1994, the cost to suppress, eradicate, and conduct research on ASM totaled $30 million with an additional $8 million for pheromone traps (Wallner 1998).

Figure 6 European Spongy Moth Defoliation in the Eastern United States

Forestry is a key industry in both Oregon and Washington, generating millions of dollars in net revenue that would be threatened in the event of an Asian spongy moth infestation. When ASM infests, the area must undergo a quarantine period. This means that any products that can potentially carry ASM must be inspected and acquire phytosanitary certificates (confirming that they are ASM-free) prior to shipping, which raises the costs for both the consumers and industries (Oregon Department of Agriculture 2021). In Oregon as of 2017, the greenhouse and nursery production industries, which includes the Christmas tree industry, was valued at approximately $1.03 billion. The majority of Oregon's Christmas trees (approximately 85-90%) are sold out of state domestically and internationally with the remaining 10-15% being sold locally. More than 80% of nursery products including herbaceous plants, ornamental trees, and shrubs are shipped out of state. An infestation of ASM would cause a large financial loss to Oregon's economy (Kearns & Tobin 2020).

Eradication programs have been implemented from the Portland Metropolitan area in the north, Ashland in the south, Fischer to the west, and Bend in central Oregon. Over 40 years, these

eradication efforts have cost up to $60 million, which does not include field supplies (traps, vehicles, and data records), annual survey costs, and seasonal personnel (Kearns & Tobin, 2020).

Since the Asian Spongy Moth has never been established in Oregon, it would be difficult to quantify with certainty what the economic costs of establishment would be, but lessons could be learned from established populations of European Spongy Moths in eastern states. Residential property owners experienced a reduction in their home values due to degraded trees with an estimated $120 million lost in property value and another total of $46 million in household control including the removal and replacement of trees. Forest landowners have experienced a total loss of $4.6 million in timber since the establishment of European Spongy Moths (Kearns & Tobin, 2020).

Human Health Impacts

Asian Spongy Moth larvae can harm human health and disrupt outdoor activities such as camping and hiking. Exposure to larvae can result in a rash similar in appearance to poison ivy or other skin irritations (Oregon Department of Agriculture 2021) **(Figure 7)**. It is also possible to experience irritation to the eyes or the respiratory tract. Individuals who experience a long term exposure to ASM (one or more years) could potentially develop an allergy to the moth.

Figure 7 Rash Attributed to Spongy Moth Larvae

Mild impacts to human health may be posed by the use of chemicals to control Asian Spongy Moth populations. *Bacillus thuringiensis* var. *kurstaki* (Btk.), a bacterium used against larvae may result in mild irritations of the respiratory tract, skin, or eyes.

Diflubenzuron (Dimilin), a chemical insecticide that interferes with the growth of immature insects likely does not result in effects to human health; however, at very high exposures, an increase in methemoglobin, an abnormal blood pigment that reduces the blood's carrying capacity of oxygen, may be detected (United States Department of Agriculture 1995). In general, Diflubenzuron has low acute toxicity levels but a metabolite of Diflubenzuron, p-chloroaniline (PCA) is a possible human carcinogen (United States Environmental Protection Agency 1997) .

Gypchek is an insecticide produced from the naturally occurring Nucleopolyhedrosis Virus found in Asian Spongy Moths. Due to limitations in data, Gypchek effects on human health cannot be assessed, but irritation of the skin, eyes, and respiratory tract are possible. Due to Gypchek containing portions of the Nucleopolyhedrosis Virus individuals with allergies could be at an increased risk of experiencing irritation.

The pest strip used in the milk-carton trap for European Spongy Moth contains the insecticide DDVP (2,2 dichloroethenyl dimethyl ester phosphoric acid). This insecticide could inhibit acetylcholinesterase production, which prevents the accumulation of acetylcholine, a neurotransmitter that plays an important role in the function of the nervous system . However, the likelihood of coming into contact with DDVP from the trap is low as an individual would have to disassemble the trap and have contact with the strip (United States Department of Agriculture 1995).

Treatment Options

SUMMARY: Pheromone trapping is an effective way to monitor Asian spongy moth introductions as well locate small, isolated moth colonies before they become widespread. After the moths reach a higher population density or degree of spread, the traps become less reliable at eradication, and it may become necessary to apply insecticides to the area of concern. Currently, Btk insecticides are the standard for such a treatment because the active ingredient is naturally produced and they pose minimal, if any, risk to humans or other plants and animals.

The most cost-effective approach to preventing the establishment of ASM populations in North America is likely through rigorous trapping, monitoring, and detection programs. Multiple barriers have been put into place in the United States to combat the ASM introduction that accompanies international shipments. The United States Department of Agriculture, in conjunction with U.S. Customs and Border Protection, has inspection and compliance procedures for incoming vessels carrying shipments from moth-populated areas, and many state governments have additional protocols in place to protect vulnerable environments. For example, the Oregon Department of Agriculture has implemented Early Detection Rapid Response (EDRR) protocol in ASM detection including a large-scale trapping program that deploys thousands of pheromone traps throughout the state every year (Oregon Department of Agriculture 2021) **(Figure 8)**. These pheromone traps contain

a synthetically-produced female sex pheromone that male moths are attracted to, and they subsequently get caught in the trap. The traps are utilized most heavily during the ASM mating season, and the elimination of many male individuals from the population means that mating opportunities are scarce. As a consequence, the entire introduced ASM population may die out if the population is still quite small (Oregon Department of Forestry 2022). While trapping is an effective tool in eliminating small, isolated moth colonies, the problem quickly overtakes the solution when high population densities or geographic spread are obtained (Sharov et al. 2002). After this threshold is met, it is necessary for more intensive management measures to be taken.

To eradicate/prevent the establishment of larger ASM populations, applications of pesticides containing *Bacillus thuringiensis kurstaki* (Btk) spores are frequently used. Btk, a naturally occurring bacterium commonly found in soil and leaf litter, produces a crystalline protein that is specifically toxic to certain insect larvae (including Lepidopterans) when consumed. The primary advantage to utilizing Btk is its host specificity – it targets Lepidopteran larvae while not having a significant impact on humans or other non-target organisms. While Btk-based insecticides may not be quite as effective as chemical alternatives if the target organism has reached a high population density, they are less toxic to the environment/human health and are certified for use on organic crops in the United States (Washington State Department of Agriculture, n.d.).

Figure 8 Moth Pheromone Trap

Case Study

SUMMARY: A major Asian spongy moth eradication effort was performed in 2016 in Portland, Oregon, after the detection of multiple moths in nearby neighborhoods and parks. The population was successfully eradicated through aerial applications of Btk insecticides. The preparation for this project involved multiple agencies and organizations and a massive outreach effort to address questions and concerns by community members. *The Eradication Playbook,* written after the 2016 project, provides environmental managers with useful organization and outreach tools to implement when planning a major eradication project.

The most recent coordinated effort to combat Asian Spongy Moth dispersal in the Portland area was executed in 2016 after the detection of multiple individuals the year prior in Forest Park and the northern section of the St. Johns neighborhood. The recognition of ASM by the United States Department of Agriculture as a "significant exotic pest of economic importance" calls for rapid action to be taken when a threat of ASM establishment is present (Oregon Invasive Species Council 2016). Multiple agencies collaborated in late 2015 to reach a consensus on the most effective method of ASM extermination given the circumstances, and it was determined that aerial applications of *Bacillus thuringiensis kurstaki* (Btk) over the areas of concern would be the best course moving forward (Oregon Invasive Species Council 2016).

Btk makes for an ideal Lepidopteran-specific pesticide for the reasons listed above in the "Treatment Options" section, and the success of previous eradication efforts using this pesticide provided support for the treatment. After detection of several moths in northwest Oregon and southwest Washington in 1991, three aerial applications of Btk across 144,200 acres between the two states as well as extensive pheromone trapping resulted in no moths being detected in the following two years. Additionally, after the detection of several European Spongy Moths in west-central Oregon in the early 1980s, applications of Btk and quarantines resulted in successful eradication within five years of detection (United States Department of Agriculture, n.d.).

Among multiple complications in the 2016 treatment plan was the potential for public dissent. The aerial application would need to take place over highly urbanized and densely populated areas including Forest Park, the St. Johns and Linnton neighborhoods, and the Port of Portland (Oregon Invasive Species Council 2016). It was recognized early on in the effort that communication with stakeholders and the general public would be crucial. Environmental managers involved in the process later reflected on the public outreach element as one of the greatest perceived successes of this effort. *The Eradication Playbook*, a document written by individuals involved in the 2016 ASM eradication effort, lists multiple "plays" with suggestions for coordinating an eradication process from start to finish, including valuable input on the social dimensions of management efforts **(Figure 9)**. Interviewed environmental managers emphasized the importance of the following elements in the 2016 effort:

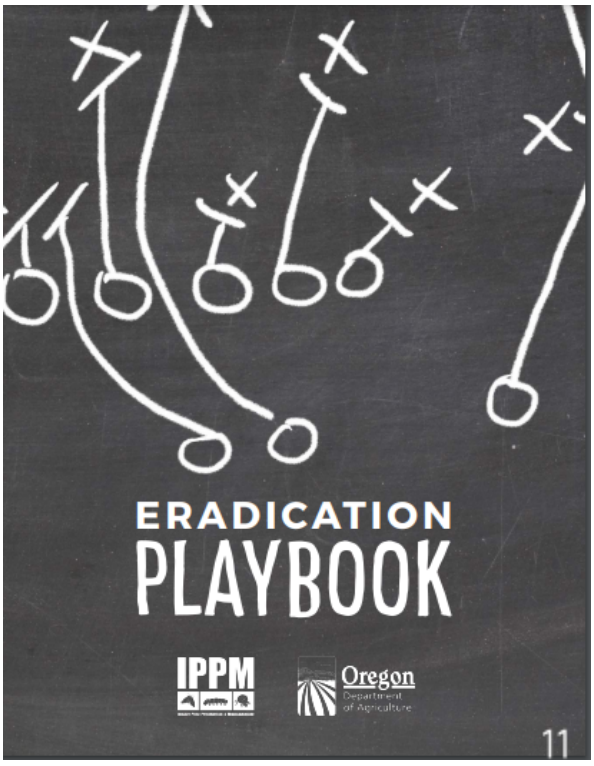

Figure 9 Cover of *The Eradication Playbook*

- Offering community members the space and resources to ask questions and understand why an eradication effort is necessary and how the eradication may take place
  - Instead of hosting a traditional question-and-answer townhall format, workshops were conducted during the 2016 ASM eradication project that allowed community members to visit different "stations", learn about ASM impacts, and have 1:1 discourse with experts and fellow community members.
  - Online resources were advertised to community members referring them to Frequently Asked Questions and further information about the eradication effort. Community members were able to sign up for notifications about the progress of the effort the day of the aerial pesticide application.
- Working to understand different community perspectives and recognizing how different communities may be impacted by an eradication effort; examples of considerations include:
  - Members of the houseless community may not have the space or resources to shelter under if they want to during an aerial insecticide application. Solutions may include providing a sheltered meeting location or setting up tarps/gazebos during the application.
  - Immunocompromised community members may require advanced notice of insecticide applications so that they are able to take shelter. Solutions may include advertisement of application timing and application when fewer individuals are likely to be outside.
  - Community members that raise/breed Lepidopteran species (ex: silkworms) may be concerned about Lepidopteran-specific insecticide applications. Solutions may include individual collaboration on a case-by-case basis with these community members to find a common solution.
- Creating multiple avenues of education and communication to reach the entire community
  - The creation of social media posts is generally not sufficient to connect with all community members. A combination of community meetings, workshops, social media, graphic design, document distribution, and other methods were employed during the 2016 ASM eradication effort to reach different types of audiences.
- Establishing a goal or intent for the eradication project early on that can be communicated easily throughout the course of the entire project development

- The communicated goal of the 2016 ASM effort was to "prevent the ecological devastation of the Pacific Northwest's forests and riparian areas" (Burfitt et al. 2018).

➔ Involving community leaders external to the effort to create a bridge of communication

➔ Involving as many agencies, organizations, stakeholders, and community members as possible

- A four-hour workshop with community partners was conducted to identify all possible avenues of involvement in the 2016 ASM effort (Burfitt et al. 2018).

- Over 90 agencies were involved in the 2016 ASM eradication project.

➔ Recognizing that building community trust and communication takes time and consistent consideration, even if a major eradication effort is not currently in progress

The Samara Group, an environmental organization dedicated to helping community-based research and projects take place, supported and provided outreach and communication resources listed above for the 2016 ASM eradication effort. Jalene Littlejohn (who is currently a Program Coordinator for the U.S. Fish and Wildlife Service and was heavily involved in the 2016 ASM response outreach) suggested that for future efforts, conflict training focused on compassionate communication and de-escalation for all individuals involved in public outreach may further improve community involvement and support.

The 2016 ASM eradication effort was a success – the first of three aerial Btk applications took place in mid-April, and monitoring efforts in October of that year indicated that no moths were found in the 3,000 traps in the Portland area. Additionally, to address concerns about the impact of the Btk application on other butterfly and moth species, a study was conducted before and after the application to monitor native populations. While these populations initially declined, they quickly recovered to pre-application levels (Williams, personal communication, 2022). This case study contributes to the body of evidence supporting Btk as an effective pesticide to target invasive moths; however, it also emphasizes how the importance of community outreach and communication when planning a major environmental project cannot be overlooked. A significant amount of the success of this project is attributed to the lack of community resistance that followed the extensive efforts to create communication and education opportunities.

Conclusion

It is likely that there will continue to be unintentional Asian Spongy Moth introductions to North America. Prevention using Early Detection Rapid Response (EDRR) protocol is the most effective way to combat establishment; although prevention costs seem high, the cost of controlling an established population and the loss of timber sales as a result of establishment would be far higher. Obtaining

funding to support the necessary distribution of pheromone traps is a significant obstacle in this prevention. If monitoring efforts indicate that a more intensive method of control is warranted, the 2016 ASM eradication project in Portland indicates that it is possible to execute a large-scale moth management effort in an urbanized effort if there is care taken to prioritize communication and transparency with stakeholders and with the community as a whole.

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