Invasive Species Management and Climate Change Adaptation: Strategies for Enhancing Native Species Resilience in the Mount Arrowsmith Biosphere Region

By:

Aisha Adelah, Maryam Vatanparast, Putuma Balintulo, Takudzwa Makuwa, Ayomide Akinfasoye

TILL 2024

Acknowledgments

We would like to acknowledge and express our deepest gratitude to the Qualicum, Sna-na-was, Snuneymuxw, K'omoks, Tseshaht, Hupacasath, and Ditidaht First Nations for welcoming us onto their traditional lands within Mount Arrowsmith Biosphere Region (MABR), where we had the opportunity to live, travel, and work for the past six weeks.

This project would not have been possible without the unwavering support of the MABR, partner institutions, and our dedicated mentor, Jim Robson, alongside other mentors. We extend our sincere appreciation to the TRANSECTS team and all members of the community who generously shared their time and knowledge with us.

A special thanks to Chief Lawrence and his family for their warm welcome and for sharing invaluable insights on their stewardship and connection to the land with us. We are also grateful to all the presenters, chiefs, and community leaders, who enlightened us with their expertise.

Finally, we are immensely thankful to the host team (MABR), Alanna Vivanni, Graham Sakaki, Pam Shaw, Courtney Vaugeois, and Jessica Pyett for their outstanding coordination and the relationships nurtured over the years to avail us of this opportunity. Their efforts made this transformative experience possible.

As we have learned, we say *Huy ch q'u, thank you.*

Table of Contents

Abstract

The report examines the interplay between climate change and invasive species management in the Mount Arrowsmith Biosphere Region (MABR) of British Columbia, Canada. It highlights how climate change exacerbates the spread of invasive species like Scotch broom and Himalayan blackberry, posing significant threats to native ecosystems. The study combines field observations, literature reviews, and interviews to identify climate change drivers and human activities contributing to invasive species proliferation. Key findings suggest that rising temperatures, land use changes, and extreme weather events facilitate the spread of these species. The report proposes a holistic approach to invasive species management that integrates climate change adaptation strategies, emphasizing early detection, rapid response, and community engagement. It advocates for policy interventions, sustainable practices, and collaborative efforts involving diverse stakeholders to enhance ecosystem resilience and sustainability. The recommendations aim to align with the United Nations Sustainable Development Goals (SDGs), particularly those related to climate action and life on land, ensuring a comprehensive strategy for managing invasive species under changing climatic conditions.

1.0 Introduction

Invasive alien plant species and climate change are the most pressing global changes and pose the most devastating threats to ecosystems (Beaury et al., 2020). The impacts of invasive species are manifold, including changes in ecosystem structure and function, which has a range of social, ecological, and economic implications. These are further exacerbated by the interaction ofinvasive species with climate change. For instance, as the climate is predicted to warm, invasive species are likely to expand up north towards the poles and in higher elevations. This poses a riskof invasion in the mountain forests of the regions in North America, particularly Canada, especially because warming temperatures are associated with declining snowpacks (Gervais et al., 2020). Furthermore, climate change disrupts the natural balance and functioning of ecosystems and creates more disturbance through extreme weather events that in turn favor the establishment and spread of invasive plant species.

Climate change not only drives the spread of invasive species but also hampers their control and management. For example, climate may alter invasive species phenology, some biological control agents and some chemicals/pesticides may not be effective in warmer temperatures, and increasing atmospheric CO2 enhances the growth of invasive species. Certainly, these complex and interconnected challenges posed by climate change and invasive species necessitate effective management strategies that consider both phenomena simultaneously to address their combined impacts on ecosystems. Yet, it remains unclear what the influence of climate change on invasive species management is, and what adaptation strategies can be implemented to facilitate ecosystem and landscape resilience in the face of these global changes. Therefore, it is indispensable to develop proactive invasive species management strategies that take into account climate change adaptation strategies in order to enhance native species resilience for sustainable ecosystem management.

Despite the negative impacts of climate change in exacerbating the spread of invasive species, they also provide opportunities for more effective management approaches. Climate change can be used to predict shifts in the distribution of invasive species, which can be leveraged to predict and map out the likely range of shifts in some invasive species, to help in early detection and rapid response (EDRR) before it becomes widespread in new areas.

This would also help with the allocation of resources to focus on more vulnerable areas. It is imperative that a holistic approach involving diverse academic fields, shared responsibility holders and actors be actively and meaningfully adopted in the management of invasive species, to achieve resilient and adaptive ecosystems for sustainable societies.

1.1 Purpose statement

Canada's geographic location makes it vulnerable to intensified climate change and the spread of invasive species. According to the Invasive Species Council of BC, Scotch broom, Himalayan blackberry, and English ivy are among the rapidly spreading species in British Columbia. The spread of invasive species within the Mount Arrowsmith Biosphere Region (MABR), is having severe impacts on forestry, water quality and quantity, soil erosion, degradation, and causing economic losses and threatening ecosystem services. The combined effect of climate change and invasive species is likely to worsen the situation.

1.2 Research question

How can climate change adaptation strategies be designed to improve the resilience of native species and ensure sustainable ecosystem management?

1.3 Aim and Objectives

This study aims to develop climate change adaptation strategies to enhance native species resilience for sustainable ecosystem management. To achieve this aim, the following objectives were developed.

1) To examine climate change variables influencing the spread of invasive plant species.
2) Identify management approaches for invasive species control.
3) Identify relevant climate change adaptation strategies to enhance native species growth and resilience.

2. Literature Review

2.1 Climate Change variables influencing the spread of invasives

According to Kathiresan and Gualbert (2016), though the invasive potential of weeds is significantly influenced by climate change through the alteration of specific biological traits, only about 10% of introduced species become invasive in new environments. This number is aided by changes in climate variables like temperature, precipitation, and carbon dioxide. The biological and genetic traits of plants through the influence of climate change lead to alterations in seed production and growth rate.

The study by Beans et al. (2012), focusing on the spread of Japanese honeysuckle (Lonicera japonica) in the United States, discovered that climate change could significantly influence the spread of invasive species, and even advance more within the poorest climatic conditions. However, they also noted the aggravation of spread coupled with anthropogenic factors. In efforts to curb their expansion, the study cautioned against the planting of non-native horticultural species.

Bradley et al. (2009), also employed bioclimatic envelope modeling to predict climate change influence five common invasive plants within western US. The model suggests that some invasive plants, like yellow starthistle and tamarisk, will likely spread further with climate change. However, variations are expected for species like cheatgrass and spotted knapweed, either increasing or declining in different areas, while leafy spurge is predicted to decline. This potential decline of some invasive species due to climate change also presents an opportunity for restoration efforts. In these circumstances, it is worth considering more suitable native plant replacements before other unwanted plants can be established.

Climate change has significant implications for biodiversity, impacting various aspects of ecosystems. Gervais et al. (2020), investigated the potential impact of climate change on the proliferation of non-native invasive species in the Pacific Northwest, highlighting the limited research and understanding in this area. The main findings emphasize that climate change can facilitate the expansion of non-native invasive species, particularly in aquatic ecosystems, necessitating urgent attention and evidence-based strategies (Gervais et al., 2020).

In a study conducted by Bradley et al. (2023), the critical importance of integrating climate change considerations into future environmental policy frameworks is highlighted. Through a comprehensive analysis, the paper shows an interplay between climate change and the expansion of non-native invasive species in the Pacific Northwest. It stresses the urgency of adopting a "climate-smart" approach to invasive species policy and management, emphasizingthe proactive mitigation of climate-driven threats (Caldwell, 2006). The methodology outlined in the study promotes expanded information sharing, proactive screening, and regulatory measures targeting high-risk species. Furthermore, it underscores the necessity of federal support for data sharing and decision support tools, alongside initiatives aimed at enhancing public awareness and incentivizing behaviors that reduce harm. The main findings highlight the complex dynamics between climate change and invasive species, emphasizing the imperative for policies thataddress both phenomena concurrently, with a primary focus on preventing introductions to mitigate adverse impacts (Bradley et al., 2023).

2.2 Climate change adaptation strategies to enhance native species growth and resilience

Lawler (2009) discusses several strategies to strengthen native species in their homelands. To empower native species and ensure their long-term survival in a changing climate, non-climate-related resilience factors must be prioritized. This means aggressively addressing threats like habitat loss, invasive species, and pollution. By minimizing these additional pressures, we can bolster native populations and enhance their capacity to adapt to the inevitable changes brought on by climate change. Secondly, there is a need to expand the number of protected areas and associated proportions to ensure that native species have the opportunity to easily migrate to new areas based on seasonal variations, to protect the biodiversity and ecosystems at large (Lawler, 2009). Thirdly, people should consider using wildfire corridors and managing lands between protected areas to facilitate species migration and gene flow that will allow native species to adapt to climate change. Also, there needs to be a focus on where ecosystem restoration is prioritized. This minimizes the need for individual species to adapt to entirely new conditions despite the seasonal variations in climate.

In British Columbia's (BC) forest industry, tackling invasive plant management presents an intricate web of challenges. This is due to the multifaceted nature of the issue, involving various jurisdictions, overlapping legislation, and a compact network of policies and guidelines. Forestry operations in BC are regulated under the Forest and Range Practice Act (Government of BC, 2023d). Division 1, section 47 states that when working with invasive plant species, a person or a company implementing forest practices must ensure that they have solutions in place to prevent the spread of invasive species even further to places that have yet to be affected. This means invasive plant species have been named in section 47 of the Invasive Plant Regulations Act (Government of BC, 2023a). Even though the Integrated Pest Management Act (Government of

BC, 2023a) controls how herbicides are used to ensure that invasive plant species are carefully managed, this is not legally binding as it does not directly address forest companies' duties when managing the spread of plant invasive species. Forest companies can develop and implement strategies at their discretion and use their management practices to mitigate the spread of invasive plant species. On the contrary, the BC government and the Invasive Species Council of BC (ISCBC), a non-profit society, have a management strategy that forestry companies can adopt to supplement what they have. The high volume of invasive plant species in the area creates an overwhelming challenge for forest companies to effectively plan and implement management strategies. To prioritize their efforts, they adopt the BC government's Invasive Plant Core Ranking Process, which is a crucial tool that helps them identify which invasive species pose the greatest threat, allowing for focused investment in eradication, control, and monitoring efforts (Government of BC, 2023b).

A mechanism of control of invasive plant species is to promote fire and drought-adapted species that are naturally resilient to the environment with their seasonal variations. This typically means that wildfires should be used to maintain forest health, reduce the risk of uncontrolled wildfires, and support fire-adapted species (Sample et al., 2022). Communities should focus on forest restoration that will consider climate variability to ensure the ecosystem remains resilient. Furthermore, there should be an increase in tools and monitoring equipment for invasive plant species, and that could include early detection tools. The tools play a role in preventing and establishing invasive plant species. Nevertheless, Sample et al. (2022), further acknowledge circumstances where non-native plants have already been established, making it more ideal to employ mechanical and chemical methods for removal. Another mechanism that can be implemented is the use of controlled burns in buffer zones, which plays a pivotal role in reducing wildfire risks and protecting surrounding ecosystems.

In order to effectively safeguard natural landscapes, a crucial first step involves thoroughly mapping habitat types across the entire region. This comprehensive inventory facilitates the identification and prioritization of the most critical areas for protection and restoration. Our efforts should then strategically focus on restoring native plant communities and vegetation structures, particularly in areas where ecological connectivity is currently limited. By giving precedence to these actions, we can create a more interconnected and resilient natural world. Planting native species adapted to future climate conditions will help ensure their long-term survival and ecological contribution. Maintaining an up-to-date inventory of native understory plant species and monitoring their health is essential for adaptive management. Silvicultural treatments should be used to enhance the diverse regeneration of native species. In areas expected to regenerate naturally, augmenting populations of desired native species through additional planting can boost their resilience and ecological function (Muzika, 2017). While managing non-native or aggressive native species, adapting strategies based on their ecological roles is essential in some cases, retaining these species may be preferable if they contribute positively to the ecosystem. Sharing climate adaptation plans and examples of successful implementation with the public can foster greater community engagement and awareness. Agency planning documents should address climate adaptation to ensure transparency and public involvement. Communicating the social benefits of climate adaptation efforts, such as increased opportunities for fuelwood production, can also help garner public support and participation in these initiatives.

2.3 Adaptation strategy: promoting native weed species as pioneer species to facilitate ecological succession

While mitigating the impacts of invasion by invasive species is increasingly urgent, there is alsoa concurrent need for building adaptation strategies to enhance native species growth and resilience in the face of a rapidly changing climate (Moore and Schindler, 2022). Literature has widely documented contemporary climate change occurrences with observed indicators such as warming atmospheric and oceanic temperatures, shrinking ice sheets, sea level rise, and shifts in precipitation patterns (Bonneau and Mucha, 2019). Indeed, global temperature will exceed the 1.5 ºC warming for several decades before it stabilizes even if greenhouse emissions drop significantly. According to Pecl et al. (2017), contemporary climate change is redistributing biodiversity, pushing species deeper into the oceans, up mountains, and toward the poles at an average speed of 17 to 72 km per decade. With the imminent threat of invasion by invasive species. Therefore, effective management approaches are needed to provide the best opportunities for promoting ecological adaptation and resilience in a climate-challenged future to maintain functioning biospheres (Moore and Schindler, 2022). Adaptation serves as the cornerstone of resilience for species, communities, and ecosystems amidst the relentless tide of global shifts and changes. Not only is this crucial for the biosphere alone, but also essential for preserving the interconnected social-ecological systems essence for humanity’s sustenance and well-being (Moore and Schindler, 2022). According to Khattak et al. (2024), it is imperative to understand the dynamics existing between native weed species and invasive species in order to develop effective management strategies and build effectively functioning ecosystems. The appreciation of the potential resistance of native weed communities to invasion presents opportunities to identify suitable native plants that can be used for rehabilitation measures of the disturbed ecosystems.

This is because native weedcommunities may possess traits and adaptations that enable them to resist invasions (Meyer et al., 2021). These adaptations include rapid germination, high seed production, phenotypic plasticity, tolerance to pollutants, and efficient resource utilization (Vilela et al., 2018). However, Del Buono et al. (2020), eloquently states that some native weeds have physio-biochemical adaptations that confer remediation or tolerance capabilities towards some environmental disturbances. When adequately harnessed, these adaptation characteristics improve the competitive advantage and reduce the establishment, growth rate and spread of invasive species. Additionally, native weeds are able to withstand the odds of ecosystems with altered resource availability as well as in compromised ecological conditions due to their adaptive capacity, thus enhancing their resilience and limiting the success of invasions (Meyer et al., 2021).

Several studies affirm the competitive advantages of native weed species in disturbed areas particularly, pointing to their capacity to survive in certain climates, soil types and light conditions (Khattak et al., 2024; Cure et al., 2014; Kamenova et al., 2017; Divíšek et al., 2018; Grainger et al., 2019), On another hand, native weed species can remarkably enhance the resilience and adaptability of native ecosystems. They play a key role in ecological succession, particularly after the removal of invasive species. This is because they've developed traits over time to adapt to specific environmental conditions and climate fluctuations (Anibaba et al., 2023). As De Vitis et al. (2022) reported, some native weeds act as pioneer species, colonizing disturbed areas like those left behind by wildfires. This creates a vital food source and habitat for other native species, ultimately aiding in ecosystem recovery.

Additionally, they can reduce soil erosion and facilitate woody plant regeneration due to their rapid growth. In some instances, where native weeds promote the transition of an ecosystem from a grassland into a shrubland, there could be a benefit of survival of nectar-feeding insects such as butterflies, indicating overall ecosystem recovery (Baker and Potter, 2018).

The translocation of plant species globally involves various activities, such as seed movement for restoration, reintroductions after local extinction, and assisted migration for conservation amidst climate change. These activities share common goals and practices, differing mainly in scale and terminology. Hof et al. (2021), argue that reintroduction and managed relocation are similar, diverging only by their reference to historical, as opposed to current species ranges. Restoration efforts are shifting to consider current ecosystems rather than historical ones due to environmental degradation and climate change, suggesting a broader approach to species movement.

As climate change progresses, seed-sourcing strategies must adapt to ensure ecosystem resilience. Despite controversies, the forestry, horticulture, agriculture, and pet industries have already introduced new species to various locales. Thomas (2011), questions why endangered species shouldn't also be introduced to these areas, though regulations and technical challenges exist.

Case studies show the difficulties of assisted migration for rare plants, which often have specialized needs making sustainable population establishment challenging. Key challenges include determining the optimal number of propagules for resilience and ensuring suitablehabitat matches. Additionally, a significant barrier is the lack of funding for plant conservation, with plants receiving minimal financial support despite comprising a majority of species under the US Endangered Species Act. Nevertheless, conservationists continue to strive to protect global flora despite these funding challenges (Vitt et al 2016).

High fecundity and large seed banks have limited the success of biological control of Scotch broom in the United States. Land managers recognize that integrating biological control with other techniques is essential for effective weed management. At Fort Lewis, Washington, repeated prescribed fire and mechanical removal have been used since the late 1980s to manage Scotch broom. This study examined whether combining physical controls with biological control by the Scotch broom seed weevil could reduce seed production and interfere with the biological control agent. The impact of three strategies was measured: biological control alone (BC), and BC combined with either fire (BC + F) or mowing (BC + M). Combining strategies (BC + M and BC + F) significantly reduced the number of pods per plant, mature seeds per plant, and seed bank density compared to BC alone. Weevil seed predation rates were higher in BC + M and BC + F plots, but these differences were not always statistically significant. However, there was a consistent reduction in healthy mature seeds per plant in BC + M and BC + F plots compared to BC alone. No differences were found between BC + M and BC + F plots for these variables, nor in the number of weevils per pod among management strategies. (Angelica et al. 2012).

According to Hererra-Reddy et al. (2012), the results indicate that integrating biological control with repeated physical control methods is necessary for managing Scotch broom. Both integrated strategies outperformed BC alone, but short-rotation prescribed fire may be more effective than mowing for long-term management due to its potential for slightly greater seed bank depletion.

3 Methods and Methodology

<table>
<tr><th>Key question</th><th>Objective</th><th>Data collection/variable</th></tr>
<tr><td>How does climate change affect the spread of scotch broom and Himalayan blackberry?</td><td>Examine climate change variables influencing spread of invasive plant species</td><td>● Field observations
● Literature review</td></tr>
<tr><td rowspan="2">What climate change adaptation strategies can bedeveloped to enhance the resilience of native species for sustainable ecosystem management?</td><td>Identify relevant climate change adaptation strategies to enhance native species recovery</td><td>● Semi structured interviews
● Literature review
● Document Review</td></tr>
<tr><td>Identify management approaches for invasive species (Scotch broom and Himalayan blackberry) control. (identify management strategies)</td><td>● Semi structured interviews
● Literature review
● Field Observations
● Document Review</td></tr>
</table>

To investigate the impacts of climate change on invasive plant spread and identify strategies for ecosystem management in the Mount Arrowsmith Biosphere Region, this study utilized a multifaceted approach. Based on objective 1, we sought to examine the influence of climate change on the spread of invasive plants. This involved a literature review to identify documented relationships between climate variables and the spread of Scotch broom and Himalayan blackberry, as well as field observations to better understand these invasive populations and their ecological context. For our 2nd objective which focused on climate change adaptation strategies for native species resilience, semi-structured interviews with key stakeholders like climate change experts, government personnel, private organizations, NGOs, and conservation experts were conducted alongside a literature review on established and emerging adaptation strategies. Additionally, relevant documents from government agencies and conservation organizations like reports were reviewed to identify existing climate change adaptation plans for the region. Finally, objective 3 sought to identify management approaches for controlling Scotch broom and Himalayan blackberry the methodology mirrored that of objective 2, through incorporated semi-structured interviews, a literature review on control methods, field observations of existing practices, and a document review of relevant management plans and control strategies. This comprehensive approach aimed to gather a holistic understanding of the challenges posed by climate change and invasive species, paving the way for potential solutions that promote ecosystem resilience in the Mount Arrowsmith Biosphere Region.

4.0 Results

4.1. Thematic Analysis and Report

Table 1: The Spread of Invasive Species due to Climate Change

The Spread of invasive species due to climate change		
Details	Total	Percentage (%)
Heat	5	71,43
Fire	6	85,71
Dry Summers	2	28,57
Flooding	3	42,86
Wet/Frozen Winter	2	28,57
Drought	3	42,86
Snowpack	3	42,86
Rain	3	42,86
Wind	2	28,57
Ocean Temperature	1	14,29
Carbon Dioxide	1	14,29
Number of Respondants	7	100,00

Figure 1: A Graph showing Climate Change Factors in Percentage

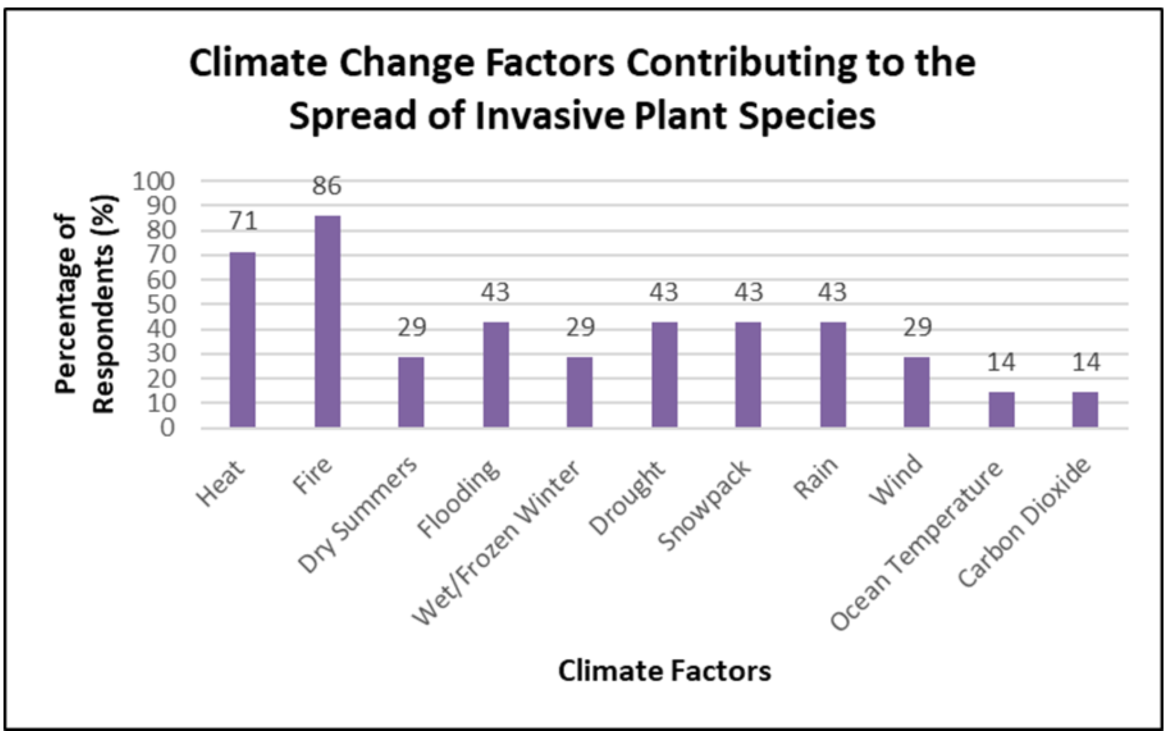


Table 2: The Spread of Invasive Species due to Human Impact

The Spead of invasive species due to human impact (human drivers)		
Details	Total	Percentage (%)
Disturbured Sites	2	28,57
Roads Cuts	3	42,86
Powerlines	1	14,29
Gas Lines	1	14,29
Habitat Iteration	3	42,86
Carbon Storage	1	14,29
Local Crafts	1	14,29
Development	1	14,29
Natural Extraction Resources	1	14,29
Logging	4	57,14
Harvest	2	28,57
Human Interactions	3	42,86
Bridges	1	14,29
Number of Respondants	7	100,00

Figure 2: A graph showing the Human Driver's Impact on Invasive Plant Species

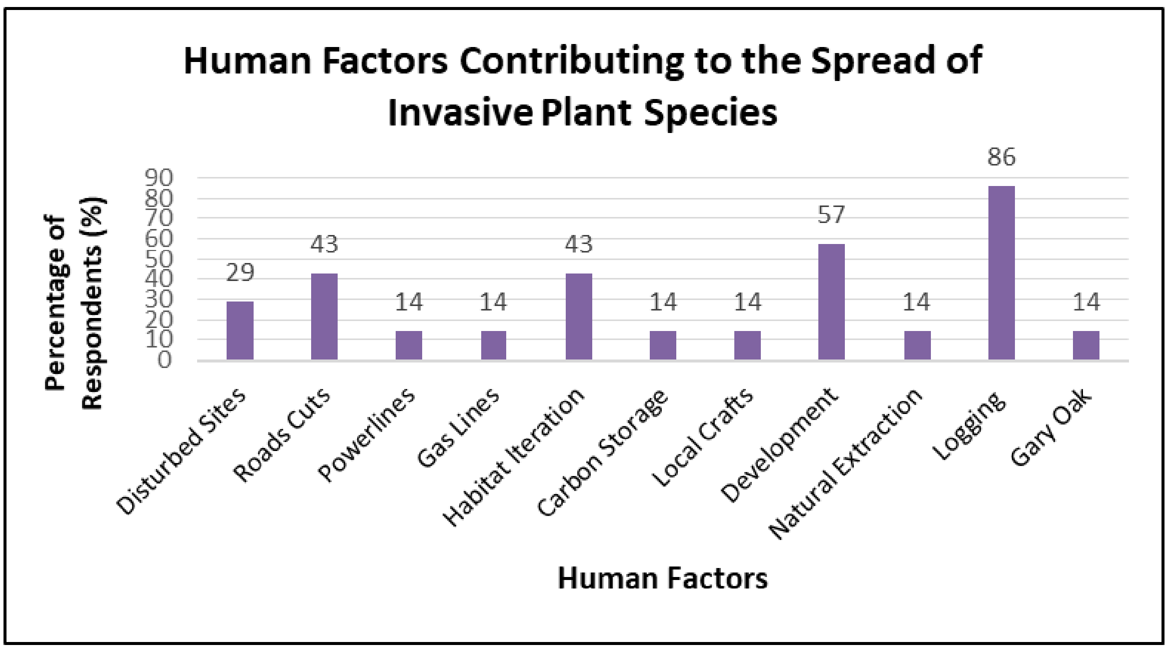


Table 3: The Management Strategies implemented

Management Strategies		
Details	Total	Percentage(%)
Carbon Taxes and Initiative	2	28,57
Electric Vehicles	1	14,29
Flood Resistance Infrastructure	1	14,29
Good Forest Practice	1	14,29
Climate Projection	1	14,29
Heavy Precipitation Assessment	1	14,29
Transistion from Fossil Fuels	1	14,29
Grow Trees	1	14,29
Fire Burn Reduction	1	14,29
Broom Pile Reduction	1	14,29
Restoration	2	28,57
Removal of Invasive (cutting)	5	71,43
Planting Native Species	2	28,57
Climate/Action Plan	1	14,29
Management Process Plan	5	71,43
Tax Policy	1	14,29
Investment	2	28,57
Number of respondants	7	100,00

Figure 3: A graph showing the management strategies

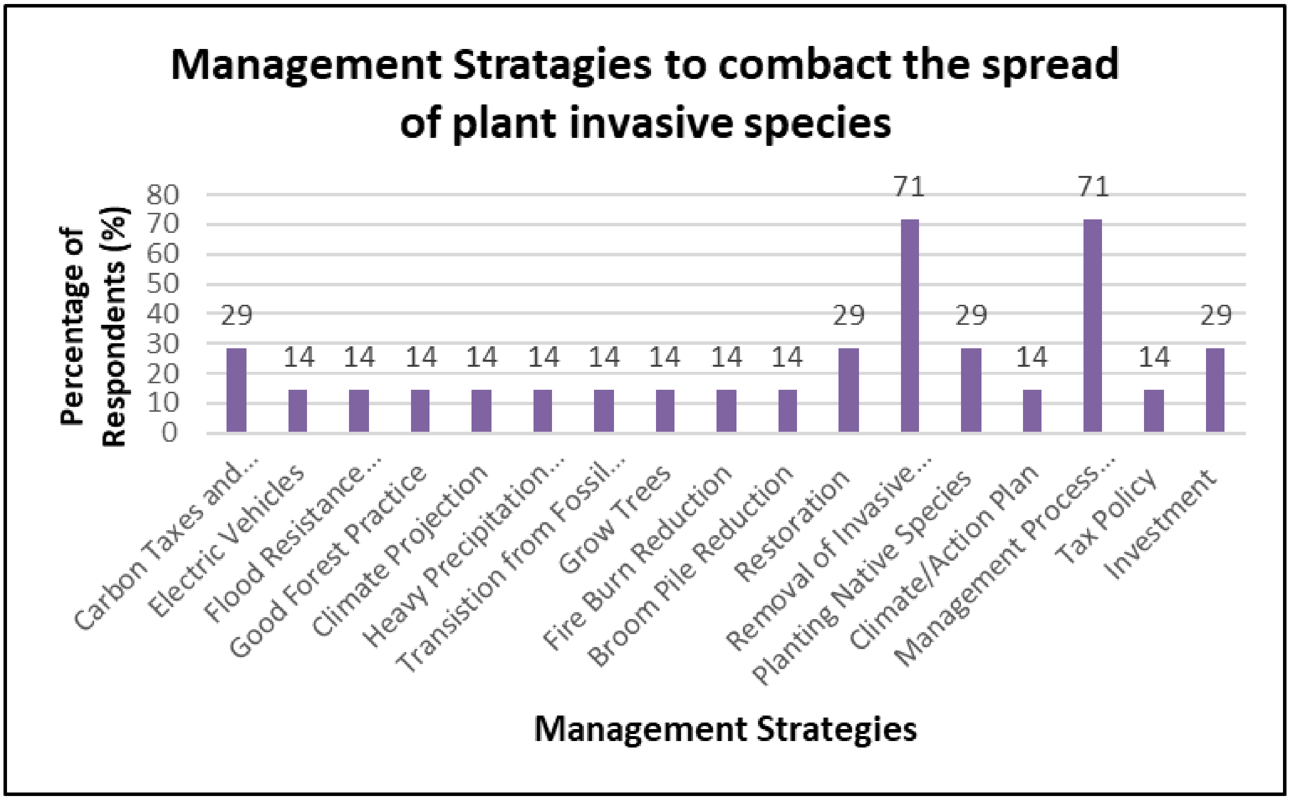
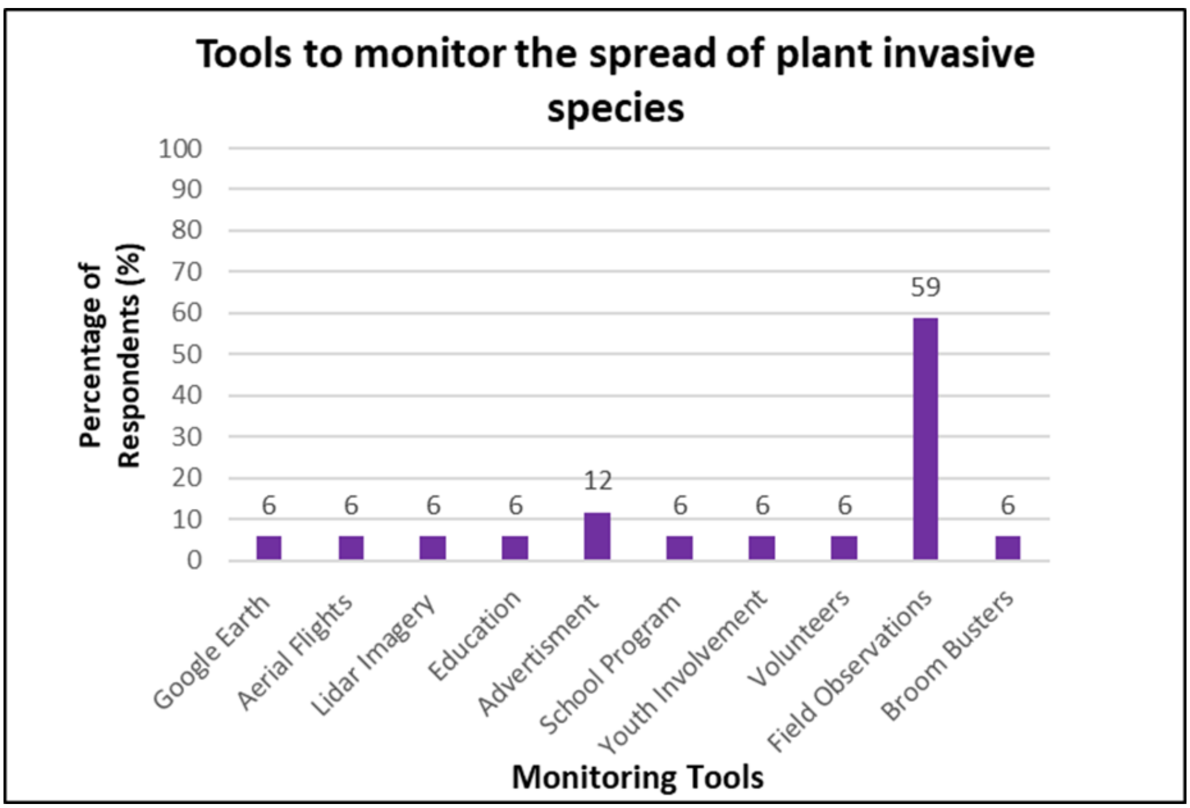


Table 4: A table showing the total number of tools that can be implemented.

Tools to monitor		
Details	Total	Percentage (%)
Google Earth	1	5,88
Aerial Flights	1	5,88
Lidar Imagery	1	5,88
Education	1	5,88
Advertisment	2	11,76
School Program	1	5,88
Youth Involvement	1	5,88
Volunteers	1	5,88
Field Observations	10	58,82
Broom Busters	1	5,88
Number of Respondants	17	100

Figure 4: A graph showing the tools to monitor the spread of invasive species



The research question "How can climate change adaptation strategies be designed to improve the resilience of native species and ensure sustainable ecosystem management?" was explored through a thematic analysis of expert contributions based on reference to the goal and objectives of the project. The analysis identified key themes and sub-themes relevant to developing effective strategies.

The primary theme of Climate Change Drivers encompasses both human and natural factors. Human drivers include temperature rise, logging and timber activities, and land use changes due to urbanization and development. Natural drivers highlight the increasing frequency and intensity of wildfires, extended drought periods, and shifts in precipitation patterns resulting in wetter winters.

Management Strategies emerged as another critical theme, divided into policy interventions, environmental approaches, and preventative measures. Policy interventions such as carbon taxes, promoting electric vehicles, and transitioning from fossil fuels to renewable energy sources are crucial. Environmental approaches include building flood resistance infrastructure, implementing good forestry practices, and utilizing climate projections for long-term planning. Preventative measures focus on reforestation, managing controlled burns to prevent large wildfires, and controlling invasive species and pests.

The resilience of native species and ecosystems is addressed through support from various parties, including government bodies, non-governmental organizations, and local stewardship groups. Effective tools for monitoring include wildfire monitoring technologies, habitat restoration efforts, and citizen science initiatives that engage the public in data collection and monitoring activities.

Economic and social aspects also play a significant role in climate change adaptation.

Highlighting the economic benefits of sustainable practices, such as local crafts and tourism, along with community engagement and education, is essential. Raising awareness about climate change impacts and involving communities in decision-making and conservation efforts ensure that adaptation strategies are inclusive and sustainable.

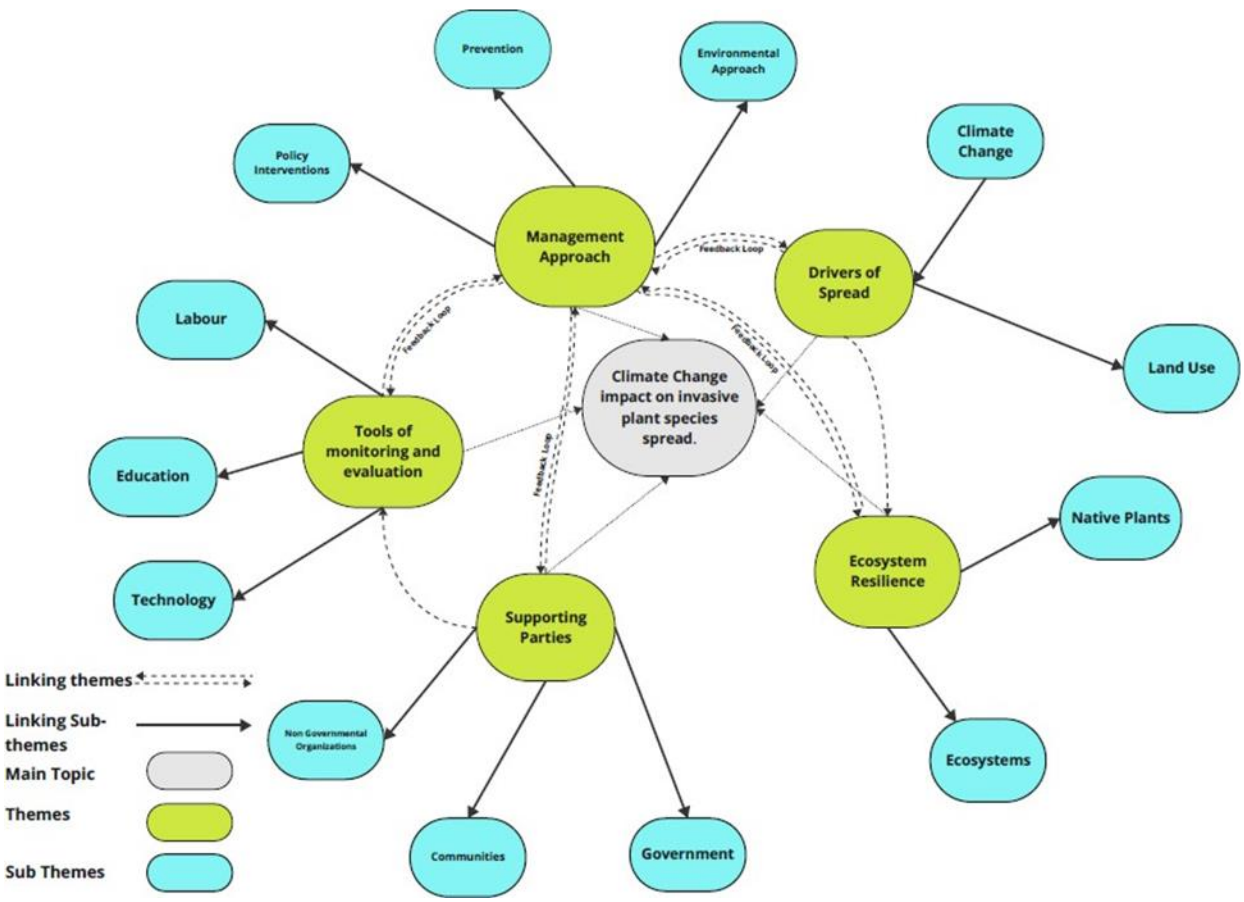


Figure 5: Showing interconnectedness of climate change factors on the spread of invasive species

In conclusion, designing climate change adaptation strategies requires a comprehensive approach that includes understanding climate change drivers, implementing effective management strategies, and ensuring the resilience of native species and ecosystems. Collaboration between government, NGOs, local communities, and other stakeholders is crucial.

Sustainable ecosystem management should incorporate policy interventions, environmental practices, and prevention measures while emphasizing economic benefits and community engagement to ensure long-term success. Recommendations include strengthening policy frameworks, promoting sustainable practices, enhancing monitoring and research, and increasing community involvement. By addressing these areas, adaptation strategies can be more effectively designed to improve the resilience of native species and ensure sustainable ecosystem management.

4.0 Discussion

4.1 Climate Change drivers

Before developing a management strategy and action plan, it is crucial to understand the factors influencing the spread of invasive plant species, particularly Scotch broom and Himalayan blackberry. Extensive literature research, data from semi-structured interviews, field observations, and document reviews have revealed that human influence as the primary driver of invasive species spread. Key findings indicate that land use changes, habitat alteration, and the construction of power lines and gas lines are major contributors. Additionally, significant observations point to climate change variables, such as flooding, wildfires, wetter winters, and increased rainfall instead of snowfall, playing a role in the spread of invasives. The significance of this theme focus is primarily to achieve three of the United Nations Sustainable Development Goals (UNSDGs), which are Climate action (SDG 13) and Life on land (SDG 15). The results indicated little to no research being conducted on the West Coast, related to the impact of climatechange on the spread of invasive plant species. Therefore, further scientific research is needed to determine the extent to which climate change contributes to the spread of invasive plant species in the Mount Arrowsmith Biosphere Region and across Canada.

4.2 Human influences on the spread of invasive species

Human activities play an active role in the spread of invasive plant species in several ways: Human activities such as logging, land clearing construction, and construction are often the result of the spread of invasive plant species, and these would allow the species to stay in the ecosystem for a long time if not carefully managed. Plants such as Scotch Broom would disturb areas within road cuts and powerlines. However, fossil fuel extraction and natural resource exploitation largely influence the Himalayan Blackberry. In British Columbia, there have been a number of reported cases of resource extraction that have derogated the problem even further. Human activities such as timber harvesting have degraded the ecosystem and made it vulnerable to invasion. Another factor to consider is the ability to disturb the solid or remove vegetation thathas also contributed to the spread and establishment of invasive plant species. As a result, it has led to a widespread ecological disruption.

The human influence on the spread impacts several Sustainable Development Goals (SDGs) with the main SDGs including SDG 13 (Climate Action) and SDG 15 (Life on Land) associated with the indirect influence on SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). Thus, a multi-faceted approach is required to mitigate the challenges within the MABR. Several considerations should be considered, including integrating ecological considerations to mitigate the spread. Additionally, there should be promotion within the communities and the utilization of community involvement as a critical mechanism to undertake the communities' challenges and help manage and mitigate the risks. It is worth mentioning that it is possible to implement these recommendations for both short- and long-term goals as part of environmental sustainability and resilience.

4.3 Tools to Monitor the Spread of Invasive Species

Monitoring the spread of invasive species is critical to effective management and control. The tools and techniques employed to track and manage these species are diverse, combining modern technology with community engagement and education. Here, several key tools identified from the interviews are discussed, and suggestions are made on how they can be integrated into a comprehensive monitoring strategy.

4.3.1 Technological Tools

Google Earth is a valuable tool for large-scale monitoring and mapping of invasive species. By providing high-resolution satellite imagery, Google Earth allows researchers to identify and track changes in vegetation over time. It can help pinpoint areas where invasive species are spreading and assess the effectiveness of control measures. Aerial flights, utilizing drones or manned flights equipped with cameras, can capture detailed images of large areas. This method is particularly effective in rugged or inaccessible terrains where ground surveys are impractical. Regular aerial surveys can provide up-to-date information on the distribution and density of invasive species. Additionally, Lidar technology uses laser pulses to create precise, three-dimensional maps of terrain and vegetation. This tool can penetrate forest canopies to detect understory invasive species, offering a detailed view of the landscape that is not possible with conventional imaging techniques.

4.3.2 Community Engagement and Education

Engaging local schools through educational programs can raise awareness among young people about the impact of invasive species. By involving students in monitoring and removal efforts, we can foster a sense of stewardship and responsibility towards the local environment. These programs can also extend to parents and the broader community, multiplying their impact. Public awareness can be significantly increased through visible reminders and information dissemination, such as road signs and billboards in strategic locations. These signs can educate the public about the risks of invasive species and discourage harmful practices such as dumping garden waste in natural areas. Direct engagement with residents through door-to-door visits and flyer distribution can provide personalized education and encourage community participation in control efforts.

This method helps in addressing specific concerns and questions from the community, fostering a collaborative approach to invasive species management. Initiatives like Broom busters in Qualicum Beach demonstrate the power of community action. Volunteers play a crucial role in physically removing invasive species and restoring native habitats. Organizing regular volunteer events and providing the necessary tools and support can sustain these efforts.

4.3.3 Field Observations and Data Collection

Regular field surveys by trained personnel and volunteers are essential for early detection and rapid response to new invasions. These observations provide ground-truth data to complement remote sensing and other monitoring techniques. Collaborating with research institutions, such as the work done by MABRI, can enhance our understanding of how climate change affectsinvasive species dynamics. Collecting data on plant phenology and weather patterns can help predict future spread and inform management strategies.

4.4 Supporting Responsibility Sharing

This analysis highlights the critical role of collaboration with shared responsibility holders in tackling invasive species within the MABR. The data indicates the need for a comprehensive multi-stakeholder approach, integrating efforts from grassroots community groups to provincial and national entities (conservation organizations, academia, MABBRi, government agencies, landowners, and Indigenous Peoples, etc). The involvement of diverse groups is crucial for effective management. A collaborative approach is necessitated by the complex interplay of environmental, social, cultural, and economic implications of climate change. Invasive species management strategies must consider these interconnected dynamics to avoid unintended consequences. For example, the removal of

Himalayan Blackberry to avoid disrupting species that have adapted to its presence. Additionally, the cultural significance of grand fir and Western Redcedar to Indigenous communities necessitates sustainable harvesting practices that maintain ecosystem services. The case of water use from the creek for irrigation impacting water levels and fish habitats, further underscores the interconnectedness of ecological processes, highlighting the need for holistic management strategies.

The emphasis on collaboration aligns with SDG 17, which focuses on building strong Partnerships for Development. For these goals to be effective, the shared responsibility holders must work together to develop strategic adaptation and management processes, targeted from a more holistic perspective. This goal necessitates collaborative efforts to manage invasive species and safeguard biodiversity within the MABR.

4.5 Adaptive Management Strategies

Although some of our interview results highlight management strategies for invasive species, it is apparent that these strategies are rarely, if ever, developed with the influences of climate change in mind. Most reported strategies involve the clearance of invasive species through mechanical and chemical approaches, which can be both ineffective and expensive to monitor over time. Given the myriad, often connected impacts of climate change and land use change on the spread of invasive species, adaptive management strategies that tackle both phenomena simultaneously are crucial. These strategies should adopt a cross-government approach to formulate policy direction for invasive species management and should consider prevention and control of invasive species through early detection and rapid response programs, reducing the risks and threats of invasive species and climate change, and managing and monitoring the spread of invasive species. Additionally, it is essential to facilitate ecological succession, restore ecosystem processes, and build the adaptive capacity of native species to enhance ecosystems and native species resilience. The increasing colonization of exotic plants, insects, earthworms, slugs, and pathogens in the boreal forest is significantly impacting ecosystem functions and services. The altered soil properties and microbial processes caused by these invasive species can hinder the growth and resilience of native plant species.Invasive grasses significantly threaten forest resilience by creating a "perfect storm."

4.6 Action Plan

Action	Responsible	Timeline	Priority	Status	Cost	Notes
Invest in research on climate change	MABR Roundt able	Long		Not started	High	Employ climate experts in MABRRI and promote research collaborations
Tax reduction as business incentives	MABR	Long		Not started	Low	In consultation with the government
Develop a comprehensive monitoring system	MABR	Medium		Not Started	High	Integrate Technological and Field Data
Develop a community-driven management plan	MABR, NGOs, Public, Gover nment	Short		Not Started	Low	Indigenous communities as key stakeholders
Facilitate active ecosystem rehabilitation	MABR, NGOs	Short		On-going	Medium	Supporting and scaling up existing ecosystem and landscape restoration programes

4.7 Invest in Research on Climate Change

Based on our analysis, data has revealed that there has been a large volume of studies and recommendations on how to combat the spread of plant invasive species in Mount Arrowsmith Biosphere Region (MABR) due to human drivers. However, there needs to be more or no study on how climate change contributes to the spread of invasive plant species in the regional area. Having identified this gap has led to investigating the matter with this paper. Besides our findings discussed in previous sections, we need to explore and scrutinize our research questions even further. Additionally, based on our research process of conducting interviews with various experts on this paper's research topic, there has yet to be an expert in climate change and plant invasive species management. They are either only proficient climate change experts or plant invasive management specialists with relatively small backgrounds in the topic presented.

Considering that, it is our key recommendation that the MABR roundtable consider investing in research on climate change. The anticipation of implementing this mentioned action is considered as long-term as this will need MABRRI to employ climate experts to work for the organization (MABBRI) and promote research collaborations. This initiative has yet to start, but it is essential to start as a priority. It will be an opportunity to expand the knowledge that helps implement upcoming projects, initiatives, or recommendations. The cost of this part of the project will be very high. Therefore, there is a need for financial support.

4.8 Tax Reduction as a Business Incentive

Evidence-based on the research shows that within British Columbia (BC), a significantly high cost has negatively impacted the ecosystem and the overall economy based on cost and benefit analysis. From 1998 to 2023, BC has contributed more than CAD 1 trillion towards mitigating the spread and removal of invasive species (costs) compared to the investment of CAD $1 billion that will improve BC's ecosystem and economy in the long run. Therefore, as a relief on government expenditure, it is recommended that the government should consider tax reduction on environmental businesses that focus on invasive species.

Decreasing the business taxes would propel high disposable income. It would allow firms to invest more money into their organizations. This would in turn allow the organizations to carry out practices to mitigate the spread and eradication of invasive species in the area.

It is expected that MABR will lead this initiative with the consultation of the roundtable and political leaders or government officials. This initiative is expected to be achievable in the long term since it has not started. Since this initiative requires several administration duties and paperwork with high levels of talk engagements, the financial cost of this action is low.

4.9 Develop a comprehensive monitoring system

BC has a mechanism in place that would allow community members to report invasive species so land managers can respond quickly and control the spread of invasive species. These reports are made through a mobile application, which requires information from the individual on the location and type of invasive species. Another alternative is to contact the council via email to report invasive species. The MABR can adopt a similar approach.

Another recommendation is to develop a comprehensive monitoring system. This can be achieved by integrating technology and field data into the system. When designing the monitoring system, it should be able to combine satellite imagery, aerial surveys, and lidar data with ground-based observations. This integral approach will provide a holistic view of invasive plant species distribution and trends over the years. The action plan has yet to start, and it is anticipated to be achievable to implement in the medium term while the costs would be relatively low.

4.9 Develop a Community Driven Management Plan

The fourth recommendation that has been put forward is to develop a community-driven management plan. Although there are several management plans for organizations, there is a gap when including the community in helping to mitigate the spread of plant invasive species. Therefore, Indigenous people should be considered as one of the key stakeholders.

Furthermore, it would become the responsibility of MABR, Non-Government Organizations (NGOs), the public, and the Government to drive this initiative. This action plan has not started, and the anticipated time for its implementation is projected to be short-term. The cost for the implementation would be low.

4.10 Facilitate an Active Ecosystem Rehabilitation

The final recommendation is to actively facilitate ecosystem rehabilitation efforts. This is a process already underway within the MABR and an action plan, that provides a welcome framework to further these ongoing initiatives. Shared responsibility holders, such as MABR and NGOs, should continue to support and scale up existing ecosystem and landscape restoration programs. Ideally, the project would be short-term with moderate financial costs to ensure its feasibility. By implementing such action plans, the MABR can become a healthier environment, ultimately fostering economic vitality and more sustainable livelihoods.

5. Conclusion

The multifaceted threats of climate change and invasive species demand a unified approach to ecosystem management in the Mount Arrowsmith Biosphere Region. Through collaborative knowledge exchange amongst Indigenous communities, academic experts, and government organizations, volunteer groups and NGOs, we were able to acquire some critical insights into the connections between climate change and invasive species. This presented us the opportunity to develop targeted strategies for building ecosystem resilience within the Mount Arrowsmith Biosphere Region. Through a deep understanding of these interconnected issues, we can invest in building native species with resilience to ensure the long-term health of the ecosystem. By working together, as emphasized in SDG 17, we can safeguard the MABR in a more sustainable way for generations to come.

References

Anibaba, Q. A., Dyderski, M. K., Woźniak, G., & Jagodziński, A. M. (2023). Native plant community characteristics explain alien species success in post-industrial vegetation. NeoBiota 85: 1–22.

Baker, A. M., & Potter, D. A. (2018). Japanese beetles' feeding on milkweed flowers may compromise efforts to restore monarch butterfly habitat. Scientific Reports, 8(1), 12139.

Beans, C. M., Kilkenny, F. F., & Galloway, L. F. (2012). Climate suitability and human influences combined explain the range expansion of an invasive horticultural plant. Biological Invasions, 14(10), 2067–2078. https://doi.org/10.1007/s10530-012-0214-0.

Beaury, E.M., Wallingford, P.D., Morelli, T.L., Allen, J.M., Blumenthal, D.M., Bradley, B.A., & Dukes, J.S., et al. (2020). Adjusting the lens of invasion biology to focus on the impacts of climate-driven range shifts. Nature Climate Change, 10, 398-405.

Bonneau, J., & Mucha, S. (n.d.). Climate Change Adaptation Strategies in VM.

Bradley, B. A., Beaury, E. M., Fusco, E. J., & Lopez, B. E. (2023). Invasive Species Policy Must Embrace a Changing Climate. BioScience, 73(2), 124–133. https://doi.org/10.1093/biosci/biac097.

Bradley, B. A., Oppenheimer, M., & Wilcove, D. S. (2009). Climate change and plant invasions: Restoration opportunities ahead? Global Change Biology, 15(6), 1511–1521. https://doi.org/10.1111/j.1365-2486.2008.01824.x.

Caldwell, B. A. (2006). Effects of invasive scotch broom on soil properties in a Pacific coastal prairie soil. Applied Soil Ecology, 32(1), 149–152. https://doi.org/10.1016/j.apsoil.2004.11.008.

Christiansen, J., & Bondzio, B. (n.d.). Spatial Analysis Report of two invasive species.

De Vitis, M., Havens, K., Barak, R. S., Egerton-Warburton, L., Ernst, A. R., Evans, M., & Kramer, A. T. (2022). Why are some plant species missing from restorations? A diagnostic tool for temperate grassland ecosystems. Frontiers in Conservation Science, 3, 1028295.

Gervais, J. A., Kovach, R., Sepulveda, A., Al-Chokhachy, R., Joseph Giersch, J., & Muhlfeld, C. C. (2020). Climate-induced expansions of invasive species in the Pacific Northwest, North America: A synthesis of observations and projections. Biological Invasions, 22(7), 2163–2183. https://doi.org/10.1007/s10530-020-02244-

Government of British Columbia (BC). 2023a. Amendments to Pesticide Legislation. Retrieved on June 5, 2024 from https://www2.gov.bc.ca/gov/content/environment/pesticides-pest-management/legislation-consultation/amendments.

Government of British Columbia (BC). 2023d. Forest & Range Practices Act (FRPA). Retrieved on June 5, 2024 from https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/laws-policies-standards-guidance/legislation-regulation/forest-range-practices-act.

Herrera-Reddy, A. M., Carruthers, R. I., & Mills, N. J. (2012). Integrated management of Scotch broom (Cytisus scoparius) using biological control. Invasive Plant Science and Management, 5(1), 69-82.

Hof, C. (2021). Towards more integration of physiology, dispersal and land-use change to understand the responses of species to climate change. Journal of Experimental Biology, 224(Suppl_1), jeb238352.

Kathiresan, R., & Gualbert, G. (2016). Impact of climate change on the invasive traits of weeds. Weed Biology and Management, 16(2), 59-66.

Khattak, W. A., Sun, J., Hameed, R., Zaman, F., Abbas, A., Khan, K. A., ... & Du, D. (2024). Unveiling the resistance of native weed communities: insights for managing invasive weed species in disturbed environments. Biological Reviews.

Lazzaro, L., Bolpagni, R., Buffa, G., Gentili, R., Lonati, M., Stinca, A., ... & Lastrucci, L. (2020). Impact of invasive alien plants on native plant communities and Natura 2000 habitats: State of the art, gap analysis and perspectives in Italy. Journal of Environmental Management, 274, 111140.

Lawler, J. J. (2009). Climate Change Adaptation Strategies for Resource Management and Conservation Planning. Annals of the New York Academy of Sciences, 1162(1), 79–98. https://doi.org/10.1111/j.1749-6632.2009.04147.x

Majorošová, M. (2016). DPSIR Framework – A Decision – Making Tool for Municipalities. Slovak Journal of Civil Engineering, 24(4), 45–50. https://doi.org/10.1515/sjce-2016-0021.

Meyer-Morey, J., Lavin, M., Mangold, J., Zabinski, C., & Rew, L. J. (2021). Indaziflam controls nonnative Alyssum spp. but negatively affects native forbs in sagebrush steppe. Invasive Plant Science and Management, 14(4), 253-261.

Moore, J. W., & Schindler, D. E. (2022). Getting ahead of climate change for ecological adaptation and resilience. Science, 376(6600), 1421–1426. https://doi.org/10.1126/science.abo3608.

Muzika, R.M. (2017). Opportunities for silviculture in management and restoration of forests affected by invasive species. Biological Invasions, 19, 3419 – 3435.

Pecl, G.T., Araújo, M.B., Bell, J.D., Blanchard, J.L., Bonebrake, T.C., Chen, I., and Clark, T.D., (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. Science, 355.

Sample, M., Thode, A. E., Peterson, C., Gallagher, M. R., Flatley, W., Friggens, M., Evans, A., Loehman, R., Hedwall, S., Brandt, L., Janowiak, M., & Swanston, C. (2022). Adaptation Strategies and Approaches for Managing Fire in a Changing Climate. Climate, 10(4), 58. https://doi.org/10.3390/cli10040058.

Smith, A. L., Hewitt, N., Klenk, N., Bazely, D. R., Yan, N., Wood, S., Henriques, I., MacLellan, J. I., & Lipsig-Mummé, C. (2012). Effects of climate change on the distribution of invasive alien species in Canada: A knowledge synthesis of range change projections in a warming world. Environmental Reviews, 20(1), 1–16. https://doi.org/10.1139/a11-020.

Stevens, J. T., & Latimer, A. M. (2015). Snowpack, fire, and forest disturbance: Interactions affect montane invasions by non-native shrubs. Global Change Biology, 21(6), 2379–2393. https://doi.org/10.1111/gcb.12824.

Thomas, C. D. (2011). Translocation of species, climate change, and the end of trying to recreate past ecological communities. Trends in Ecology & Evolution, 26(5), 216–221. https://doi.org/10.1016/j.tree.2011.02.006.

Vilela, A. E., González-Paleo, L., Ravetta, D. A., Murrell, E. G., & Van Tassel, D. L. (2020). Balancing forage production, seed yield, and pest management in the perennial sunflower Silphium integrifolium (Asteraceae). Agronomy, 10(10), 1471.

Vitt, P., Belmaric, P. N., Book, R., & Curran, M. (2016). Assisted migration as a climate change adaptation strategy: Lessons from restoration and plant reintroductions. Israel Journal of Plant Sciences, 63(4), 250–261. https://doi.org/10.1080/07929978.2016.1258258.