into forest health monitoring in the state of Maine, specifically through policy and task force goals, can help forest managers adopt some of these technologies. Identifying cost-effective and efficient ways to use remote sensing for forest health applications is important to forest managers in Maine. The results of this study can be instrumental in informing policy development in Maine to ensure a healthy and sustainable future for Maine's forest ecosystems and forest products industry.

ACKNOWLEDGMENTS

We would like to thank the Cooperative Forestry Research Unit and all of the survey participants who shared their perspectives regarding spruce budworm monitoring, management, and remote sensing practices. Funding for this project was provided by the National Science Foundation Grant No. 1828466.

NOTES

1 Survey was administered under the University of Maine Institutional Review Board protocol no. 2023-03-15. The survey instrument was pilot-tested with participants who have experience in research and forest management before distribution to minimize misunderstandings (White et al. 2005).

2 We used IBM SPSS Statistics version 29 to run frequencies and descriptive statistics on the Likert scale questions. To compare the 2010 and 2023 data, we ran summary statistics on means (and standard deviations), when possible) to look at changes. Data were analyzed further using R software version 4.2.2. Fisher's exact test was used to test the relationship between variables due to small sample size (stats package; R Core Team 2022). To assess the ranking of importance for forest managers when choosing a detection technique, we ran a Plackett Luce model to determine the probability items being ranked together.

3 Remote sensing technology (mean = 3.42, SD = 1.02), the ability to access the imagery (mean = 2.58, SD = 0.72). The barriers of personnel capacity and limited knowledge/skills have a Pearson correlation coefficient of 0.71, indicating a strong relationship between the variables ($p < 0.001$).

4 (mean = 4, SD = 0.853)

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