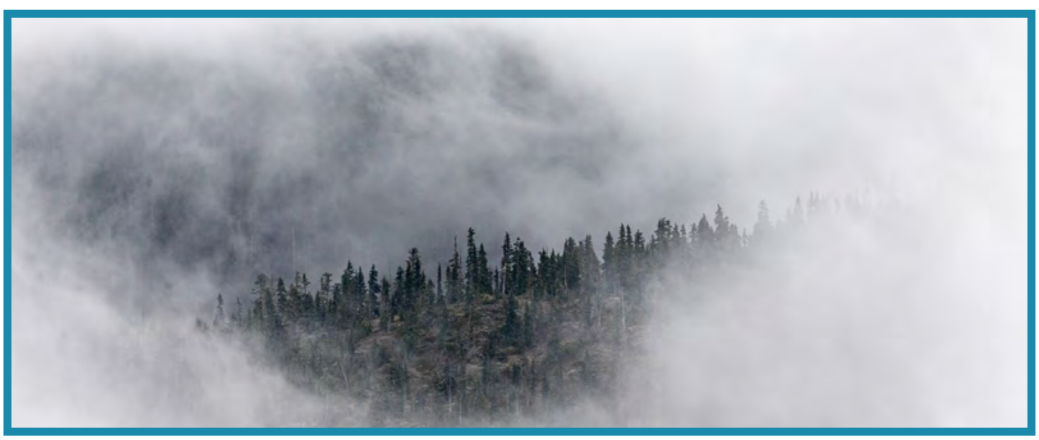
TREE CHANGE IN VANCOUVER ISLAND MARMOT COLONIES:

Best Management Practices, Past Efforts, & Photo Analysis



Report prepared by Chelsea Brager & Cheyney Jackson,
with files from Michael Lester & Kevin Gourlay

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MARMOT
RECOVERY FOUNDATION

Acknowledgements

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In addition to the authors, this report draws on files by Kevin Gourlay and Michael Lester. Habitat improvement objectives, best practices, and guiding principles were development with input from the Vancouver Island Marmot Recovery Team, and in particular the Habitat Improvement sub-committee. We are grateful to Erica McClaren (BC Parks), Sean Pendergast (BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development), Liz Gillis (Vancouver Island University), Wayne Wall (Independent biologist) and Malcolm McAdie (Independent Wildlife Veterinarian) who contributed their time and expertise.

We recognize the unique and enduring relationship that exists between Indigenous People and their traditional territories, and honor with gratitude the land itself and the people who have stewarded it since time immemorial. Much of the work that we carry out takes place on the unceded territories of the Namgis, Kwakiutl, Wei Wai Kum, K'omoks, Mowachaht/Muchalaht, Snaw-Naw-As, Qualicum, Hupacasath, Tseshaht, Snuneymuxw, Stz'uminus, Songhees, Esquimalt First Nations and Cowichan Tribes. We are grateful for the opportunity to learn and work on their traditional lands.

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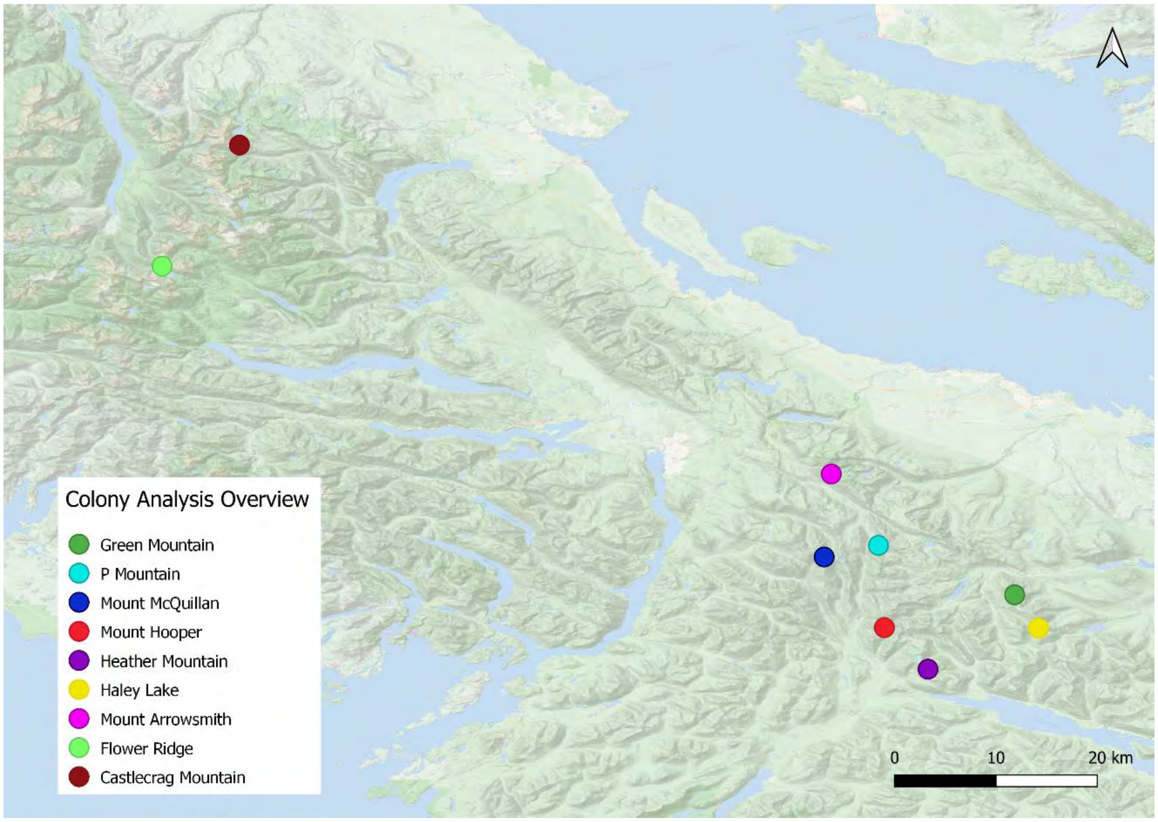

***Figure 1**. Overview of analyzed sites ((Google Earth Pro (H) 7.3.4.8248 (64-bit) 2016).*

The Vancouver Island Marmot (*Marmota vancouverensis*) is an endangered species of ground squirrel endemic to the mountainous regions of Vancouver Island. This species inhabits subalpine meadows between 800-2000 m, in which natural processes such as snow creep and seasonal avalanches prevent expansive tree establishment (Vancouver Island Marmot Recovery Team 2017). Limited tree growth within subalpine meadows makes these areas highly suitable to *M. vancouverensis*, as it provides long sightlines used to detect primary terrestrial predators from a distance.

Through a combination of warming temperatures and shrinking seasonal snowpacks, climate change is well-known for rapidly altering tree growth patterns within subalpine meadows on Vancouver Island (Jackson *et al.* 2016). The synergistic effect from these two changes results in rapid tree encroachment into core Vancouver Island Marmot ("VIM") habitat: subalpine meadows occupied by *M. vancouverensis*. This positively influences the hunting efficacy of primary terrestrial predators by increasing stalking cover, while negatively influencing detection efficacy of resident marmots through shortened sightlines from marmot habitat features, such as hibernacula, burrows, or sunning rocks used for predator detection. As a result, changes to the main characteristic that makes subalpine meadows suitable for *M. vancouverensis* may contribute to future surges in terrestrial predation events.

This document may serve as a guideline for future *M. vancouverensis* habitat restoration projects.

Included are objectives and best practices for habitat restoration, examples of previous restoration efforts, as well as an assessment of historical tree growth over time within sites suitable for future restoration. The assessment aims to quantify tree growth between historical and present-day aerial imagery of 7 focal colonies by comparing estimated tree cover percentages and two metrics of tree growth (canopy closure and tree ingression). In doing so, the Foundation hopes to provide justification for immediate action on tree growth within these sites, wherein restoration activities would otherwise not be allowed by jurisdictional policies. The main goal of this guide is to improve overall terrestrial predator detection of *M. vancouverensis* by restoring historical sightlines within core habitat.

Habitat Improvement Objectives

The goal of the Foundation's habitat improvement work is to increase the survival of Vancouver Island Marmots by improving their ability to detect and evade terrestrial predators. We are guided by three objectives to achieve this goal:

1. **Increase sightlines from and reduce stalking cover near known marmot habitat features through tree removal and/or modification in designated high priority stands.**
    - *Measurable objectives include* the removal of young trees (<15 cm DBH) and pruning of lower branches below 120 cm in height on larger trees (>15 cm DBH).
    - *Stand prioritization* within a sub-location will be assessed by crew members based on the following factors: stand density, feasibility with mitigation efforts in place, and potential influence on sightlines from marmot habitat features.

2. **Mitigate harm to known marmot habitat features during restoration activities.**
    - *Harm may be defined as* the loss of trees providing structural support to marmot habitat features, loss of upslope trees that shelter marmot habitat features from avalanche activity, and the loss of spring foraging resources through the removal of non-arboreal shrub and tree species.

3. **Document the work to measure success and guide similar projects in the future (Lester 2017)**

Best Practices in Habitat Improvement

To prevent any potential harm incurred to marmot habitat features from the removal or modification of adjacent woody vegetation, the Foundation has established a series of recommended mitigation efforts, as listed below (as per Objective #2). These mitigation efforts have been adopted from Appendix A. Through restoration activities, there is potential to negatively impact hydrological systems (such as seasonal avalanche cycles), natural levels of soil compaction, and the structural integrity of burrows. While the full effect of how restoration activities influence marmot habitat is not fully known, these mitigations are in place using the precautionary principle.

1. **Establish minimum 10m buffer zones around known marmot habitat features (hibernacula and burrows)**
    - The purpose of this is to avoid damage to underground burrow structure that may occur when removing adjacent trees. Adjacent trees may play a role in upholding burrow entrances and underground tunnels.
    - This mitigation effort will involve measuring 10m from each feature and adequately delineating the buffer zone with colour-coded flagging tape. The result is a flagged area encircling each marmot habitat feature, which would be readily identified by crew members as “no-go” zones on restoration days. Any trees within the flagged circle will not be permitted for cutting.
    - 10m is a recommended minimum distance from each marmot habitat feature, however crew members may increase buffer zone distances on an as needed basis.

2. **Establish “no-work” zones around stands directly upslope from marmot habitat features**
    - The purpose of this practice is to mitigate the potential risk of increasing localized avalanche severity after removing stands directly upslope from marmot habitat features. Stands of trees directly upslope of features may play a role in sheltering burrows from avalanche activity.
    - This mitigation effort will involve the identification of upslope stands and delineating these areas with colour-coded flagging tape.
    - This signals to crew members to not remove or modify any trees within the flagged area. The extent of these zones will depend on how much tree coverage is directly above marmot habitat features, as well as terrain conditions.
        - For instance, if there is a stand that is located above a marmot habitat feature on a rocky shelf, there is potential that the alteration of this stand will not influence avalanche activity due to the terrain feature. A modification of this mitigation may be established. This can include only removing/modifying 50% of the trees and is up to Team and Project Manager discretion.

3. **Preserve non-coniferous woody vegetation within entire sub-location**
    - The purpose of this practice is to mitigate the potential loss of spring foraging resources. Non-coniferous woody vegetation is thought to be suitable forage during the early growing season where preferred herbaceous plants are not yet available. The role non-coniferous woody vegetation plays in the spring diet of *M. vancouverensis* is not yet well known. It is also possible that vegetation changes in marmot habitat are resulting in taller plant species becoming more abundant in meadows, which could provide stalking cover. However, as changes in non-coniferous woody vegetation has not been documented, and its role in the marmot's diet is unknown, this mitigation is in place out of an abundance of caution.
    - This mitigation effort will require crew members to actively identify what trees they are targeting during restoration activities.

Summary of Past Restoration Efforts

Mount Hooper - Main Meadow Vancouver Island Marmot Habitat Improvement 2017

Report composed by Mike Lester

Location

Mt. Hooper (1486m; Figure 1) is located 30 km southeast of Port Alberni and 42 km southwest of Nanaimo. The upper slopes (1320-1430m) are moderately treed subalpine meadows in the Mountain Hemlock Biogeoclimatic Zone (MHmm1).

Background

Mt. Hooper was first documented as a marmot colony in the 1970's, and has been home to a successful colony of Vancouver Island marmots since it was re-established in 2009. The colony has shown high reproductive success as well as strong recruitment of offspring, but has lost several marmots to predation in the past few years. The invasion of trees into open marmot habitat has been associated with climate change, and is a concern because marmots rely on open habitat to detect and avoid approaching predators. Tree ingress is evident throughout the southwest meadow. Removal or reduction of the amount of stalking cover provided by invading trees should increase the annual survival rates of colony residents, thereby improving colony persistence and supporting the regional population.

Objectives

- Protect important marmot habitat features (hibernacula and well-established burrows).
- Remove ingrowth of younger trees and prune the lower branches of older trees in the Mt Hooper southwest meadow to reduce local predation risk for Vancouver Island Marmots protecting important habitat features (hibernacula and established burrows).
- Document the work to measure success and guide similar projects in the future.

Steps

- Attain approval from landowners for improvement work.
- Engage with stakeholders and experts to discuss intent and seek assistance with methodology (see Appendix 1, Habitat Improvement Working Group's Draft Guiding Principles for Clearing Work, Oct 1, 2017).
- Assess the site for safe clearing.
- Conduct habitat enhancement.
- Report results.

Methods

The site was assessed from the air on Sep 14, 2017 and on the ground immediately prior to clearing work on Oct 3, 2017.

During the surveys the following factors were assessed:

- Site safety: Approach and egress, evacuation routes, helicopter access, site hazards.
- Scope of work achievable with a small clearing team.

The site was cleared on Oct 3 and Oct 4, 2017 with a daily team of five personnel. Personnel included two Marmot Recovery Foundation crew, two BC Wildfire Service crew and a volunteer crew member. BC Wildfire Service lead, Matt Kelly, provided a safety briefing, after which crew conducted a safety assessment and thorough site inspection. Field crew then identified trees proximal to [3] known hibernacula and established burrows. A 10-metre arc from any known hibernacula or burrow and the nearest stand of trees was measured with a survey tape and trees that fell within 10m were flagged. Flagged trees were not removed or modified. Trees and limbs of the largest trees in the targeted removal zone were cut with a chainsaw. Further trimming was conducted with a bowsaw and loppers, and debris was moved out of the meadow area and disposed of within the adjacent treeline.

The decisions on where to leave cut woody debris were based on:

- ensuring no burrows or hibernacula were obstructed;
- ensuring no marmot foraging areas were covered;
- avoiding the creation of piles of woody debris, which could have increased fire risk and also served as new sources of stalking cover;
- landowner preferences; and
- site-specific context.

This meadow has multiple hidden refugia and burrows spread throughout the talus field; therefore, the talus was assessed to be a poor location for the disposal of woody debris for eventual burning. Following the chainsaw work each day, the chainsaw operators assisted with a debris removal and this facilitated a thorough spark check which was followed up with a further spark check from the air upon departure. Clearing effort was directed at four main stands of trees that surrounded the meadow and one small stand in the middle of the meadow (Figure 2).

Habitat improvement within these areas was conducted as follows:

- Mid Meadow – One small hemlock (30cm diameter) were removed. The main benefit of the latter was a vast improvement in terms of sightlines from the loafing rock immediately downslope.
- Upper Middle Stand – Mountain hemlock and yellow cedar (10-20cm diameter). The trees at the lower west extent were within 10m of a known hibernaculum and therefore could not be removed or modified. Outside the 10m restriction, most trees were removed or pruned (Figure 3).
- Upper East Stand – Mountain hemlock (10-20cm diameter). Because this stand was too large to remove and undoubtedly contributed significantly to slope stability, improvement activities were restricted to pruning of the lower branches (Figure 4). Considerable improvement was

nevertheless observed in terms of sightlines through the stand for any potential marmot navigating the adjacent steep talus (Figure 5).

- Lower East Edge – Some trees adjacent to a known burrow were protected, but all other trees along the west margin of this large stand were cut back to allow better visibility into, and in some areas through, the treeline.
- West Stand – This area consisted of large trees (mountain hemlock, 20-40cm diameter), many of which were adjacent to known hibernacula and burrows (Figure 6). After flagging the exclusion zone, the remaining trees were prioritised to facilitate the opening up of a large sightline or corridor between the lower main meadow and a [4] known burrow inhabited by the only remaining telemetered marmot (present, underground during clearing).

Results / Outlook

Marmots emerging from the known hibernacula and associated burrows now have clear sightlines to most of the meadow to detect and alert other marmots to the approach of predators (Figures 7-9). Due to the slow growth of trees at this elevation, it is expected that the effects of habitat improvement should last for at least 10 years. It should be noted that there are several other sublocations on Mt. Hooper, such as the eastern slopes and smaller meadows to the west of the cleared area, where marmot occupation has been observed and which could benefit from additional improvement efforts in the future.

Acknowledgements

Matt Kelly and Cam William-Johnston of the BC Wildfire Service for their professional and safety minded approach, chainsaw skills and fire stories; Trudy Chatwin, for sharing her wealth of ecosystems knowledge and her boundless energy (and her photography skills, Figure 10); Trevor Dickinson, for his insights into avalanche slide terrain and incomparable enthusiasm; Norberto Pancera, for his comprehensive knowledge of the marmots in recent years at the Mt. Hooper site and his solid team-oriented work ethic. Thank you to Environment and Climate Change Canada's Habitat Stewardship Program for providing funding for the project. Thank you to the private landowner, TimberWest, for their permission and assistance in accessing the site and conducting this work.

Figures

Figure 2 Location of Mt. Hooper.

Figure 3 Clearing effort by area – Mt Hooper southwest meadow.

Figure 4 Volunteer and former MRF field crew member, Trevor Dickinson, clearing woody debris from the Upper Middle Stand. Photo by Mike Lester.

Figure 6 Upper East Stand (post-improvement). Trees were pruned in the lower 1.5m only as slope stability concerns precluded tree removal. Photo by Mike Lester.

Figure 5 Matt Kelly, BC Wildfire Service, clearing limbs from trees in the Upper East Stand. Photo by Mike Lester.

Figure 8 Trudy Chatwin assisting with measuring clearance activity exclusion zones in the West Stand and documenting the site prior to clearing. Photo by Mike Lester.

Figure 7 Aerial photo before improvement (Oct 3, 2017). Photo by Mike Lester.

Figure 10 Aerial photo after improvement (Oct 4, 2017). Photo by Mike Lester.

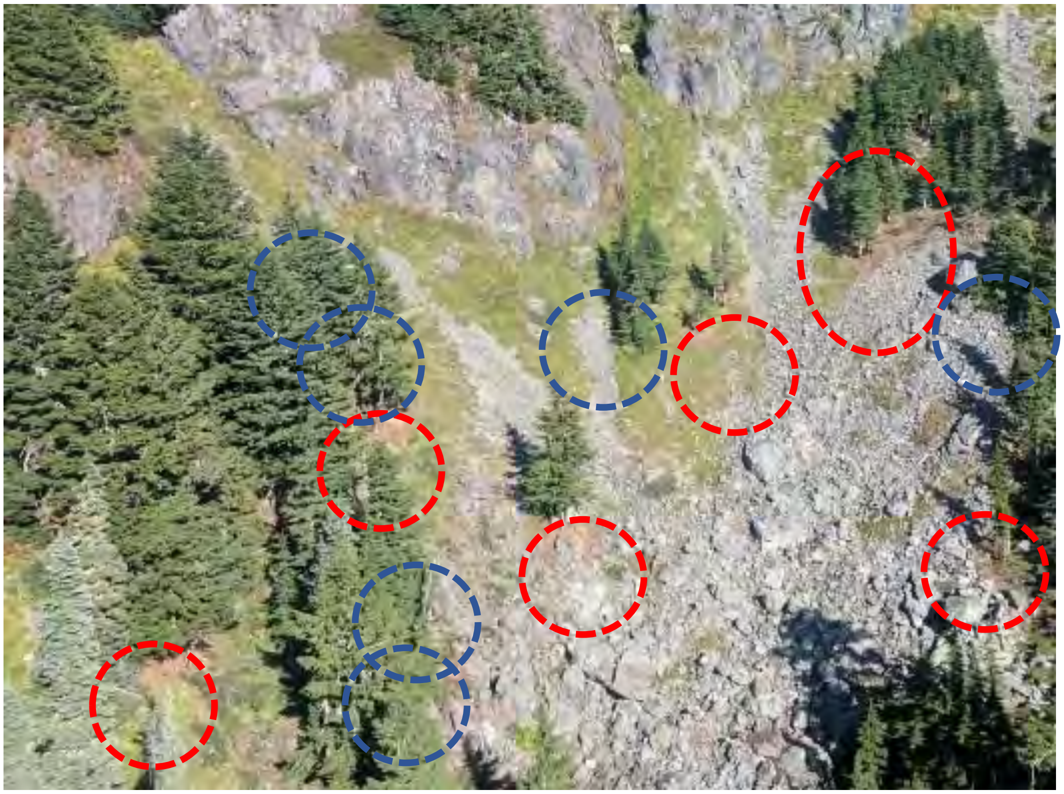

Figure 9 Aerial photo showing extent of clearing effort (red ovals) and trees that were retained because of <10m proximity to known burrows (blue ovals). Photo by Mike Lester.

Figure 11 Mt Hooper Clearing Crew (day two). Left to right: Norberto Pancera, Mike Lester, Trudy Chatwin, Cam William-Johnston, Matt Kelly. Photo by Trudy Chatwin.

Douglas Peak – China Bowl Vancouver Island Marmot Habitat Improvement 2021

Report composed by Kevin Gourlay and Mike Lester

Location

Mt. Douglas (1480m; Figure 1) is located 17km southeast of Port Alberni and 50km west of Nanaimo. The China bowl (1300-1400m) is a steep bowl on the NW aspect of the summit with heavy talus and multiple avalanche chutes descending into the runout zone at the base of the bowl. Heavy mature conifers line the sides of the bowl and the runout zone spills into a recent clear-cut bellow.

Background

The invasion of trees into open marmot habitat has been associated with climate change and is a concern because marmots rely on open habitat to detect and avoid approaching predators. Tree ingress is evident along all borders of the bowl. Removal or reduction of the amount of stalking cover provided by invading trees should increase the annual survival rates of colony residents, thereby improving colony persistence and supporting the regional population.

Objectives

- Protect important marmot habitat features (hibernacula and well-established burrows).
- Remove ingrowth of younger trees and prune the lower branches of older trees in the Mt Douglas China bowl to reduce local predation risk for Vancouver Island Marmots.
- Document the work to measure success and guide similar projects in the future.

Steps

- Attain approval from landowners for improvement work.
- Engage with stakeholders and experts to discuss intent and seek assistance with methodology (see Appendix 1, Habitat Improvement Working Group's Draft Guiding Principles for Clearing Work, Oct 1, 2017).
- Assess the site for safe clearing.
- Conduct habitat enhancement.
- Report results.

Methods

The site was assessed on the ground immediately prior to clearing work on Oct 19, 2021. During the initial survey the following factors were assessed:

- Site safety: Approach and egress, evacuation routes, helicopter access, site hazards.
- Delineation of exclusion zones using flagging tape around known marmot hibernacula and other marmot features.
- Identification of highest priority zones and scope of work achievable with a small clearing team.

The site was cleared on Oct 19 and Oct 31, 2021 with a team of six personnel and four personnel, respectively. On October 19, personnel included two Marmot Recovery Foundation crew, two Calgary Zoo crew and two independent contractors, and only hand tools were used. On October 31, personnel included one Marmot Recovery Foundation crew member, one Calgary Zoo crew member, one independent contractor who all use hand tools, and one BC Wildfire Service crew member who operated a power saw. BC Wildfire Service lead, Derek Rushton, provided a safety briefing, after which crew conducted a safety assessment and thorough site inspection. Field crew then identified trees close to known hibernacula and established burrows. A 10-metre exclusion zone from any known hibernacula or burrow was measured with a survey tape and trees that fell within 10m were flagged. Flagged trees were not removed or modified. Trees and limbs of the largest trees in the targeted removal zone were cut with a chainsaw. Further trimming was conducted with bowsaws and loppers. Some cut woody debris was moved to the sides or bottom of the bowl and piled where possible, while the remainder was spread out where it was cut.

The decisions on where to leave cut woody debris were based on:

- ensuring no burrows or hibernacula were obstructed;
- ensuring no marmot foraging areas were covered;
- avoiding the creation of piles of woody debris, which could have increased fire risk and also served as new sources of stalking cover;
- landowner preferences; and
- site-specific context. This bowl has dense forest and steep topography on all sides except the runout, making removal of cut debris difficult. The runout zone was identified as a well used path for marmots traveling down into the clear-cut bellow and was not suitable for piling cut woody debris; therefore, the talus around the perimeter of the bowl was assessed to be the best location for spreading out the woody debris.

Clearing effort was directed at four main stands of trees that surrounded the bowl (Figure 2). Habitat improvement within these areas was conducted as follows:

- Upper meadow – Mountain hemlock and yellow cedar (5-15cm diameter). This zone contained the only meadow in the bowl which was the best foraging habitat for the marmots within the vicinity. Severe tree ingress from above was identified as a high priority for clearing effort to maintain open habitat for marmot foraging (Figures 3 and 4). Many small trees within the meadow were removed and larger trees along the perimeter of the headwall were limbed. (Figure 5).
- North Stand – Mountain hemlock (10-20cm diameter). This stand was the largest group of conifers that was directly adjacent to multiple burrows and hibernacula in the lower talus, and therefor represented another high priority for clearing effort. As many of the trees were larger than 20cm in diameter at chest height, approximately 40% of the trees were limbed while the remaining smaller trees were felled. Two burrow exclusion zones, one near the top (Figures 6 and 7) and one near the base of the stand (Figures 8 and 9), also prohibited the cutting of some trees in this stand. Considerable improvement was nevertheless observed in terms of sightlines throughout the stand for any potential marmots using the adjacent marmot infrastructure (Figure 10).

- Lower south avalanche chute – Many small conifers in this small avalanche chute were creating dense low-lying stalking cover close to multiple burrows and sunning rocks and were therefore removed (Figure 11).
- Runout rocks – this zone represented a pinch point for marmots travelling between China bowl and the cut block bellow, which is also known to have multiple burrows and be actively used by marmots. Vegetation cut from this zone was transported out of the talus to the edges of the mature forest and distributed to prevent the formation of obstacles and more stalking cover in this narrow area (Figure 12).

Results / Outlook

Marmots emerging from the known hibernacula and associated burrows now have clear sightlines to most of the bowl to detect and alert other marmots to the approach of predators (Figures 7-9). Due to the slow growth of trees at this elevation, it is expected that the effects of habitat improvement should last for at least 10 years. It should be noted that the dense mature coniferous forest surrounding this bowl is likely to continue to ingress into the talus at an accelerated rate due to the lower elevation of this colony and potential climate change-induced reduction in frequency and magnitude of avalanches which would naturally remove vegetation and maintain talus and meadow habitat.

Acknowledgements

Thank you to Derek Rushton of the BC Wildfire Service for his professional and safety minded approach, chainsaw operating skills, and use of drone for arial photography. Thank you to Chelsea B., Savita F., Shayne M., Emily U, and Chloe S. for their dedicated work ethic using hand tools to remove considerable amounts of vegetation from marmot habitat (Figures 13 and 14). Thank you to the Habitat Stewardship Program for species at risk for providing funding for the project. Thank you to the private landowner, Mosaic, for their permission and assistance in accessing the site and conducting this work.

Figures

Figure 12 Location of Douglas

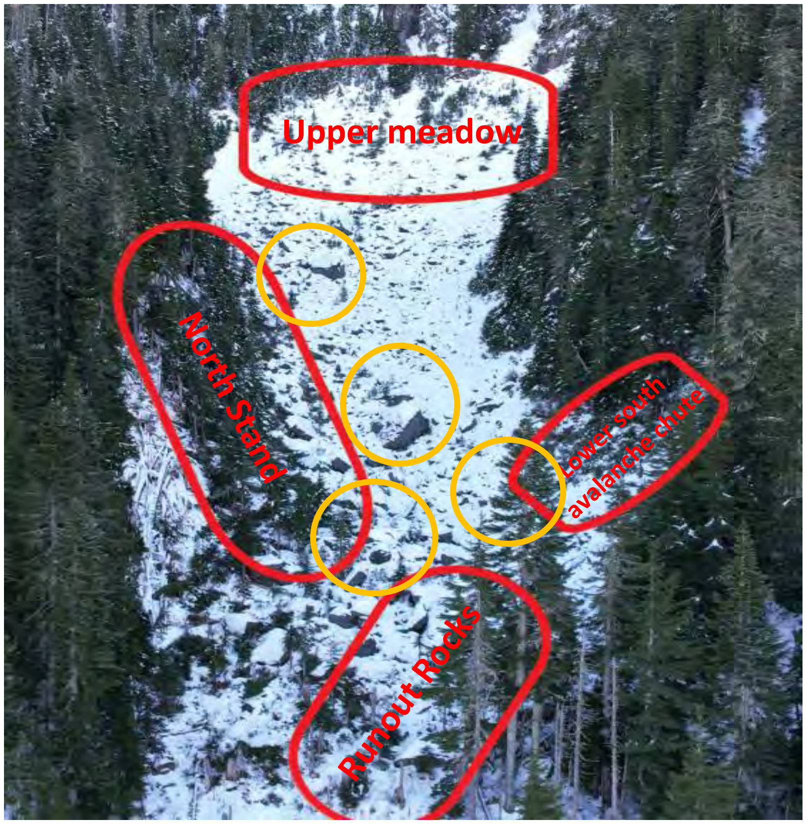

Figure 13 Aerial photo of China bowl on Mt. Douglas (post- habitat improvement) showing clearing effort by area (red ovals) and location of primary marmot burrow exclusion zones (yellow circles). Photo by Derek Rushton.

Figure 14 Aerial photo of Upper meadow (post- habitat improvement), showing considerable improvement in terms of tree removal, yet substantial tree ingress persists along upper left margin of meadow (red arrow). Photo by Derek Rushton.


Figure 15 Upper meadow (pre- habitat improvement), showing considerable tree ingress into marmot foraging habitat. Photo by Shayne McAskin.


Figure 16 Upper meadow (post- habitat improvement) with crew members Shayne and Savita in background. Photo by Kevin Gourlay.

Figure 17 Top of north stand (pre-habitat improvement) taken from perspective of upper burrow entrance. Photo by Derek Rushton

Figure 18 Top of north stand (post-habitat improvement) showing improved sightlines from burrow entrance. Photo by Derek Rushton.

Figure 19 Bottom of north stand (pre-habitat improvement) taken from perspective of lower burrow entrance. Orange flagging showing boundary of exclusion zone. Photo by Kevin Gourlay.

Figure 20 Bottom of north stand (post-habitat improvement) taken from lower burrow entrance showing improved sightlines. Photo by Derek Rushton.

Figure 21 Photo taken from within middle of north stand (post improvement), showing high density of coniferous vegetation and improved sightlines throughout the stand. Photo by Derek Rushton.

Figure 22 Aerial photo (post habitat improvement) showing avalanche track (red arrow) and young trees adjacent to lower borrow exclusion zones (yellow ovals).

Figure 23 Photo of runout rocks pinch point (post habitat improvement) showing improved sightlines out of bowl down to cut-block below.

Figure 24 Mt Douglas clearing crew (day one). Left to right: Savita Owens-Frank (lower), Shayne McAskin (upper), Chloe Swabey (lower), Kevin Gourlay, Emily Upham-Mills, Chelsea Brager. Photo by Chelsea Brager.

Figure 25 Mt Douglas clearing crew (day two). Left to right: Kevin Gourlay, Shayne McAskin, Savita Owens-Frank, and Derek Rushton. Photo by Derek Rushton.

Gemini Mountain, Main Meadow October 2021 Vancouver Island Marmot Habitat Restoration

Report composed by Chelsea Brager and Mike Lester

Site Background

Gemini Mountain (1516 m) is located 51 km northwest of Nanaimo, BC within the *M. vancouverensis* Nanaimo Lakes metapopulation. This report's focal site is the Main Meadow of Gemini Mountain. This sub-location is located on the summit's southwest aspect and is a highly treed subalpine meadow within the Mountain Hemlock Biogeoclimatic Zone (MHmm1).

The main meadow is of particular concern to tree invasion due to the proximity of dense subalpine forest. While this sublocation has received supplemental marmot releases in recent years, data shows several predations located just downslope from the meadow. Tree ingression appears to have moved uphill, having two distinct stands dividing the Main Meadow sublocation into three micro-meadows. Such forested divisions were designated as priority areas for restoration. Through manual thinning and tree removal, the goals of restoration activities were to increase sightlines through thick stands bisecting the Main Meadow, with hopes to reduce local predation risk to colony residents (Lester 2017).

Objectives

1. **Increase sightlines from known marmot habitat features such as hibernacula and well-established burrows, through manual tree removal in designated high priority stands.**
    - *Measurable objectives include* the removal of young trees (<15 cm DBH) and pruning of lower branches below 120 cm in height on larger trees (>15 cm DBH).

2. **Mitigate harm to known marmot habitat features during restoration activities.**
    - *Harm may be defined as* the loss of trees providing structural support to marmot features, loss of upslope trees that shelter marmot features from avalanche activity, and the loss of important spring foraging resources through the removal of non-arboreal shrub and tree species.
    - *Identified mitigation actions* include the establishment of 10m (minimum) buffer zones around known marmot habitat features (hibernacula and burrows) and the delineation of "no-work" zones around tree stands upslope from marmot habitat features.

3. **Document the work to measure success and guide similar projects in the future (Lester 2017)**

Steps

- Attain landowner approval for restoration work.
- Engage with stakeholders and experts to discuss intent and seek assistance with methodology (see Appendix 1, Habitat Improvement Working Group's Draft Guiding Principles for Clearing Work, Oct 1, 2017).
- Assess the site for safe clearing.
- Conduct habitat enhancement.
- Report results.

Methods

Site assessment was conducted on the ground on October 13th 2021, one week prior to restoration activities. The following factors were considered during pre-work assessment surveys:

- **Site safety**: Site-specific hazards, approach and egress routes, muster points
    - **Note**: Previous restoration efforts were aided with a helicopter approach. Due to limited helicopter availability in Fall 2021, restoration efforts were completed with manual hand-tools and access was completed on foot. Safety considerations were tailored to accommodate such changes.
- **Scope of work**: Designated priority work areas appropriate for a 5-person clearing crew, delineated marmot habitat features and associated buffer/"no work" zones with colour-coded flagging.

Site Assessment

To follow the restoration project's objective #2, 10 m (minimum) buffer and "no-work" zones around known marmot habitat features were first established.

This began by flagging known marmot habitat features to identify points to measure from. Using survey tape, a 10 m buffer zone was delineated with yellow flagging and formed a 10 m buffer encircling the central habitat feature. Yellow flagging signalled brushers not to cut and limb trees within the flagged circle. Where 10 m buffers from nearby marmot features intersected, flagged circles were merged to create one large buffer.

Following this, "no-work" zones were established. Any stand of trees upslope from marmot features were secluded from restoration efforts. During site assessment, only one small patch of trees was identified. Risk class of this stand (based on the risk of removal increasing avalanche activity above marmot features) was vague due to the stand occurring on flat terrain upslope from the feature, but topographically separated by a rocky outcrop. This section was delineated with yellow flagging as a "no-work" zone at the time of site assessment.

Prioritized work areas were delineated with green flagging. Decisions were based on the proximity of dense forest stands to flagged marmot features. Two main priority areas were delineated (Figure 2) – two stands that bisected the main meadow, both on either side of two known marmot features, including a plugged burrow (suggesting a hibernating marmot underground).

Additional delineation points included burn pile locations, for burning the following year (with approval from landowners). Important considerations for burn pile locations included distance from overhead canopy, and distance from marmot habitat (as far as possible). Two areas suitable for burn piles were located, both at the bottom of the main meadow as it transitions to forest in flat depressions.

Site Clearing

Site clearing was completed on October 18th 2021, with a brushing crew of 5 personnel (all Marmot Recovery Foundation crew members). The day began with a safety briefing at the trailhead regarding all site-specific hazards, PPE required, and mitigations for safety hazards.

Approach was on foot. Upon arrival to the site, a revision of priority and off-limit areas was conducted. All trees less than 15 cm DBH were removed, using a combination of bowsaws, folding handsaws, and loppers. Trees greater than 15 cm DBH were limbed up to a height of 120 cm. Large, down-sloping limbs were observed to still obstruct sightlines even if above the 120 cm cut-off. Such limbs were removed where safe and reasonable to do so.

Clearing efforts were directed at three main stands of trees, of which two completely divided the main meadow into 3 micro meadows, and one stand obstructing sightlines to the upper portion of the meadow. Clearing in all three stands has the potential to expand sightlines from 3 known marmot features, one of which currently holds a hibernating marmot, confirmed with the presence of a plugged entrance.

- **Lower Meadow – West:** This stand consisted of large trees that were filled in with a dense sapling layer, completely obstructing meadow habitat to the west of 1 hibernaculum, 2 burrows and a sunning rock (Figure 3). An estimate of 40 saplings were removed (5-10 cm diameter), as well as the lower limbs of approximately 15 larger trees (>30 cm diameter). The result was an opening to the west that allowed for restored sightlines from marmot habitat features to additional meadow habitat located at the west end of the Main Meadow (Figure 4).
- **Lower Meadow – East:** This stand consisted of larger trees, however with a sparser sapling layer (Figure 5). This stand obstructed sightlines to meadow habitat east of the hibernaculum, 2 burrows, and one sunning rock. An estimate of 30 saplings were removed (5-10 cm diameter), as well as the lower limbs of approximately 20 larger trees (>30 cm diameter). The result was restored sightlines through the stand to additional meadow habitat on the east side of the Main Meadow (Figure 6).
- **Upper Meadow – Upslope trees:** This stand initially consisted of saplings with a few medium sized trees (Figure 7). 20-30 saplings were removed (5-10 cm diameter), as well as the lower limbs of approximately 3 larger trees (>15 cm diameter). This identified stand of upslope trees was initially delineated as a “no-work” zone during site assessment, however, the decision was made to include it in clearing efforts. The benefit of restoring sightlines from multiple burrow entrances to the top of the meadow outweighed the low risk of increased avalanche activity, considering the topographical separation (as described in the Site Assessment section; see Figure 9). To accommodate for the unknown effect of complete tree removal on snow stability, only 50% of the upslope stand was removed, where applicable by size of trees. As a result, sightlines were lengthened from all marmot habitat features towards the top of the meadow (Figure 8).

Results/Outlook

As confirmed by the presence of a plugged burrow entrance within the Main Meadow, there is at least one marmot to emerge from hibernation next spring. As a result, there are now clear sightlines from the following marmot features: the hibernaculum, two other known marmot burrows, and one sunning rock. The clearing efforts within the Main Meadow will allow for hibernating marmots to emerge with restored sightlines towards the top and bottom of the meadow, as well as into micro-meadows that were once hidden from dense stands. Due to the slow growth of trees at this elevation, it is expected that the effects of habitat improvement should last for at least 10 years (Lester 2017).

Acknowledgements

Thank you to a great crew of brushers who brought bounds of enthusiasm to the day. Despite unforeseeable circumstances preventing helicopter access and chainsaw crews, our crew members shared smiles, laughs, and an appreciation of the hard work completed. Thank you Shayn McAskin, Kevin Gourlay, Chloe Swabey, and Emily Upham-Mills! As well, thank you to Cheyney Jackson for your tireless dedication to getting us all out for a fun and safe workday in the mountains.

Thank you to our funders, Environment and Climate Change Canada's Habitat Stewardship Program, and the private landowners, Mosaic, for the opportunity to complete this project. We would like to express our gratitude to work and learn on the unceded, occupied territories of the sovereign Snuneymuxw, Snaw-Naw-As, Stz'uminus, as well as the traditional homelands of the Mid-Island Metis Nation.

References

Lester, M. (2017). Vancouver Island Marmot Habitat Improvement 2017 – Mt. Hooper – Southwest Meadow. Marmot Recovery Foundation.

Figures

Figure 26 Gemini Mountain – Main Meadow burrows and high-priority areas. Burrows encircled in orange, and high-priority areas in green. Note, areas encircled in green also extend downslope. Green arrow refers to the Upslope Trees priority stand, as described in the Site Clearing section. Photo by Chelsea Brager.

Figure 27 Lower Meadow – West stand, pre-work photo. Highly dense stand looking towards 2 known marmot habitat features. Heavy sapling layer evident in older, closed-in canopy. Photo by Chelsea Brager.

Figure 28 Lower Meadow – West stand, post-work photo. Only older, large trees remain. Sapling layer dramatically reduced and larger trees limbed. Now facilitates sightlines to the patch of meadow with the hibernaculum, 2 burrows, and one sunning rock. Photo by Chelsea Brager

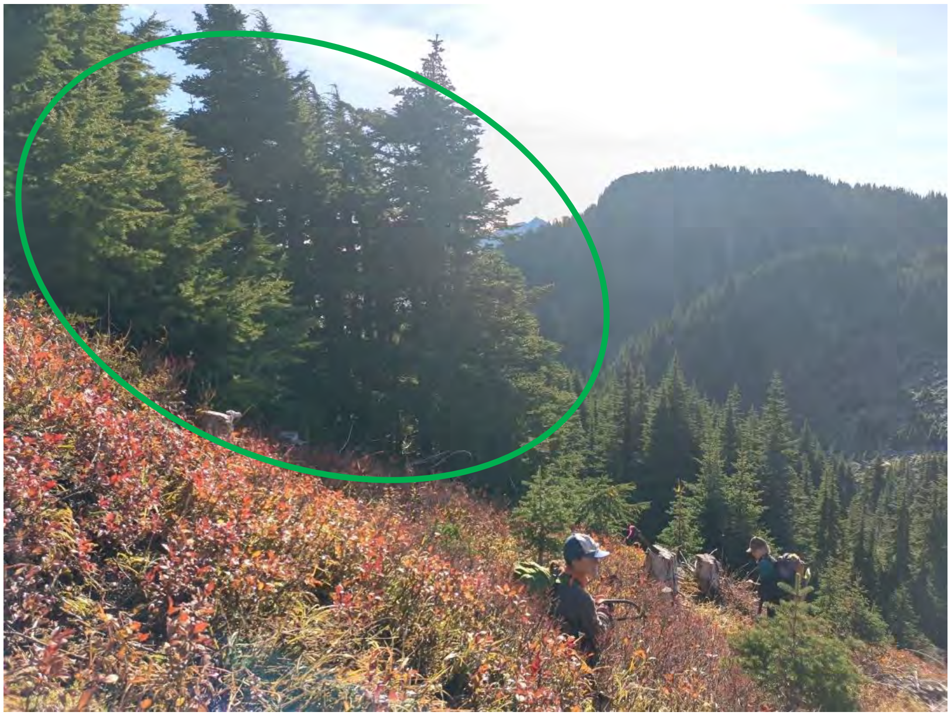

Figure 29 Lower Meadow – East stand, pre-work photo. Targeted area is dense patch of tall trees immediately across from marmot burrow (encircled in green). Photo taken from perspective of marmot burrow entrance. This stand separates micro-meadow habitat to the east of this stand, out of shot. Photo by Kevin Gourlay.

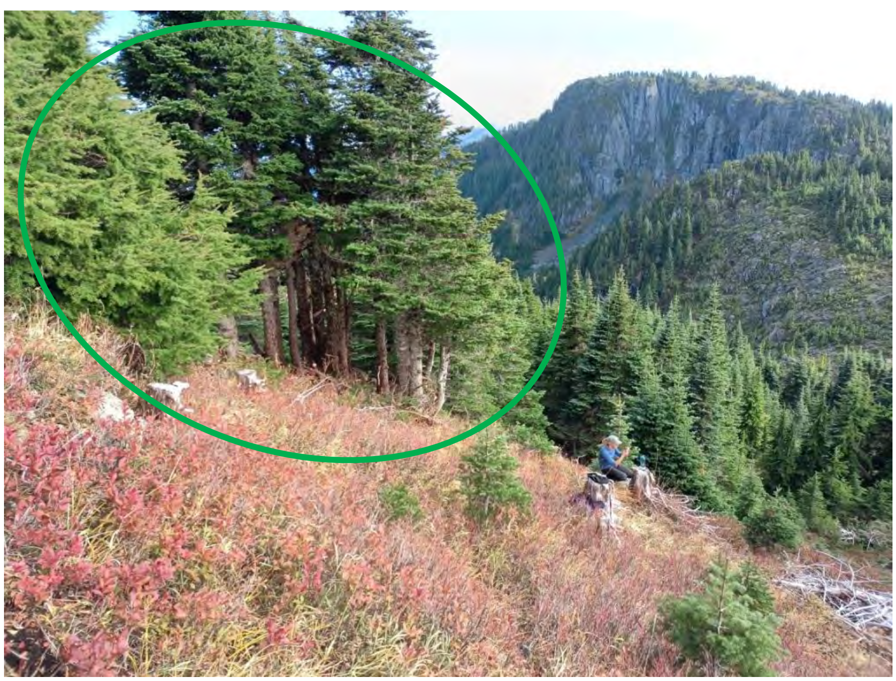

Figure 30 Lower Meadow – East stand, post-work photo. Note only remaining trees in stand are limbed, large diameter trees. Photo taken from perspective of marmot burrow. Photo by Kevin Gourlay.

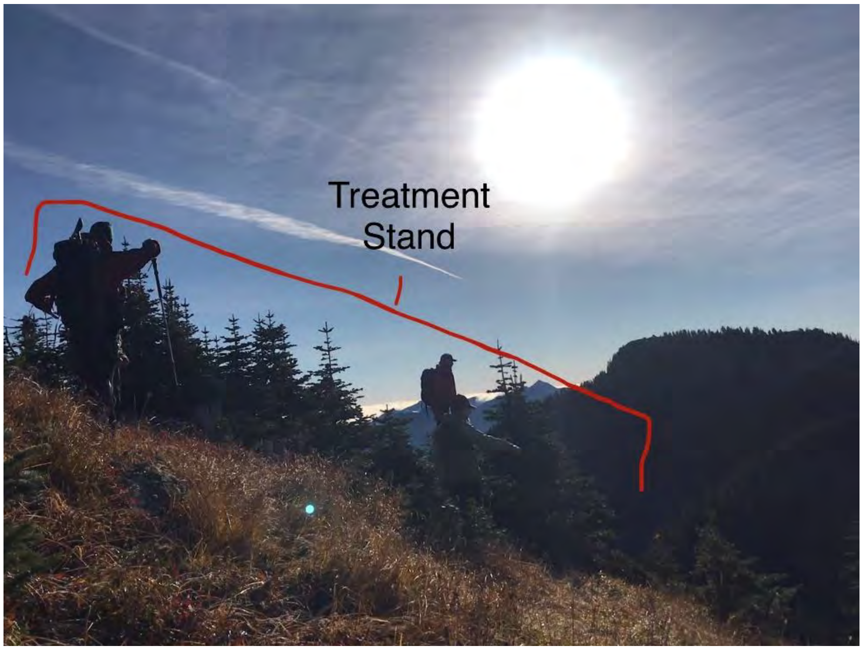

Figure 31 Upper Meadow – Upslope trees, pre-work photo. Treatment stand behind crew members. Note dense stand of primarily saplings, topographically separated from burrow at base of cliffs (see Figure 9 for photo of cliffs). Photo by Chelsea Brager.

Figure 32 Upper Meadow – Upslope trees, post-work photo. Stand thinned by 50% - all that is remaining are limbed, medium sized trees. Photo by Chelsea Brager.

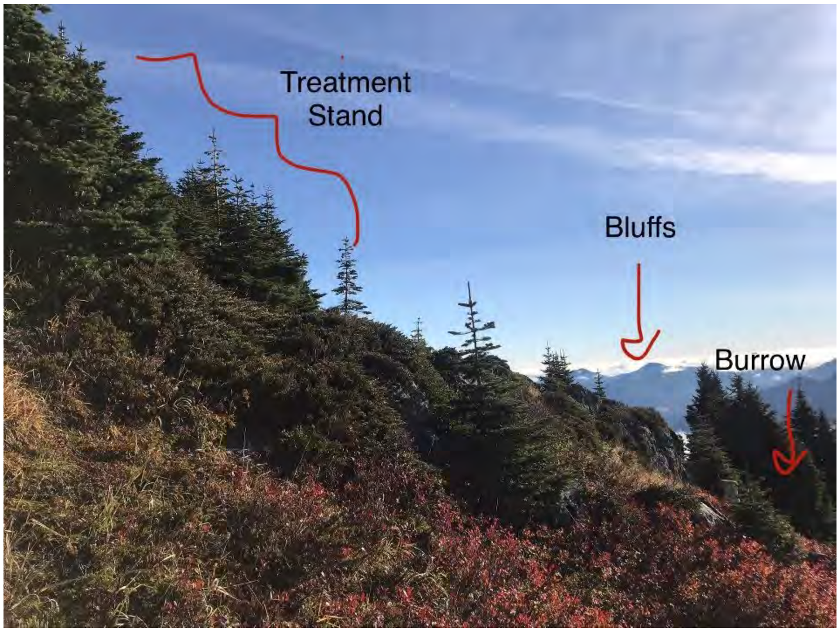

Figure 33 Upper Meadow – Upslope trees, topographical separation (pre-work photo). Due to the presence of the rock bluffs, a topographical separation between the treatment stand and burrow is present. The decision was made to cut only 50% of this stand due to the lowered risk of impacting snow stability, compared to the greater benefit of gaining sightlines from this burrow to the upper meadow. Photo by Chelsea Brager.

Figure 34 Gemini Main Meadow 2021 Restoration Crew. From left to right: Chelsea Brager, Shayn McAskin, Emily Upham-Mills, Chloe Swabey, and Kevin Gourlay. Photo by Chelsea Brager.

Gemini Mountain, Aster's Bowl October 2021 Vancouver Island Marmot Habitat Restoration

Report composed by Chelsea Brager and Mike Lester

Site Background

Gemini Mountain (1516 m) is located 51 km northwest of Nanaimo, BC within the *M. vancouverensis* Nanaimo Lakes metapopulation. Our focal site is Aster's Bowl, one of three sub-locations on Gemini Mountain. This sub-location can be found 1 km along the ridgeline extending southwest from Gemini's summit. Aster's Bowl is a moderately treed, south-facing talus field within the Mountain Hemlock Biogeoclimatic Zone (MHmm1).

Tree invasion is of concern to this sub-location along its peripheral edges. Due to Aster's Bowl being primarily talus field, there is negligible tree growth directly within the bowl and near known marmot habitat features. Despite this, tree ingression along the perimeter of Aster's Bowl should be addressed due to a high potential for stands to enclose marmot habitat features at the bowl's centre as succession takes place.

Trees at the western corner of Aster's Bowl have been observed extending downslope from the summit's southwest ridge. Several sightings of cougar scat as well as known mortality locations suggest that this southwest ridge is heavily trafficked by predators. The ingression of trees from said ridge may allow for predators to stalk further into marmot habitat as trees extends into the bowl. Additionally, the spread of small saplings on the eastern edge of Aster's Bowl has been identified as a second priority area. This stand has high potential for the already established, young trees to develop thick stands, eventually connecting with the forested bowl below. Our objective for this sub-location was to prevent further encroachment from the bowl's periphery towards its centre, where a majority of the marmot habitat features are.

Objectives

- **Increase sightlines from known marmot habitat features such as hibernacula and well-established burrows, through manual tree removal in designated high priority stands.**
    - *Measurable objectives include* the removal of young trees (<15 cm DBH) and pruning of lower branches below 120 cm in height on larger trees (>15 cm DBH).
    - *Site-specific high priority stands* include the north-west periphery stand and the eastern periphery stand.
- **Mitigate harm to known marmot habitat features during restoration activities.**
    - *Harm may be defined as* the loss of trees providing structural support to marmot features, loss of upslope trees that shelter marmot features from avalanche activity, and the loss of important spring foraging resources through the removal of non-arboreal shrub and tree species.
    - *Identified mitigation actions* include the establishment of 10m (minimum) buffer zones around known marmot habitat features (hibernacula and burrows) and delineated "no-work" zones around tree stands upslope from marmot habitat features.
    - ***Note:*** Due to the reduced presence of trees within Aster's Bowl itself (thus, very few trees within 10m of marmot burrows), buffer zones were implemented on an as needed

basis. As a result, only one marmot habitat feature required the delineation of a 10m buffer zone.

- **Document the work to measure success and guide similar projects in the future (Lester 2017)**

Steps

- Attain landowner approval for restoration work.
- Engage with stakeholders and experts to discuss intent and seek assistance with methodology (see Appendix 1, Habitat Improvement Working Group's Draft Guiding Principles for Clearing Work, Oct 1, 2017).
- Assess the site for safe clearing.
- Conduct habitat enhancement.
- Report results.

Methods

Site assessment was conducted on the ground on October 13th 2021, 9 days prior to restoration activities. The following factors were considered during pre-work assessment surveys:

- **Site safety**: Site-specific hazards, approach and egress routes, muster points, hiking route from landing spot.
- **Scope of work**: Designated priority work areas appropriate for a 4-person clearing crew, delineated marmot habitat features, associated buffer/"no work" zones, and high priority cutting zones with colour-coded flagging.

Site Assessment

To follow the restoration project's objective #2, 10 m buffer and "no-work" zones around known marmot habitat features were first established.

As previously mentioned, only one marmot habitat feature required a 10 m buffer. Buffer delineation began by flagging all known marmot habitat features. Despite most of the features not requiring a buffer, it was proven useful from previous sites to delineate where burrows were for reference points during cutting.

For the one burrow requiring a 10 m buffer, delineation began by measuring 10 m upslope, downslope, to the right, and to the left of the marmot burrow using survey tape. Yellow flagging was used for the 10m radius around the marmot burrow. This signalled to brushers not to cut and limb trees within the yellow-flagged circle.

Following this, "no-work" zones were established. For this site, "no-work" zones were the primary mitigation action required. A "no-work" zone was identified as any stand of trees upslope from marmot features that were to be secluded from restoration efforts. We have identified a large swathe of trees at the northeast corner of Aster's Bowl that were directly above 3 known marmot features (Figure 2). These areas were delineated with yellow flagging, signalling brushers that they cannot cut or limb trees at or above this line.

Prioritized work areas were delineated with green flagging. Decisions were based on stands at the bowl's periphery that were furthest into the bowl's centre. Two main priority areas were delineated: one stand at the northwest corner of the bowl descending from Mt. Gemini's southwest ridge, and another stand at the eastern end of Aster's bowl where trees are ascending from a densely forested shelf below (Figure 3).

Additional delineation points included burn pile locations, for burning the following year (with approval from landowners). Important considerations for burn pile locations included distance from overhead canopy, and distance from marmot habitat (as far as possible). One open, topographical depression at the eastern edge of the sublocation was decided as a suitable burn pile location.

Site Clearing

Site clearing was completed on October 22nd 2021 with a brushing crew of 4 personnel (all Marmot Recovery Foundation crew members). The day began with a safety briefing at the helicopter pick up site regarding all site-specific hazards and PPE required. Approach was via helicopter, and a full helicopter safety briefing regarding entering/exiting, gear loading, no-go zones, etc. were provided by the pilot.

Upon arrival to the site, a discussion of priority and off-limit areas was conducted, as outlined above in the Site Assessment. All trees less than 15 cm DBH were removed, using a combination of bowsaws, folding handsaws, and loppers. Trees greater than 15 cm DBH were limbed up to a height of 120 cm. Large, down-sloping limbs were observed to still obstruct sightlines even if above the 120 cm cut-off. Such limbs were removed where safe and reasonable to do so. While a suitable burn pile location was chosen, brushers decided on laying branches flat around the periphery of the sub-location due to time and crew-size constraints.

Clearing efforts were directed at the following two stands of trees:

- **Peripheral northwest stand:** This stand consisted of a dense sapling layer alongside large trees with wide, low-lying branches. These trees extended downslope into Aster's Bowl from Mt. Gemini's southwest ridge, completely obstructing views from 3 marmot habitat features to the ridgeline (Figure 4). Sightlines to this area are particularly important to restore as there are several confirmed accounts of predator traffic along the ridgeline. An estimate of 30-40 saplings were removed (5-10 cm diameter), as well as the lower limbs of 20 larger trees (>15 cm diameter). The result was an opening into the upper slopes leading into the southwest ridge (Figure 5).
- **Peripheral east stand:** This stand consisted of a heavy sapling layer encroaching into the meadow, eventually leading into sections of large trees with low-lying branches. This stand obstructed sightlines to the south where additional talus fields are, as well as to the east where there is a dense, contiguous forested band directly below (Figure 6). While predator sightings have not been confirmed in this area, this stand was identified as high priority due to the potential for predators to travel through contiguous forest, with a quick transition into stalking cover right at the edge of Aster's Bowl, as well as the potential for separation from adjacent marmot habitat to the south. An estimate of 50 saplings were removed (5-10 cm diameter), as well as the lower limbs of 20 larger trees (15-30 cm diameter). The result was restored sightlines to the eastern edge of Aster's Bowl, as well as into additional talus slopes to the south (Figure 7).

Results/Outlook

Data from the 2021 field season suggests the potential for 3-4 yearlings and two adults to emerge from Aster's Bowl the following spring. Crew size of the restoration efforts for Aster's Bowl was a limiting factor in the extent of clearing completed, however sightlines that were restored may be just enough to increase chances of survival throughout next year's growing season. Sightlines from all marmot habitat features (3 burrows and one sunning rock) were restored towards two areas: one area that is a confirmed predator source, and the other a potential predator source. This will allow for emerging marmots to better detect predators from a further distance. While there is still work to be done (Figure 8), this year's clearing efforts have tackled stands with the highest probability of use by predators, thus mitigating potential mortality the following year. Due to the slow growth of trees at this elevation, it is expected that the effects of habitat improvement should last for at least 10 years (Lester 2017). Priority areas for future clearing efforts should include the stand identified in Figure 8 – a descending patch of saplings that has the potential to bisect Aster's Bowl if allowed to grow freely.

Acknowledgements

Thank you to a great crew of brushers who brought bounds of enthusiasm to the day. Despite unforeseeable circumstances limiting crew size and chainsaw crews, our crew members shared smiles, laughs, and an appreciation of the hard work completed. Thank you to Shayn McAskin, Kevin Gourlay, and Savita Owens-Frank! As well, thank you to Cheyney Jackson for your tireless dedication to getting us all out for a fun and safe workday in the mountains.

Thank you to our funders, Environment and Climate Change Canada's Habitat Stewardship Program, and the private landowners, Mosaic for the opportunity.to complete this project.

We would like to express our gratitude to work and learn on the unceded, occupied territories of the sovereign Snuneymuxw, Snaw-Naw-As, Stz'uminus, as well as the traditional homelands of the Mid-Island Metis Nation.

References

Lester, M. (2017). Vancouver Island Marmot Habitat Improvement 2017 – Mt. Hooper – Southwest Meadow. Marmot Recovery Foundation.

Figures

Figure 35 Mt Gemini Aster's Bowl – Trees above yellow line represent "no-go" zone. This area was identified as such due to its position directly upslope from the three known marmot habitat features in Aster's Bowl (numbered in orange). Photo by Chelsea Brager.

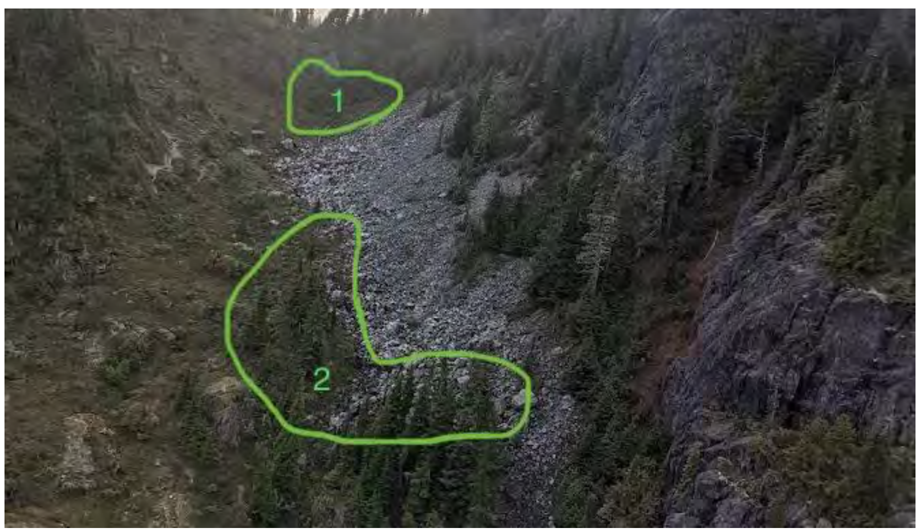

Figure 36 Mt Gemini Aster's Bowl – Delineated high priority areas in green. #1 has been named the peripheral northwest stand. #2 has been named the peripheral eastern stand. Photo by Savita Owens-Frank.

Figure 37 Mt Gemini Aster's Bowl – Peripheral northwest stand, pre-clearing circled in green. Note dense sapling layer amongst larger trees. Note potential for snow to press down saplings. Photo by Chelsea Brager.

Figure 38 Mt Gemini Aster's Bowl – Peripheral northwest stand, post-clearing circled in green. Still more work can be completed with a larger crew but note larger spaces between large trees. Photo by Chelsea Brager.

Figure 39 Mt Gemini Aster's Bowl – Peripheral eastern stand, pre-work photo circled in green. Photo looking east. Photo by Kevin Gourlay.

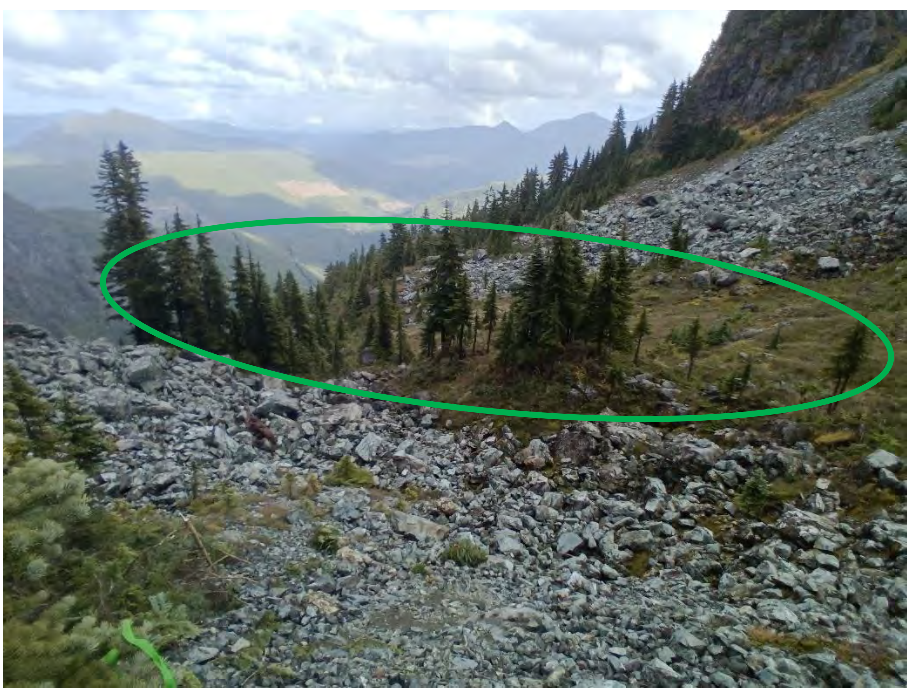

Figure 40 Mt Gemini Aster's Bowl – Peripheral eastern stand, post-work photo circled in green. Photo looking southeast. On right side of photo, sapling layer completely removed. From the centre to the left of the photo, all large trees have been limbed, creating wider spaces to see into meadow habitat across. Photo by Kevin Gourlay.

Figure 41 Proposed stand for future restoration work, encircled in green. A descending stand of saplings that poses risk to the residents of Aster's Bowl. If allowed to grow, this stand has the potential to bisect the talus field, potentially creating smaller micro meadows. There are no known marmot habitat features that exist directly below the site, so this would be a suitable stand to prioritize for future restoration work. Photo by Chelsea Brager.

Figure 42 Chelsea Brager and Kevin Gourlay ready for a day of crushing the brush at Aster's Bowl on Mount Gemini, October 22nd 2021. Photo by Savita Owens-Frank.

Figure 43 Savita Owens-Frank and Andy, our pilot on clearing day at Aster's Bowl on Mount Gemini, October 22nd 2021. Savita's very first helicopter ride! Photo by Chelsea Brager.

P Mountain Main Meadow October 2021 Vancouver Island Marmot Habitat Restoration

Report composed by Chelsea Brager and Mike Lester

Site Background

P Mountain is a small summit (1352 m) located 26 km northwest of Parksville, BC within the *M. vancouverensis* Nanaimo Lakes metapopulation. Our focal site is the main meadow, one of many sub-locations on P Mountain. The main meadow is a lightly treed, south-facing meadow within the Mountain Hemlock Biogeoclimatic Zone (MHmm1).

Tree invasion is not yet a large concern to this sub-location, however, there are two stands of concern that have high potential to expand eastwards towards marmot burrows. At this site, it was decided to forego the implementation of 10 m buffers and "no-go" zones as all marmot habitat features are located on the opposite end of the meadow. Despite this, restoration action on the two patches of trees is a worthwhile, proactive objective due to the potential of heavy tree growth towards marmot habitat features. These stands are located on the western edge of the main meadow, both clusters comprised of 10-20 saplings and 2-3 large trees (Figure 2). Our goal for this restoration project was to mitigate future tree encroachment and to prevent the future loss of sightlines from marmot habitat features.

Objectives

- **Increase sightlines from known marmot habitat features such as hibernacula and well-established burrows, through manual tree removal in designated high priority stands.**
    - *Measurable objectives include* the removal of young trees (<15 cm DBH) and pruning of lower branches below 120 cm in height on larger trees (>15 cm DBH).
    - *Site-specific high priority stands* – two small tree clusters at the western edge of the main meadow.
- **Mitigate harm to known marmot habitat features during restoration activities.**
    - *Harm may be defined as* the loss of trees providing structural support to marmot features, loss of upslope trees that shelter marmot features from avalanche activity, and the loss of important spring foraging resources through the removal of non-arboreal shrub and tree species.
    - *Identified mitigation actions* include the establishment of 10m (minimum) buffer zones around known marmot habitat features (hibernacula and burrows) and the delineation of "no-work" zones around tree stands upslope from marmot habitat features.
    - *The decision to forego mitigation actions was made due to the presence of trees well beyond 10 m in distance from marmot habitat features.*
- **Document the work to measure success and guide similar projects in the future (Lester 2017)**

Steps

- Attain landowner approval for restoration work.
- Engage with stakeholders and experts to discuss intent and seek assistance with methodology (see Appendix 1, Habitat Improvement Working Group's Draft Guiding Principles for Clearing Work, Oct 1, 2017).
- Assess the site for safe clearing.
- Conduct habitat enhancement.
- Report results.

Methods

Site assessment was conducted on the same day of clearing efforts on October 29th 2021, both on the ground and via helicopter. The following factors were considered during pre-work assessment surveys:

- **Site safety**: Site-specific hazards, approach and egress routes, landing spots, muster points, hiking route from landing spot.
- **Scope of work**: Designated priority work areas appropriate for a 4-person clearing crew, determined need for mitigation actions (10 m buffers and “no-go” zones) and high priority cutting zones with colour-coded flagging.

Note: A site assessment of another sublocation on P Mountain (Northwest Meadow) was completed to determine the scope of work available and priority work areas for a large crew with chainsaws. While clearing efforts are set to occur in the following years, we found it useful to determine the status of restoration work available at this sub-location for future planning. The NW meadow is of particular concern due to heavy tree encroachment at its western edge; however, it was not the focal site for this year’s efforts at P Mountain due to crew size restrictions (Figure 3).

Site Assessment

Due to an absence of stands near known marmot habitat features, the crew decided to forego mitigation efforts (see Objective #2). A distance of at least 50 m between marmot burrows used by residents this year and our priority working areas was enough to determine mitigation efforts were not needed. This included the delineation of buffer zones, “no-go” zones, and marmot habitat features.

Prioritized work areas were delineated with green flagging. Priority work areas were defaulted to the two lone stands within the main meadow. These two stands were identified as high priority as they were the only trees within the sub-location. While relatively small, these two stands took preference over trees at the western peripheral edge of the main meadow due to their potential to encroach on marmot burrows the fastest (Figure 2).

This site did not host suitable locations for burn piles for burning the following year. As a result, the decision was made to lay and organize branches flat along the ground within forested areas to avoid creating additional stalking cover.

Site Clearing

Site clearing was completed on October 29th 2021, with a brushing crew of 4 personnel (all Marmot Recovery Foundation crew members). The day began with a safety briefing at the helicopter pick up site regarding all site-specific hazards and PPE required. Approach was via helicopter, and a full helicopter safety briefing regarding entering/exiting, gear loading, no-go zones, etc. were provided by the pilot.

Upon arrival to the site, a discussion of priority areas was conducted, and a group decision to forego mitigation actions was made, both of which outlined within the Site Assessment above. Due to time constraints, the crew was unable to clear both stands. As a result, the largest stand was prioritized. All trees less than 15 cm DBH were removed, using a combination of bowsaws, folding handsaws, and loppers. Trees greater than 15 cm DBH were limbed up to a height of 120 cm. Large, down-sloping limbs were observed to still obstruct sightlines even if above the 120 cm cut-off. Such limbs were removed where safe and reasonable to do so.

Directed clearing efforts:

- **West Stand #1:** This stand consisted of 5-10 large trees with dense, low-lying branches. Many of these large branches were undergoing "layering", wherein vegetative reproduction allows for branches to take root if low enough. As a result, there was a very dense sapling layer, formed by a mixture of layering branches, as well as natural regeneration (Figures 4 and 5). This patch of trees is located halfway down the main meadow on its western edge. It is the closest and largest stand to the known marmot habitat features, therefore has high potential to expand eastwards and further reduce sightlines. As well, it blocks sightlines towards a forested, descending ridgeline along the western perimeter of the main meadow. We found it vital to take a proactive approach in preventing encroachment before it seriously degrades sightlines. An estimate of 30-40 saplings were removed (5-10 cm diameter), as well as the lower limbs of 6 larger trees (>15 cm diameter). As a result of clearing activities, sightlines to the western perimeter have been restored and future encroachment has been mitigated (Figures 6 and 7).

Results/Outlook

While clearing efforts were limited to one stand, this year's efforts have strong potential to improve sightlines for resident marmots emerging from hibernation next year. Sightlines to the western edge of the main meadow are restored, allowing marmots to see as far as possible throughout the main meadow. Due to the slow growth of trees at this elevation, it is expected that the effects of habitat improvement should last for at least 10 years (Lester 2017). As identified within the Site Assessment section above, the NW meadow should be the focus of next year's restoration efforts. This sub-location will require a larger crew with chainsaws, as there is an extensive stand of young trees that has encroached into the western half of the meadow (Figure 8).

Acknowledgements

Thank you to the awesome crew of brushers for yet another great day in the mountains. Thank you to Shayn McAskin, Savita Owens-Frank, and Emily Wharin! As well, thank you to Cheyney Jackson for your tireless dedication to getting us all out for a fun and safe workday in the mountains.

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References

Lester, M. (2017). Vancouver Island Marmot Habitat Improvement 2017 – Mt. Hooper – Southwest Meadow. Marmot Recovery Foundation.

Figures

Figure 44 P Mountain Main Meadow – Prioritized stands for restoration activities October 29 2021. The larger stand of the two was cleared on clearing day. All marmot habitat features on the eastern edge of meadow, in direction of orange arrow. Descending stand of trees on left of image (west periphery of main meadow) would have been an additional option to clear, but the stands encircled in green were of highest priority. Photo by Savita Owens-Frank.

Figure 45 P Mountain – NW Meadow. Proposed focal site for restoration activities on P Mountain in following years, encircled in green. Photo by Shayn McAskin.

Figure 46 P Mountain Main Meadow – West Stand #1, pre-work photo. Note stand of taller trees filled in with darker, young trees. Photo by Shayn McAskin.

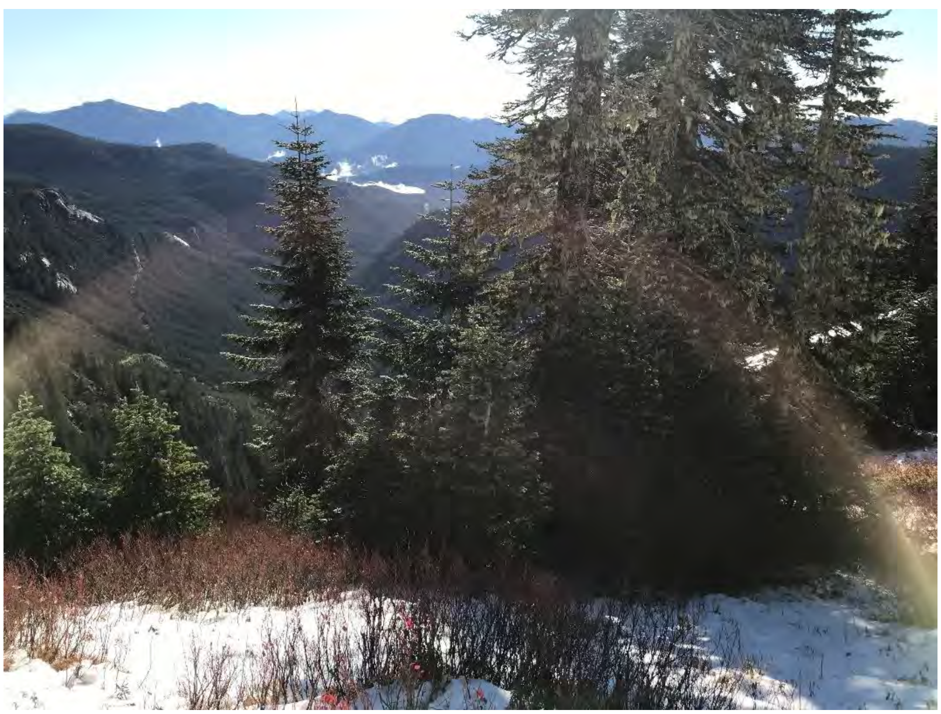

Figure 47 P Mountain Main Meadow – West Stand #1, pre-work photo, close-up. Photo taken looking south. Note stand of taller trees filled in with darker, young trees. Photo by Chelsea Brager.

Figure 48 P Mountain Main Meadow – West Stand #1, post-work overview photo. Photo taken looking northwest. Note that only large trees remain. Photo by Shayn McAskin.

Figure 49 P Mountain Main Meadow – West Stand #1, post-work close-up photo. Photo taken looking east. Note that only large trees remain. Photo by Chelsea Brager.

Figure 50 P Mountain NW Meadow – Pre-photo of high priority stand for future clearing efforts. Note dense stand of trees encroaching towards the centre right of the meadow, encircled in green. Would be suitable for a large crew with chainsaws. Photo by Chelsea Brager

Figure 51 P Mountain Clearing Crew on October 29th 2021. Photo by Andy, our helicopter pilot.

Mount McQuillan – Main Meadow Vancouver Island marmot Habitat Improvement 2021

Report composed by Kevin Gourlay and Mike Lester

Location

Mt. McQuillan (1570m) is located 20km southeast of Port Alberni and 50km west of Nanaimo (Figure 1). The main meadow (1400-1480m) is a large shelf on the eastern aspect of the southern ridge with patches of heavy talus, large areas of meadow filled with herbaceous vegetation, and several intermittent patches of coniferous tree stands. The lower border of the meadow is defined by more dense coniferous vegetation and a steep drop off to the lowlands below.

Background

The invasion of trees into open marmot habitat has been associated with climate change and is a concern because marmots rely on open habitat to detect and avoid approaching predators. Tree ingress has occurred in the McQuillan main meadow at various location, likely contributing to the success of predators hunting marmots in this area; cougar scat containing marmot remains has been observed on game trails immediately adjacent to marmot habitat in the main meadow. Removal or reduction of the amount of stalking cover provided by invading trees should increase the annual survival rates of colony residents, thereby improving colony persistence and supporting the regional population.

Objectives

- Protect important marmot habitat features (hibernacula and well-established burrows).
- Remove ingrowth of younger trees and prune the lower branches of older trees in the Mt Douglas main meadow to reduce local predation risk for Vancouver Island Marmots.
- Document the work to measure success and guide similar projects in the future.

Steps

- Attain approval from landowners for improvement work.
- Engage with stakeholders and experts to discuss intent and seek assistance with methodology (see Appendix 1, Habitat Improvement Working Group's Draft Guiding Principles for Clearing Work, Oct 1, 2017).
- Assess the site for safe clearing.
- Conduct habitat enhancement.
- Report results.

Methods

The site was assessed from the air and on the ground immediately prior to clearing work on October 29, 2021. During the initial survey the following factors were assessed:

- Site safety: Approach and egress, evacuation routes, helicopter access, site hazards.
- Delineation of exclusion zones around known marmot hibernacula and other marmot features using colour coded biodegradable flagging tape.

- Identification of highest priority zones and scope of work achievable with a small clearing team.

The site was accessed via helicopter and habitat improvement work was conducted on October 29, 2021 with a team of five crew members. Personnel included one Marmot Recovery Foundation crew member, one BC Wildfire Service crew member who operated a power saw, and three independent contractor who all use hand tools. BC Wildfire Service lead, Derek Rushton, provided a safety briefing, after which crew conducted a safety assessment and thorough site inspection. Field crew then identified trees close to known hibernacula and established burrows. A 10-metre exclusion zone from any known hibernacula or burrow was measured with a survey tape and flagged. Trees within the exclusion zone were not removed or modified. Trees and limbs of the largest trees in the targeted removal zone were cut with a chainsaw. Further trimming was conducted with bowsaws and loppers. Some cut woody debris was moved to the sides or bottom of the meadow and spread out where possible, while the remainder was spread out where it was cut.

The decisions on where to leave cut woody debris were based on:

- ensuring no burrows or hibernacula were obstructed;
- ensuring no marmot foraging areas were covered;
- avoiding the creation of piles of woody debris which could have increased fire risk and also served as new sources of stalking cover;
- landowner preferences; and
- site-specific context. The large size of the meadow and sitance from the tree stands to the perimeter of the meadow largely inhibited dragging cut woody debris out of the meadow. Instead, cut debris was spread out evenly across areas adjacent to tree stands and, where possible, place in depressions and low areas to avoid the creation of new stalking cover.

Clearing effort was directed at two main stands of trees, one in the middle of the main meadow and the second above a pinch point on the lower north side of the meadow where marmots were observed travelling through to reach a talus field on the opposite side (Figure 2). Habitat improvement within these areas was conducted as follows:

- Mid meadow – Mountain hemlock and yellow cedar (5-25cm diameter). This zone contained multiple connected stands of young and older conifers directly adjacent to multiple marmot burrows and high-quality marmot foraging habitat (Figure 3). As such, it contained the largest amount of stalking cover within the meadow itself and represented the highest priority for habitat improvement effort. Many small trees were removed and several of the larger trees (>20cm at chest height) were limbed (Figure 4 and 5).
- Lower north stand – Mountain hemlock and yellow cedar (10-30cm diameter). This stand was the largest group of conifers close to marmot habitat and created a pinch point for marmots traveling between the main meadow and the lower north talus. Marmots (adults and pups) were also observed sunning and foraging near a burrow directly adjacent to the stand in 2021. One burrow exclusion zones around this location prohibited the cutting of some trees in this stand. As the stand was large and the terrain became very steep within the stand, clearing effort

was concentrated on the periphery where marmots were most likely to be near stalking cover. Many of the trees were larger than 20cm in diameter at chest height and therefore were delimbed up to head height. Considerable improvement was nevertheless observed in terms of sightlines throughout the stand for any potential marmots using the adjacent marmot infrastructure (Figures 6, 7, 8, 9).

Results/Outlook

Marmots emerging from the known hibernacula and associated burrows now have clear sightlines to most of the meadow to detect and alert other marmots to the approach of predators. Due to the slow growth of trees at this elevation, it is expected that the effects of habitat improvement should last for at least 10 years. It should be noted that multiple sublocations on the west side of the ridge were observed to support marmots in 2021, including a pup litter and several yearlings. As this was out of the scope of a single days effort with a small crew, the west side of the ridge is recommended as a location that could benefit greatly from future habitat improvement efforts (Figures 10 and 11).

Acknowledgements

Thank you to Derek Rushton of the BC Wildfire Service for his professional and safety minded approach, and chainsaw operating skills. Thank you to Caleb McIntyre, Sam Simard-Provencal, and Jessie Mayes for their dedicated work ethic using hand tools to remove considerable amounts of vegetation from marmot habitat (Figure 12). Thank you to the Habitat Stewardship Program for species at risk for providing funding for the project. Thank you to West Coast Helicopters and pilot Andy Hatfield for getting the crew safely in and out of the site and assisting with the arial survey. Thank you to the private landowner, Mosaic, for their permission and assistance in accessing the site and conducting this work.

Figures

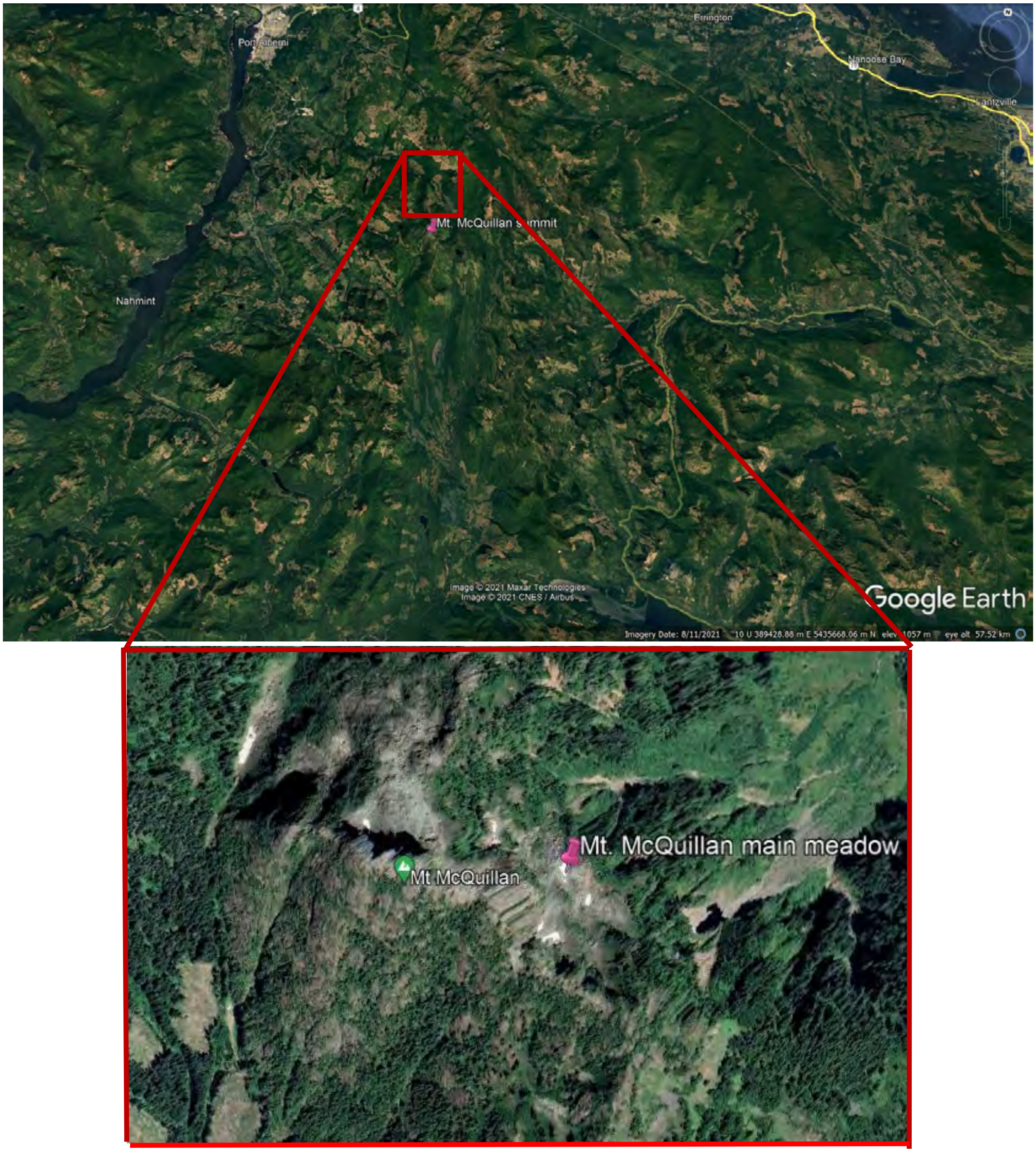

Figure 52 Location of McQuillan

Figure 53 Aerial photo of main meadow on Mt McQuillan (pre-habitat improvement) showing clearing effort by area (red ovals) and location of primary marmot burrow exclusion zones (yellow circles). Photo by Kevin Gourlay.

Figure 54 Photo of mid-meadow tree stand (pre-habitat improvement), showing tree ingress into marmot foraging habitat. Photo by Derek Rushton.

Figure 55 Photo of mid-meadow tree stand (post- habitat improvement) with Derek Rushton in background, showing improved sight lines. Photo by Kevin Gourlay.

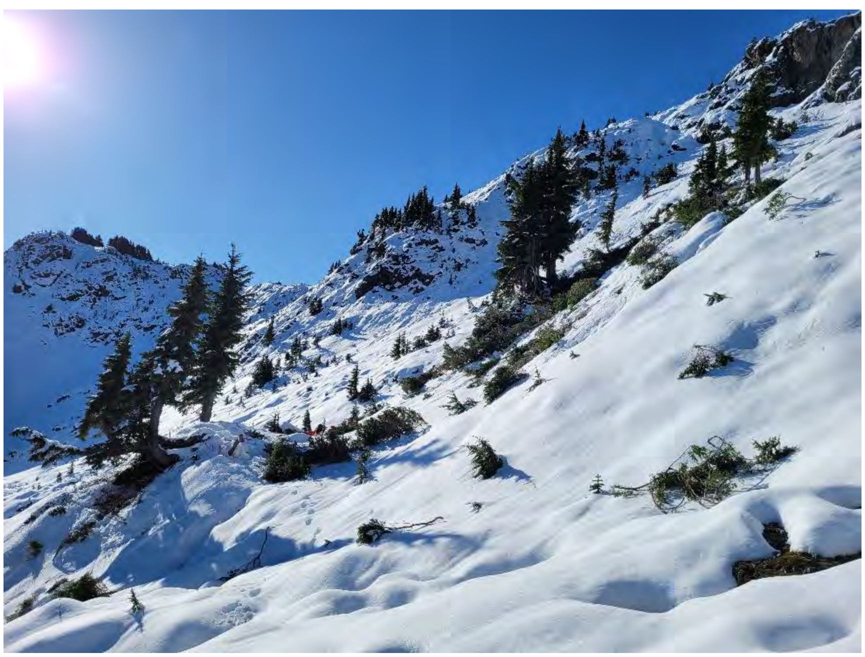

Figure 56 Photo of mid-meadow tree stand (post- habitat improvement), showing extent of habitat improvement work. Photo by Kevin Gourlay.

Figure 57 Photo of side of lower north stand (post-habitat improvement) taken from near burrow entrance showing improved sight lines. Photo by Derek Rushton.

Figure 58 Photo of top of lower north stand (post-habitat improvement) showing improved sightlines from burrow entrance. Photo by Derek Rushton.

Figure 59 Photo of bottom of lower north stand (pre-habitat improvement). Photo by Kevin Gourlay

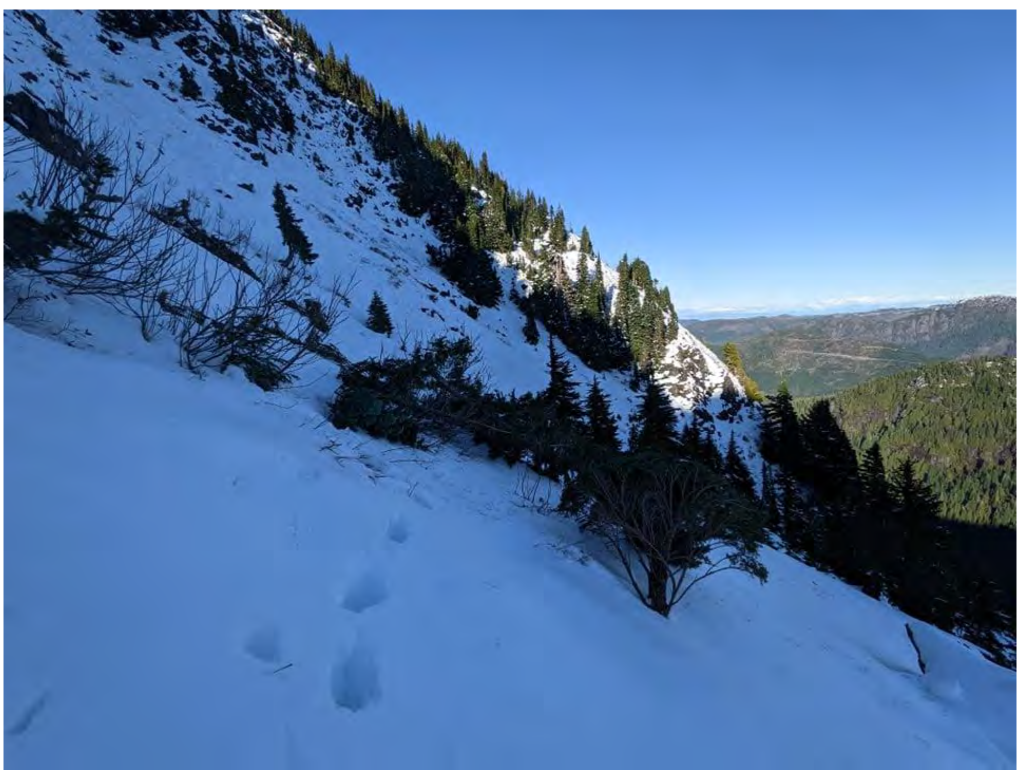

Figure 60 Photo of bottom of lower north stand (post-habitat improvement). Photo by Derek Rushton.

Figure 61 Aerial photo of west side of the ridge (looking southeast) showing tree ingress into meadow. Recommended location of future habitat improvement effort. Photo by Kevin Gourlay.

Figure 62 Aerial photo of west side of ridge (looking northeast) showing tree ingress into meadow. Recommended location of future habitat improvement effort. Photo by Kevin Gourlay.

Figure 63 Mt McQuillan clearing crew. Left to right: Caleb McIntyre, Derek Rushton, Sam Simard-Provence, Jessie Mayes, and Kevin Gourlay. Photo by Kevin Gourlay.

Mount Moriarty – Main Meadow Vancouver Island marmot Habitat Improvement 2021

Report composed by Chelsea Brager and Mike Lester

Site Background

Moriarty Mountain is a large, prominent summit (1603 m) located 23 km west of Parksville, BC within the *M. vancouverensis* Nanaimo Lakes metapopulation. Our focal site is the main meadow, the largest of several micro meadows featured on Mount Moriarty. This site is a heavily treed, southwest facing meadow within the Mountain Hemlock Biogeoclimatic Zone (MHmm1).

Most of the meadow is already encircled by contiguous subalpine forest, making sightline reduction by tree encroachment highly risky to resident marmots. Within proximity to 3 well-used hibernacula is the tailing edge of a large contiguous subalpine forest on the southern edge of the main meadow. Several mortalities have been documented at the entrance of one of three hibernacula. Remote camera footage from the 2021 field season confirmed predator use of the nearby trees, revealing a cougar's ability to stalk right up to the hibernaculum entrance itself. As a result, restoration efforts are imperative to mitigate any future mortalities, particularly those at close proximity to marmot habitat features.

Objectives

- **Increase sightlines from known marmot habitat features such as hibernacula and well-established burrows, through manual tree removal in designated high priority stands.**
    - *Measurable objectives include* the removal of young trees (<15 cm DBH) and pruning of lower branches below 120 cm in height on larger trees (>15 cm DBH) by hand. Removal of large trees (>15 cm DBH) is permissible by use of chainsaw where safe to do so.
    - *Site-specific high priority stands* – one large band of trees extending downslope at the southern edge of the main meadow, focusing on patches nearest (but outside 10 m buffers) to the 3 hibernacula.
- **Mitigate harm to known marmot habitat features during restoration activities.**
    - *Harm may be defined as* the loss of trees providing structural support to marmot features, loss of upslope trees that shelter marmot features from avalanche activity, and the loss of important spring foraging resources through the removal of non-arboreal shrub and tree species.
    - *Identified mitigation actions* include the establishment of 10m (minimum) buffer zones around known marmot habitat features (hibernacula and burrows) and the delineation of "no-work" zones around tree stands upslope from marmot habitat features.
- **Document the work to measure success and guide similar projects in the future (Lester 2017)**

Steps

- Attain landowner approval for restoration work.
- Engage with stakeholders and experts to discuss intent and seek assistance with methodology (see Appendix 1, Habitat Improvement Working Group's Draft Guiding Principles for Clearing Work, Oct 1, 2017).
- Assess the site for safe clearing.
- Conduct habitat enhancement.
- Report results.

Methods

Site assessment was conducted on the ground and by helicopter on the same day of clearing efforts (November 1st 2021). The following factors were considered during pre-work assessment surveys:

- **Site safety**: Site-specific hazards, approach and egress routes, landing spots, muster points, hiking route from landing spot.
- **Scope of work**: Designated priority work areas appropriate for a 5-person clearing crew with a chainsaw, delineated mitigation actions (10 m buffers and "no-work" zones) and high priority cutting zones with colour-coded flagging.

Site Assessment

To follow the restoration project's objective #2, 10 m buffer and "no-work" zones around known marmot habitat features were first established.

This began by flagging known marmot habitat features to identify points to measure from. Two out of three hibernacula required buffer zones. Using survey tape and yellow flagging, the crew formed a 10 m buffer encircling each habitat feature. Yellow flagging signalled brushers not to cut and limb trees within the flagged circle.

Following this, "no-work" zones were then established. Any stand of trees upslope from marmot features were secluded from restoration efforts. Due to the presence of an extensive cliff band directly above the hibernacula, there were no high priority trees upslope from features that could be cut. As a result, the crew decided on foregoing the delineation of "no-work" zones.

Prioritized work areas were delineated with green flagging. A single, large stand was identified as high priority for the main meadow. Located along the southern edge of the sub-location, this descending patch of trees was directly adjacent to three hibernacula (Figure 2). Wherever trees lay outside the 10 m buffer zones, restoration goals for the day were to cut from this point southward. A small micro-meadow exists on the opposite side of this stand, so long-term restoration goals could be to eventually connect the main meadow with isolated micro-meadows.

This site did not host suitable locations for burn piles for burning the following year. As a result, the decision was made to lay and organize branches flat along the ground within forested areas to avoid creating additional stalking cover.

Site Clearing

Site clearing was completed with a brushing crew of 5 personnel, one of whom was clearing with a chainsaw (all Marmot Recovery Foundation crew members). The day began with a safety briefing at the helicopter pick up site regarding all site-specific hazards and PPE required. Approach was via helicopter, and a full helicopter safety briefing regarding entering/exiting, gear loading, off-limit areas of the helicopter, etc. were provided by the pilot.

Upon arrival to the site, a discussion of priority areas and mitigation actions was conducted. For manual removals, all trees less than 15 cm DBH were removed, using a combination of bowsaws, folding handsaws, and loppers. Trees greater than 15 cm DBH were limbed up to a height of 120 cm. Large, down-sloping limbs were observed to still obstruct sightlines even if above the 120 cm cut-off. Such limbs were removed where safe and reasonable to do so. For chainsaw removal, trees too large for manual clearing were removed, where safe and reasonable to do so. Extent of work was highly limited by weather window availability for helicopter access. As a result of this, there is still work available in this stand for future years (Figure 2).

Directed clearing efforts:

- **South Stand:** This stand consisted of over 30-50 large trees, all with dense, low-lying branches. This patch of trees was fully closed in by a dense sapling layer (Figures 3, 5, and 7). The priority for this stand was to thin tree cover near hibernacula sunning rocks and entrances, as well as thin branches and trees at mid-torso height, to allow resident marmots the chance to detect predators from a further distance. Due to weather and time restrictions, only 2 out of 3 hibernacula were cleared (Figure 2). The third, uncleared hibernaculum was secluded from restoration efforts as it hosted the longest sightlines, whereas the upper two hibernacula were completely closed in and were mortality sites. An estimate of >100 saplings were removed (5-10 cm diameter), as well as ~50 large trees limbed and/or removed (>15 cm diameter). As a result of clearing activities, sightlines have been increased dramatically, particularly from the marmot habitat features themselves (Figures 4, 6, and 8).

Results/Outlook

Due it's proximity to several marmot habitat features and confirmed predator-caused mortalities at hibernaculum entrances, this stand required immediate restoration action. Despite limitations in weather windows, this year's effort has strong potential to mitigate mortalities at and/or near the main meadow's hibernacula for the upcoming growing season. Sightlines that were once only 0-5 m from the entrance of the two hibernacula have been expanded to roughly 20-30 m through the thinning of low-lying branches and thick sapling layers. Due to the slow growth of trees at this elevation, it is expected that the effects of habitat improvement should last for at least 10 years (Lester 2017). For future restoration projects on Mount Moriarty, it is recommended to continue thinning this stand to improve connectivity between the main meadow and isolated micro-meadows. As well, it is recommended to manage young trees around the lower third hibernaculum in the main meadow that did not receive treatment this year.

Acknowledgements

Thank you to the awesome crew of brushers for yet another great day in the mountains. Thank you to Shayn McAskin, Savita Owens-Frank, Emily Wharin, and Derek Rushton! As well, thank you to Cheyney Jackson for your tireless dedication to getting us all out for a fun and safe day of work in the mountains.

Thank you to our funders, Environment and Climate Change Canada's Habitat Stewardship Program, and the private landowners, Mosaic for the opportunity.to complete this project.

We would like to express our gratitude to work and learn on the unceded, occupied territories of the sovereign Snuneymuxw, Snaw-Naw-As, Stz'uminus, as well as the traditional homelands of the Mid-Island Metis Nation.

References

Lester, M. (2017). Vancouver Island Marmot Habitat Improvement 2017 – Mt. Hooper – Southwest Meadow. Marmot Recovery Foundation.

Figures

Figure 64 Mount Moriarty Main Meadow – high priority areas. Areas in orange circles represent 3 well-used hibernacula. Prioritized work area is encircled in green, a descending patch of trees that is growing very closely to 2 well-used hibernacula in the main meadow. The patch of trees encircled in blue is a suitable area to prioritize in future restoration efforts to promote connectivity between the main meadow and isolated micro-meadows, as well as to manage stands near the third hibernacula that was not treated this year due to time and weather constraints. Photo by Shayn McAskin.

Figure 65 Mount Moriarty Main Meadow – Pre-clearing close-up shot, taken from upper hibernaculum, looking west downslope. Photo by Chelsea Brager.

Figure 66 Mount Moriarty Main Meadow – Post-clearing close-up shot. Taken from upper hibernaculum looking west, downslope. Photo by Chelsea Brager.

Figure 67 Mount Moriarty Main Meadow – Pre-clearing close-up shot. Taken from upper hibernaculum looking south, across slope towards contiguous subalpine forest. Photo by Chelsea Brager.

Figure 68 Mount Moriarty Main Meadow – Post-clearing close-up shot. Taken from upper hibernaculum looking south, across slope towards contiguous subalpine forest. Photo by Chelsea Brager.

Figure 69 Mount Moriarty Main Meadow – Pre-clearing close-up shot. Taken from upper hibernaculum looking southwest. This hibernaculum was a confirmed mortality site. Photo by Chelsea Brager.

Figure 70 Mount Moriarty Main Meadow – Post-clearing close-up shot. Taken from middle hibernaculum looking southwest. This hibernaculum was a confirmed mortality site. Photo by Chelsea Brager.

Figure 71 Mount Moriarty Clearing Crew November 1st 2021 group photo. From left to right: Derek Rushton, Shayn McAskin, Savita Owens-Frank, Emily Wharin, and Chelsea Brager. Photo by Chelsea Brager.

Measuring Change in Target Colonies – Tree Growth Assessment

A total of 9 of 29 colonies were chosen for an assessment of tree growth between present-day and historical imagery. This included 2 colonies from the Strathcona metapopulation, and 7 colonies from the Nanaimo Lakes metapopulation. A full list of sites is available in Appendix B. These sites were prioritized based on anecdotal observations of heavy tree growth, growing predation rates, as well as recorded evidence of predations within marmot habitat. Additionally, many of these sites are difficult to access for restoration activities due to jurisdictional restrictions. The purpose of this section is to systematically assess tree ingress using repeatable methodology to facilitate discussion of habitat restoration needs and priorities.

Tree growth within marmot habitat was assessed by estimating relative change in average tree cover percentages between present-day and historical imagery. In addition to this, two qualitative metrics of tree growth were estimated where imagery resolution allowed. This included canopy closure and tree ingression and are meant to be treated as observations taken during the quantitative assessment. The goal of this is to further augment recommended priority areas for future restoration projects.

Methods

Imagery Acquisition

Historical imagery was acquired through GeoBC's air photo database, with a goal of obtaining the earliest possible photo available for each sub-location. Images would have been ideally taken between the 1930's – 1950's. Steps to acquiring historical imagery from GeoBC's historical flightline index maps was followed using GeoBC's *Historical Airphoto Indices for British Columbia* document (GeoBC 2015). Spatial data for each selected marmot colony was uploaded into Google Earth from the Foundation's Inventory (Google Earth 7.3.4.8248 (64-bit). This includes waypoints on known marmot habitat features and recovered mortalities. An image of this spatial data with present-day imagery from Google Earth as a base map was taken. This information will help locate sub-locations when index maps are uploaded into Google Earth, as well as provide comparisons post-analysis on the proximity of new tree growth to marmot mortality locations and marmot habitat features. Spatial data was organized per sub-location of each colony.

After uploading spatial data, a central coordinate was acquired in latitude/longitude format for each sub-location. This central coordinate was inputted using the latitude/longitude search method on GeoBC's Imagery Finder. Results were filtered by inputting the desired timeframe and largest possible scale to assure high resolution. GeoBC's earliest photos available with the finest detail fall within the timeframe of 1946 to 1957 at a medium scale of 1:31,680 to 1:40,000 (GeoBC 2015). Search results yielded original maps of air photo flightlines per sub-location and were then uploaded into Google Earth as KML files.

Once the index map has been uploaded into Google Earth and the desired sub-location was located, the frame/roll combination closest to the target sub-location was selected. Frame/roll combination selection was selected by ensuring all sub-locations of each colony, and if not possible, prioritized sub-locations of each colony would be covered in each photo. Where colonies fall between each 10^{th} plotted coordinate, the closest frame number was interpolated. According to GeoBC, there is an overlap of each individual image about 60% forward along the flightpath, and 20-30% laterally between flightpaths (GeoBC 2015).

These steps were repeated for all 9 target colonies, where suitable historical imagery was available in the GeoBC database. Once all frame/roll combinations were acquired, an order for digital scans was placed using GeoBC's Base Map Online Store using the instructions on page 4 of GeoBC's *Historical Airphoto Indices for British Columbia* document (GeoBC 2015). All digital scans were requested as a digital TIFF file within the order form, rather than the default option of receiving a physical CD. Google Earth satellite imagery was used as present-day imagery for all analyses, ranging between the years of 2016-2018 depending on suitability. This included considerations of snow cover and shading at the sub-location level.

Image Overlay

Overlay occurs per sub-location within each colony. The colony's associated TIFF file was uploaded to Google Earth as a new layer using the Image Overlay tool. Following this, a series of landmarks[1] (where available) were searched for by comparing common terrain features within the historical and present-day image. After suitable landmarks have been identified, the position and rotation of this landmark within the historical image was adjusted to match that of the present-day image. Adjusting the opacity of the historical image to 50% was exceptionally helpful in aligning landmarks. This was completed using the opacity tool within the Image Overlay layer properties. Opacity was reverted to 100% once landmark matching was complete.

The following conditions were considered while overlaying a historical image to determine whether it is appropriate for comparison with present-day imagery:

- Does the image include all sub-locations of the target colony?
    - If no, are the prioritized sub-location(s) within the target colony included?
- At the sub-location scale, is there an unreasonable level of warping within the image?
- Is the image properly exposed? (i.e. no overexposure leading to an inability to see terrain or forested areas)
- How much snow is present around the sub-locations to be analyzed? Is there too much snow to appropriately compare with present-day imagery?

As a result of these conditions, not all sub-locations of each target colony (and even, not all colonies) were able to undergo analysis. Refer to Appendix B for a full list of analyzed colonies and sub-locations. Once all images have been inspected and suitable sub-locations have been chosen for analysis, a polygon was drawn per sub-location using the "Add Shape" tool in Google Earth. Polygons were drawn using the historical boundaries of upper and lower treelines around the sub-location. This was completed with the historical image layer turned on at full opacity, tracing the treelines that determine the shape of the sub-location during that particular year. Once polygon drawing was complete, the

[1] Landmarks = unchanging terrain features that are present in both the historical and present-day image that may be used as reference points to overlay two images of the same location. Examples include lakes, well-established gully systems, or ridgelines.

polygon was edited by opening the “Altitude” tab within layer properties. On the drop-down menu to the right, the altitude option “Relative to Ground” was selected. The altitude height was then adjusted to a suitable height at which the polygon may be viewed fully above the image overlay. Under the “Style, Cover” tab within the layer properties, the outline and area colours were adjusted to the colony’s colour-code (Appendix B). Within this same tab, the drop-down menu under the “Area” section was changed to “Filled+Outlined” and Opacity set to 45%. For some historical imagery in which exposure was higher than average, opacity was set to 15%. In some circumstances the polygon was not filled in at all.

Imagery Analysis

Imagery analysis began once historical and present-day imagery were properly overlaid at the sub-location level, with polygon layers visible. The sub-location for analysis was positioned so the viewfinder can showcase the entire area. Using Google Earth’s “Save Image” tool, two images at the same scale were created; one with the historical image overlay layer turned on, and one with that same layer turned off.

These images were then uploaded into Microsoft Paint to divide sub-locations into quadrants. The orientation of the division of sub-locations into quadrants depended on the shape of the sub-location’s polygon. For larger sub-locations, 4 quadrants were used. Using the “Cover Estimator” (Appendix C) as a guide for estimating percentage tree cover, a value between 0-100% was given to each quadrant for both historical and present-day imagery. Tree cover percentages were averaged across all quadrants for both the historical and present-day imagery. Average change in tree cover percentages between historical and present-day imagery was calculated in relative terms, using the following formula:

$$\mathbf{(x^2 - x^1) / x^2 * 100 = \text{average relative change in tree cover \%}}$$

After this, historical and present-day imagery were qualitatively compared for observational change in tree ingression[2] and canopy closure[3] between the same quadrants. It is important to note that this is a qualitative metric of tree growth, with the goal of providing commentary on the spatial distribution of changes in tree growth in relation to the changes in percent tree cover, and to further supplement recommendations for future restoration actions. This was repeated for all quadrants for each sub-location. Sub-locations were ranked on a scale of minimal, moderate, and heavy tree ingression/canopy closure, based on the approximate visuals provided in Appendices E and F. Using a combination of quantitative and qualitative changes in tree growth, location of known marmot habitat features, and anecdotal experience from the 2021 field season, a recommendation of where to focus future restoration efforts was made.

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[2] Tree ingression: Early stages of treeline expansion, suggested by the presence of scattered young trees extending from a forest edge. Can also result in the movement of treelines or expansion of larger patches of forest.
[3] Canopy closure: Infilling of pre-existing forest stands, creating more dense patches of trees. Can be inferred by darkening of pre-existing patches of trees in image, or the infilling of meadows between forest patches.

Results

Mount Arrowsmith – South Meadow

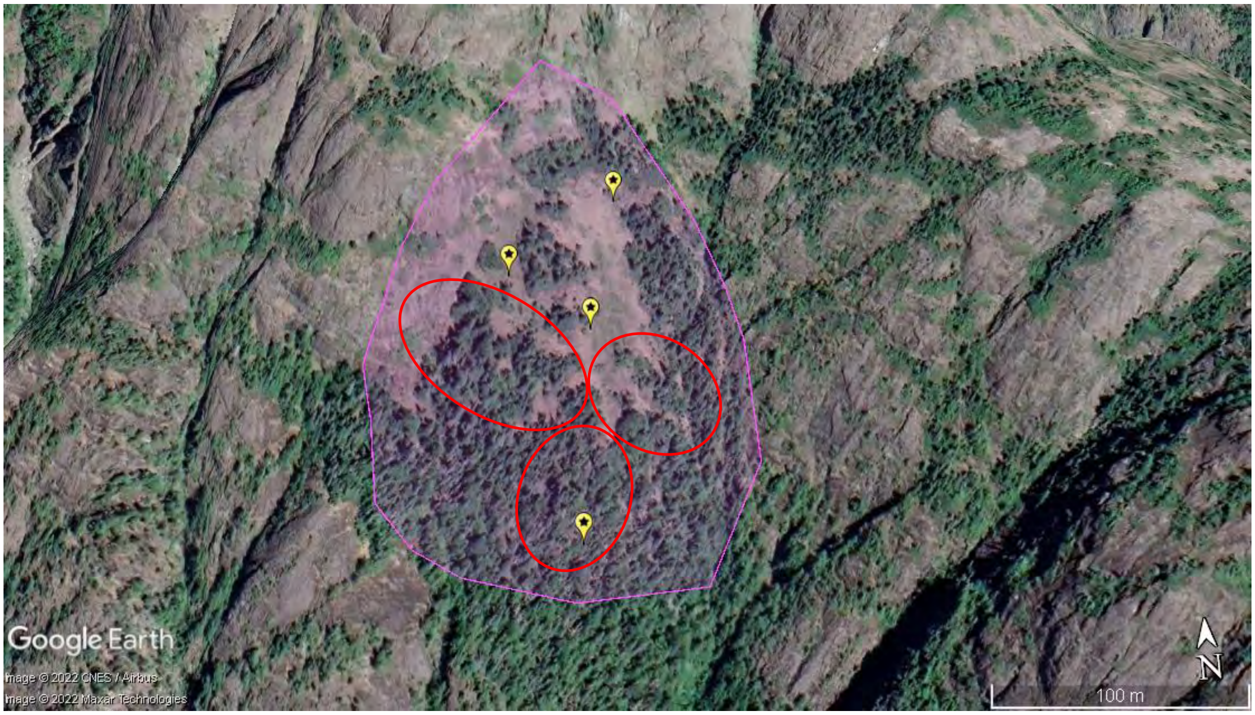

Figure 72 Mount Arrowsmith's South Meadow present-day imagery with marmot habitat features and recommended areas for restoration circled in red (Google Earth Pro (A) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 68% between 1949 to 2016. The most dramatic changes occurred within the largest stand of trees located at the bottom of the comparison polygon, as well as some changes to the riparian zone of the central gully in Quadrant B (Figure 3). 1949 imagery of Quadrant B suggests that tree ingression was already well underway within a large patch of open forest (Figure 3). In contrast to this, tree ingression is comparatively minimal in the 1949 imagery of Quadrant A (Figure 3). The mismatch in tree growth patterns within 1949 explains why Quadrant B is dominated by a large, high-density forest with considerable canopy closure in 2016 while Quadrant A in 2016 still reveals patterns of ongoing tree ingression (Figure 3). Nonetheless, areas that were initially scattered trees are now dense forest patches, and areas that were once meadow are now encroached by scattered trees.

Priority actions for a future restoration project at Mount Arrowsmith's south meadow could be selective thinning within and along the periphery of existing meadow habitat (Figure 2). Thinning smaller patches of trees near marmot habitat features within the meadow could help restore sightlines, as this area was historically open meadow. Additionally, selective thinning at the periphery of pre-existing meadow habitat, particularly along the treelines of contiguous forest within the lower half of the sub-location, could help lengthen sightlines into areas where terrestrial predators may be sourced from (Figure 2).

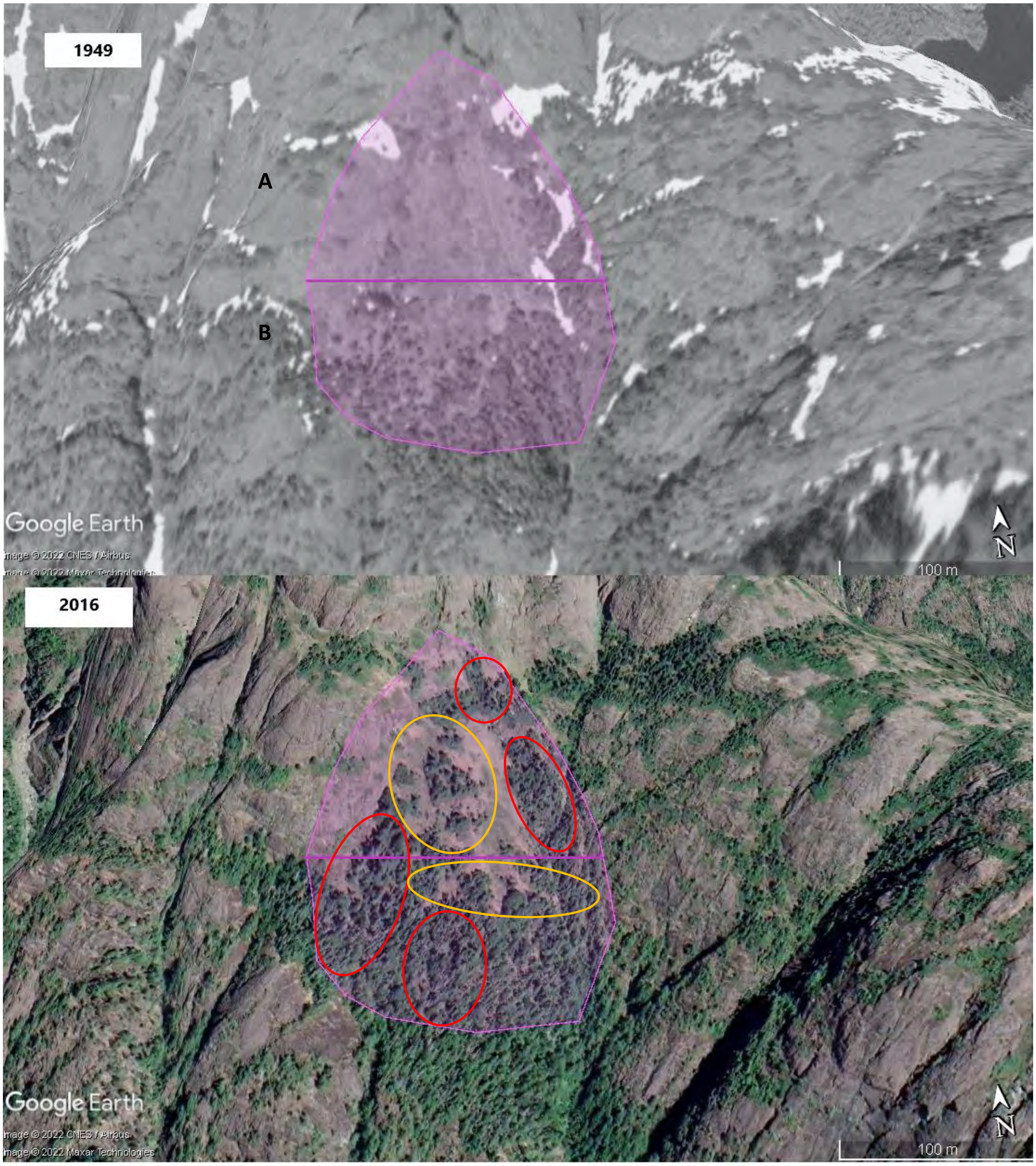

Figure 73 Mount Arrowsmith's South Meadow Analysis Quadrants. ***.*** *Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (A) 7.3.4.8248 (64-bit) 2016); (GeoBC Mount Arrowsmith Massif Regional Park 2021)).*

Table 1. *Mount Arrowsmith's South Meadow Analysis Results – Estimated % Tree Cover.*

Mount Arrowsmith South Meadow	Estimated % Tree Cover
Quadrant A (1949)	15%
Quadrant A (2016)	60%
Quadrant B (1949)	30%
Quadrant B (2016)	80%
1949 Average % Tree Cover: 22.5 %	
2016 Average % Tree Cover: 70%	
Relative change in Average % Tree Cover: 68% increase	

Table 2. *Mount Arrowsmith's South Meadow Analysis Results – Observations on changes in tree growth patterns.*

Mount Arrowsmith South Meadow	Canopy Closure?	Tree Ingression?
Quadrant A 1949 - 2016	Changes in canopy closure was heavy between 1949 and 2016. Abrupt transition from open meadow with virtually no canopy cover in 1949 to the expansion of larger forest patches scattered throughout the meadow.	Changes in tree ingression between 1949 and 2016 was heavy. A significant amount of trees have travelled upslope within the meadow, and have formed larger patches of trees.
Quadrant B 1949 - 2016	Changes in canopy closure was heavy between 1949 and 2016. Present-day imagery suggests the potential for dramatic infilling throughout already established forest.	Changes in tree ingression between 1949 and 2016 was moderate. Upslope movement of the forest line is evident, as well as an increase in scattered trees along the forest line's periphery.

Green Mountain - Snowbowl

Figure 74 Marmot habitat features and recommended priority areas for future restoration projects circled in red at Green Mountain's Snowbowl (Google Earth Pro (B) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 47% between 1951 to 2016. In 1951 it appears that tree cover was confined to the periphery of the Snowbowl talus field, and primarily as an early successional stand of scattered deciduous trees. A major shift appears to have occurred wherein heavy levels of tree ingression has resulted in a massive upslope movement of the lower treeline across the entire sub-location (Figure 5). As well, stands appear to now be well-established mixed forests comprised of both deciduous and coniferous trees. The primary concern for this sub-location appears to be ongoing tree ingression infilling the remaining talus field, rather than canopy closure.

Suitable objectives for a future restoration project at Snowbowl could be along the bottom edge of the remaining talus field in the centre of this sub-location. This area features the leading edge of tree ingression, and thus restoration efforts can be focused on removing encroaching trees at this elevation and moving downslope into canopy closure hotspots. This could have the potential to restore sightlines in an area that was historically open talus fields, as well as address areas of potentially the fastest tree growth.

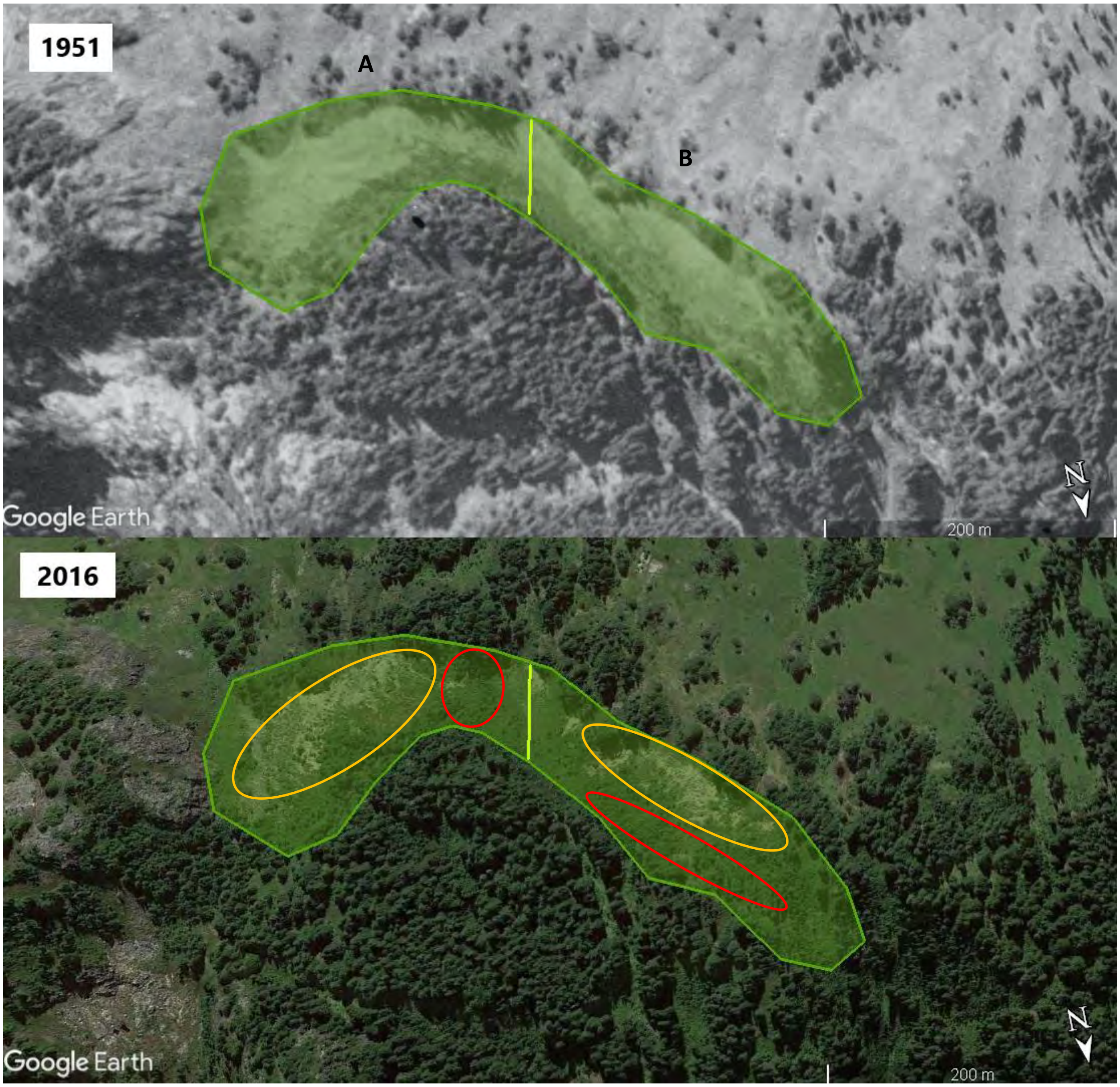

Figure 75 Green Mountain's Snowbowl Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (B) 7.3.4.8248 (64-bit) 2016); (GeoBC Green Mountain Wildlife Management Area 2021)).

Table 3. *Green Mountain's Snowbowl Analysis Results – Estimated % Tree Cover.*

Green Mountain Snowbowl	Estimated % Tree Cover
Quadrant A (1951)	15%
Quadrant A (2016)	40%
Quadrant B (1951)	20%
Quadrant B (2016)	70%
1951 Average % Tree Cover: 17.5%	
2016 Average % Tree Cover: 55%	
Relative change in average % tree cover: 68%	

Table 4. *Green Mountain's Snow Bowl Analysis Results – Observations on changes in tree growth patterns.*

Green Mountain Snowbowl	Canopy Closure?	Tree Ingression?
Quadrant A 1951 - 2016	Relatively minimal change in canopy closure between 1951 and 2016.	Changes in tree ingression between 1951 and 2016 was heavy. Present-day imagery reveals the potential for a massive upwards elevational shift to have occurred during this timeframe. As well, present-day imagery suggests a dramatic increase in density of scattered, individual trees. This has the potential to completely erase present-day talus field in the future.
Quadrant B 1951 - 2016	Changes in canopy closure between 1951 and 2016 was heavy, however this area is primarily dominated by deciduous trees. 1951 imagery suggests young deciduous trees are scattered throughout the lower half of this quadrant. This has since formed a well-established stand of mixed conifer-deciduous forest.	Changes in tree ingression between 1951 and 2016 was heavy, particularly along the lower half of the quadrant. Present-day imagery potentially suggests a dramatic upwards shift in the lower treeline during this timeframe, as revealed by a near-filled in talus field.

Green Mountain - North Green

Figure 76 Marmot habitat features and recommended priority areas for future restoration projects circled in red at Green Mountain's North Green (Google Earth Pro (B) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 32% between 1951 to 2016. While this estimated increase in average tree cover is relatively small, the distribution of tree growth is cause for concern. Changes in tree cover percentages presented itself as an infilling of micro-meadows that would have otherwise served as large breaks between contiguous, mature forest. Most infilling appears to be skewed towards the right side of this sub-location. As a result, micro-meadow habitat on North Green appears to have decreased in size, and in some cases, filled in. This results in larger, more contiguous patches of well-established forests directly within marmot habitat.

Areas suitable for future restoration projects in the North Green sub-location can be upper meadow habitat within Quadrant A (Figure 6, Figure 7). This area appears to have only moderate levels of tree ingression and is also the only area holding known marmot habitat features (Figure 7). As a result, restoring sightlines here would be most efficient due to the manageable levels of tree ingression, as well as most pertinent due to the proximity of marmot habitat features. To best inform a future restoration project, it is important to confirm the occupation of these marmot habitat features, as well as determine whether there are other areas of occupation in this sub-location as well.

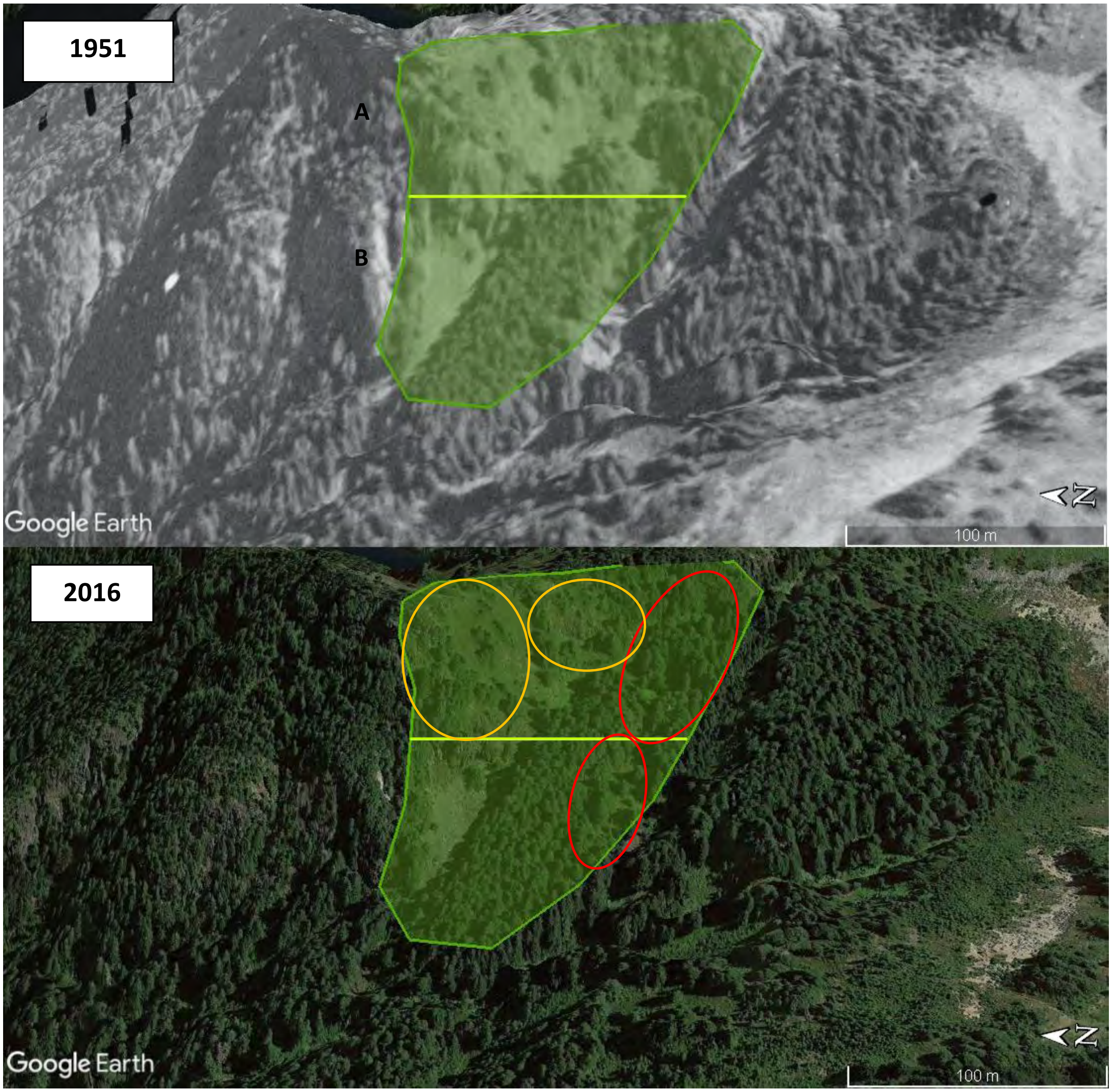

Figure 77 Green Mountain's North Green Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (B) 7.3.4.8248 (64-bit) 2016) and (GeoBC Green Mountain Wildlife Management Area 2021)).

***Table 5**. Green Mountain, North Green Analysis Results – Estimated % Tree Cover.*

Green Mountain North Green	**Estimated % Tree Cover**
Quadrant A (1951)	25%
Quadrant A (2016)	40%
Quadrant B (1951)	50%
Quadrant B (2016)	70%
1949 Average % Tree Cover: 37.5%	
2016 Average % Tree Cover: 55%	
Relative change in average % tree cover: 32% increase	

***Table 6**. Green Mountain, North Green Analysis Results - Observations on changes in tree growth patterns.*

Green Mountain North Green	**Canopy Closure?**	**Tree Ingression?**
Quadrant A 1951 - 2016	Moderate change in canopy closure between 1951 and 2016. Present-day imagery suggests that micro-meadows amongst larger patches of dense forest have potentially shrunk in size.	Changes in tree ingression was moderate between 1951 and 2016. Present-day imagery suggests that tree ingression is slightly increasing within meadow habitat, which may pose risk to habitat availability as it already exists as a patchwork of micro meadows.
Quadrant B 1951 - 2016	Changes in canopy closure was moderate between 1951 and 2016. The most dramatic change occurred along the right edge of this quadrant, wherein present-day imagery suggests this micro-meadow has nearly completely filled in.	Changes in tree ingression was minimal between 1951 and 2016. Present-day imagery suggests that tree ingression is not as large of an issue within this quadrant, as there are not many individual, scattered trees present.

Green Mountain - Summit West

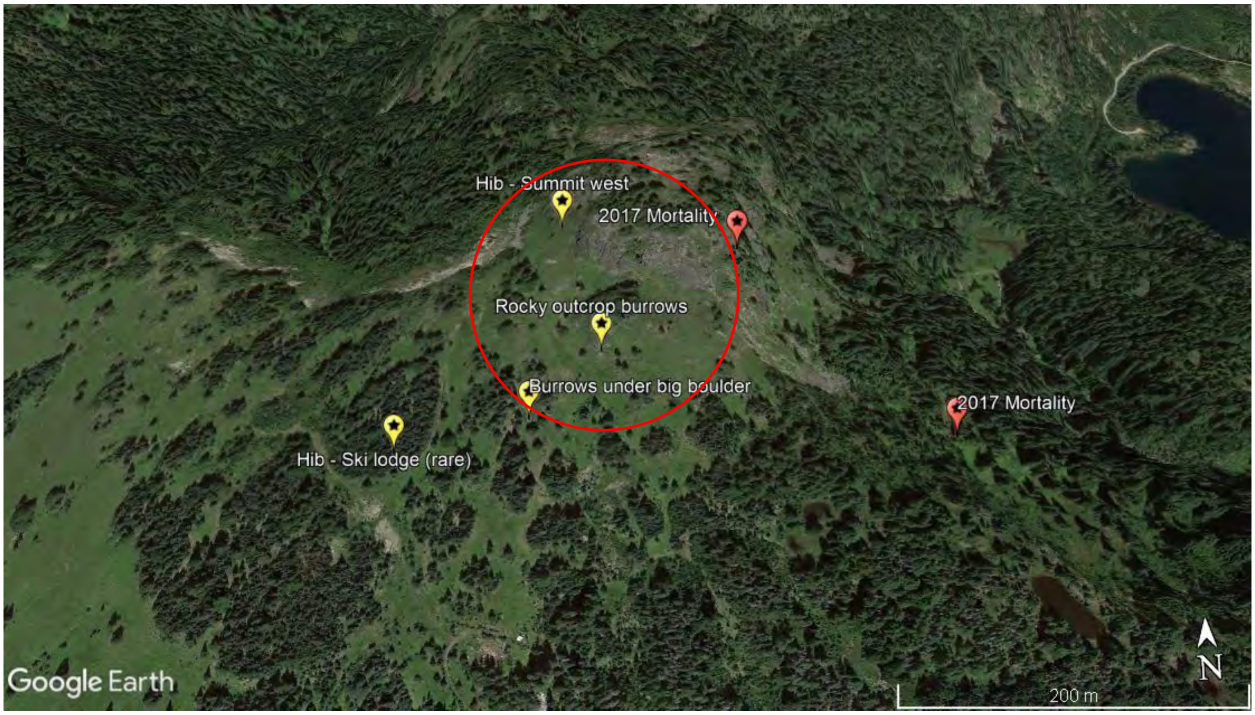

Figure 78 Marmot habitat features, marmot mortalities, and recommended priority areas for future restoration projects circled in red at Green Mountain's Summit West (Google Earth Pro (B) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 63% between 1951 to 2016. There appears to have been a large shift from open meadows interspersed with scattered trees to the establishment of contiguous forests. This primarily occurred as the colonization of meadows by encroaching trees and the infilling of larger tree patches within the comparison timeframe.

A suitable focal area for a future restoration project at Summit West can be the upper portions of this sub-location where tree ingression is still at a moderate level, such as within Quadrant A and B (Figure 8, Figure 9). This is because tree ingression appears to be at a manageable level, and addressing this area can open up a potential travel corridor between the Snowbowl and SE Talus sub-location (Figure 8). This area also has a historical mortality location closest to marmot habitat features (Figure 8).

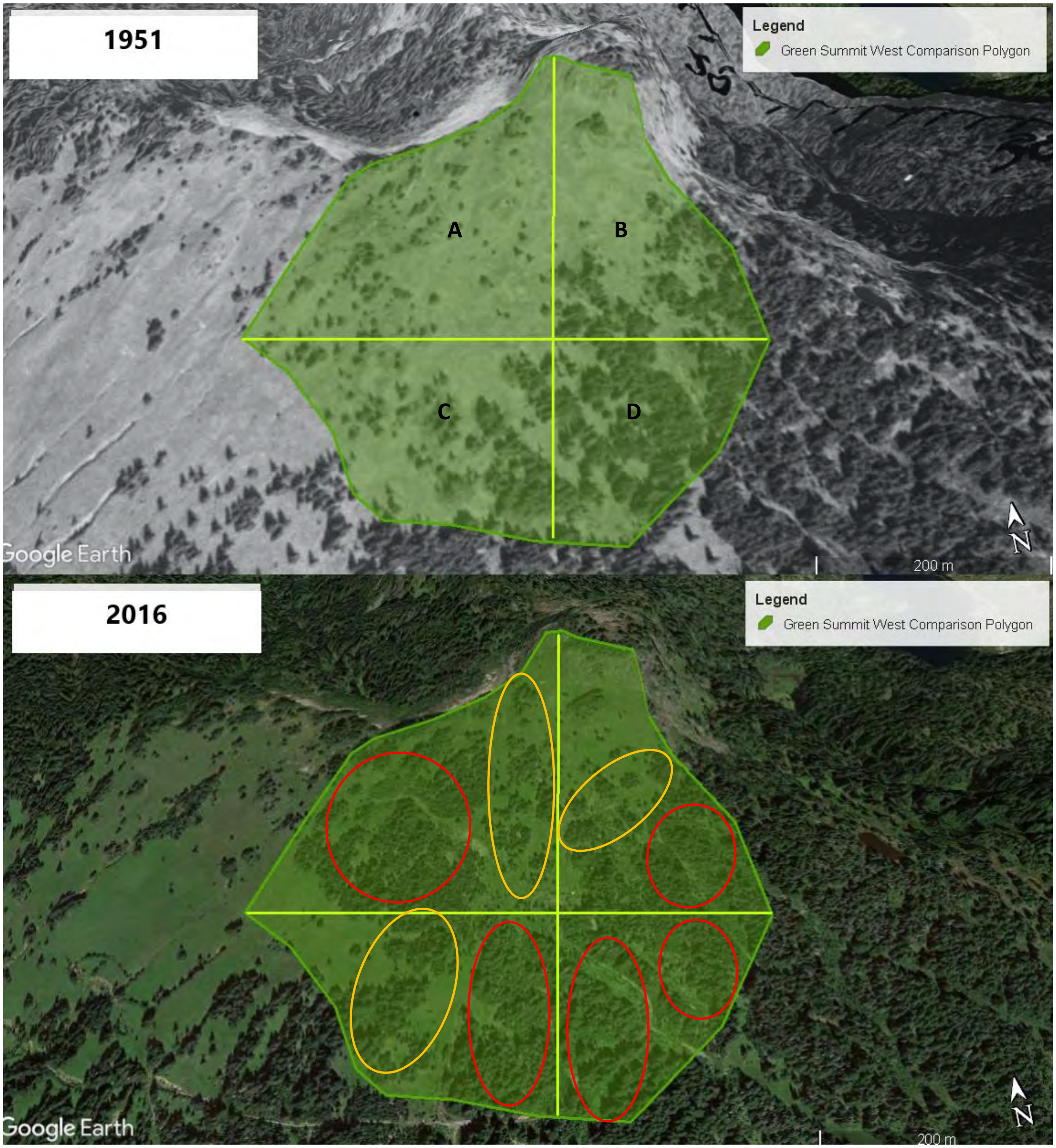

Figure 79 Green Mountain's Summit West Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (B) 7.3.4.8248 (64-bit) 2016) and (GeoBC Green Mountain Wildlife Management Area 2021).

Table 7. *Green Mountain, Summit West Analysis Results – Estimated % Tree Cover.*

Green Mountain Summit West	Estimated % Tree Cover
Quadrant A (1951)	5%
Quadrant A (2016)	40%
Quadrant B (1951)	25%
Quadrant B (2016)	50%
Quadrant C (1951)	20%
Quadrant C (2016)	40%
Quadrant D (1951)	30%
Quadrant D (2016)	85%
1951 Average % Tree Cover: 20%	
2016 Average % Tree Cover: 53.75%	
Relative Change in Average % Tree Cover: 63% increase	

Table 8. *Green Mountain, Summit West Analysis Results - Observations on changes in tree growth patterns.*

Green Mountain Summit West	Canopy Closure?	Tree Ingression?
Quadrant A 1951 - 2016	Canopy closure has increased considerably within Quadrant A between 1951 and 2016. Stand characteristics in 1951 was initially scattered individual trees and since then, appears to have transitioned into well-established, dense forest in 2016.	Changes in tree ingression between 1951 and 2016 was heavy. There was a dramatic shift from individual scattered trees dominating this quadrant in 1951, to the formation of large, contiguous stands as well as a dramatic upshift in the forest line. Based on imagery alone it is difficult to infer the cause of this dramatic increase in tree ingression, however, may be related to the opening and de-activation of a historic ski resort operating in this area.
Quadrant B 1951 - 2016	Changes in canopy closure was heavy in Quadrant B between 1951 and 2016. Open forest present in 1951 appears to have filled in within 2016.	Changes in tree ingression between 1951 and 2016 was moderate. 1951 tree growth distribution suggests that tree ingression had potentially increased from previous years at this point. As a result, tree ingression from 1951 to 2016 was still moderate, but not as dramatic of a change compared to other quadrants.
Quadrant C 1951 – 2016	Changes in canopy closure between 1951 and 2016 was heavy. Relatively open patches of forest within 1951 has infilled considerably in 2016. This has resulted in several large patches of contiguous forest.	Moderate tree ingression between 1951 and 2016 has potentially resulted in the upwards shift of contiguous forest patches in 2016.
Quadrant D 1951 - 2016	Changes in canopy closure between 1951 and 2016 was heavy. While forest patches were initially quite dense in 1951, breaks in patches were still present. 2016 imagery reveals that these patches have nearly filled in since that time.	Changes in tree ingression was moderate between 1951 and 2016. Much of the change in this quadrant occurred as canopy closure into micro-meadows.

Haley Lake - Main Meadow

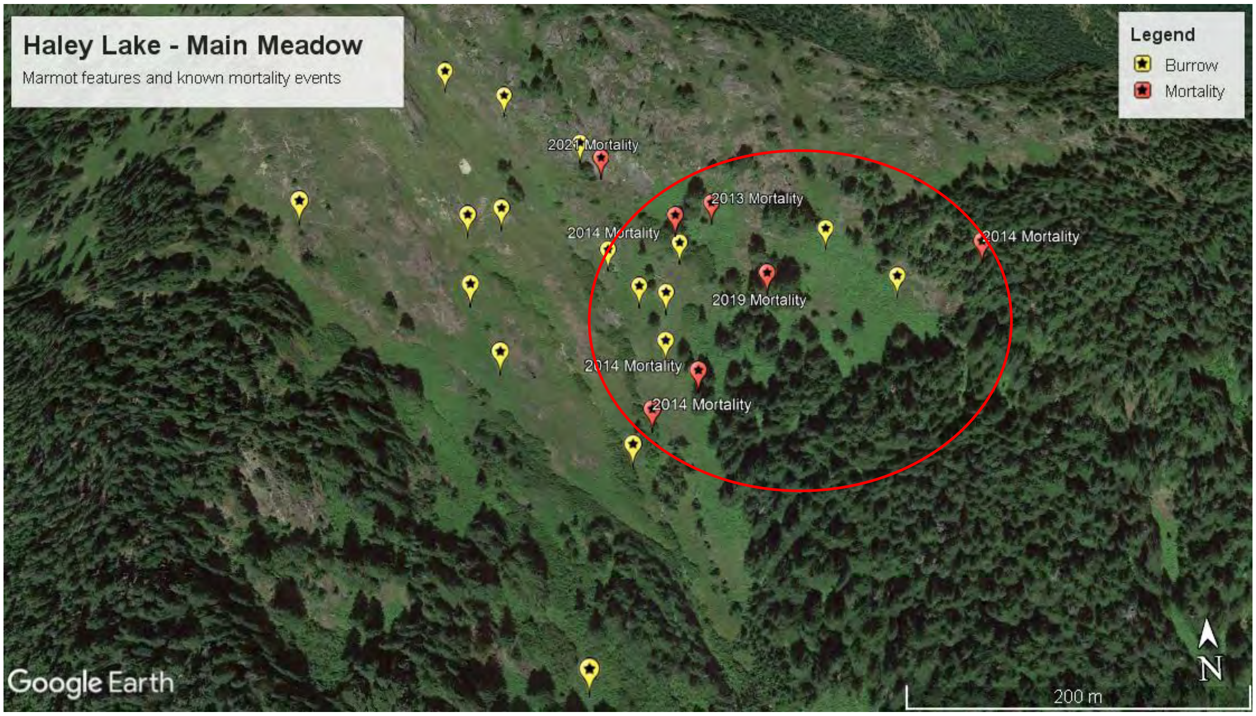

Figure 80 Haley Lake's Main Meadow present-day, with marmot habitat features and recent mortality events. Recommended priority areas for future restoration projects are circled in red. (Google Earth Pro (C) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 35% between 1951 to 2016. Changes in tree cover primarily occurred as tree ingression, particularly towards the sub-location's central gully, as well as upslope towards the upper ridgeline. With that said, canopy closure appeared to still have a considerable impact within areas of already established contiguous forest, in which micro-meadows have shrunk in size considerably, particularly micro-meadows within the lower half of Quadrant B (Figure 11).

Recommendations for a future restoration project at Haley Lake's Main Meadow should be the areas of fastest tree growth, such as the leading edge of tree ingression within the upper half of Quadrant B (Figure 11). This area is not only a tree ingression hotspot but is also an area of the highest concentration of mortalities and marmot habitat features (Figure 10). Addressing tree ingression within this corner of the meadow could immediately restore sightlines. Where additional resources are available, opening up dense forest directly below this leading edge of tree ingression can help restore sightlines into areas where terrestrial predators are being sourced.

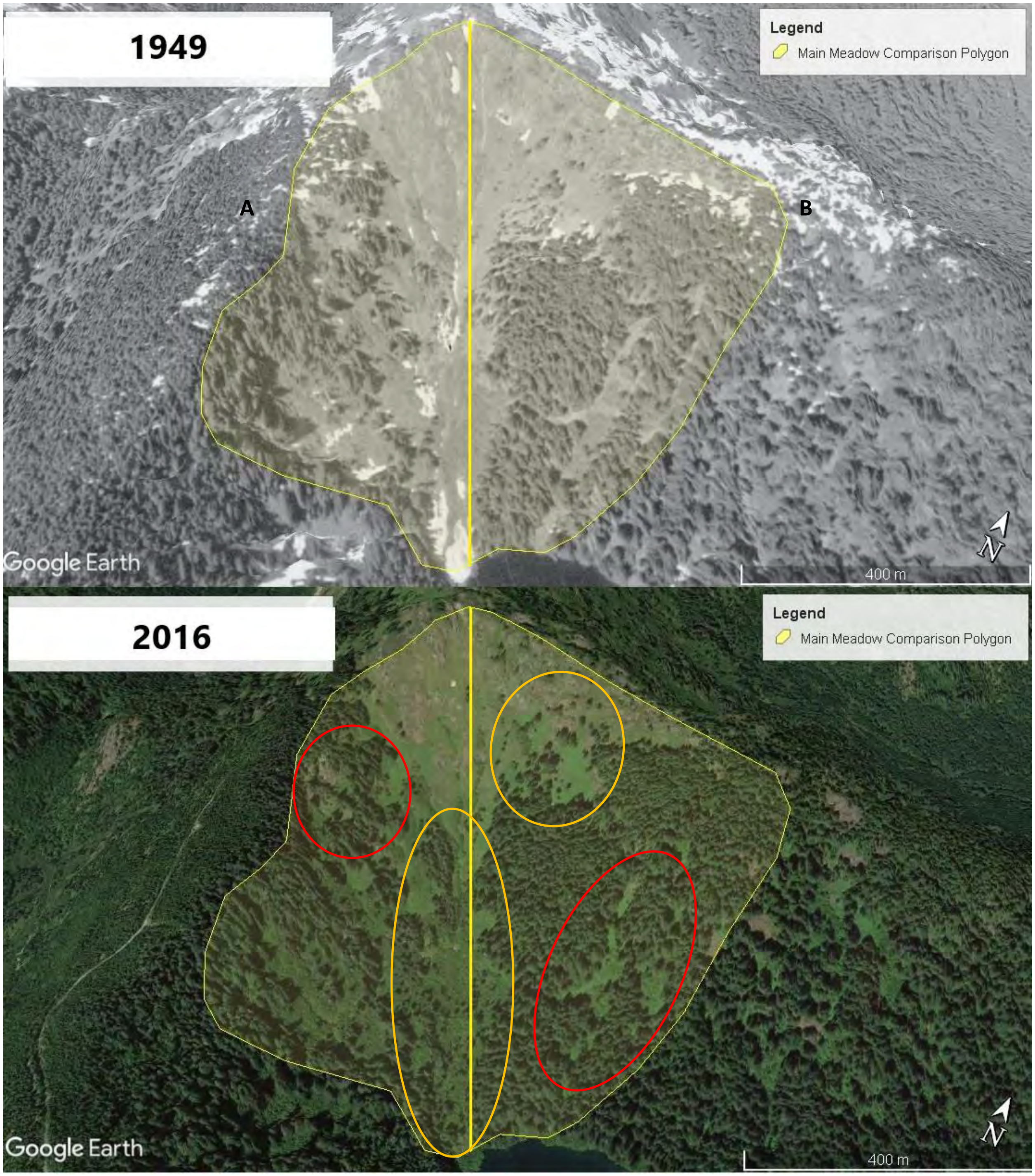

Figure 81 Haley Lake's Main Meadow Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (C) 7.3.4.8248 (64-bit) 2016) and (GeoBC Haley Lake Ecological Reserve 2021)).

Table 9. *Haley Lake, Main Meadow Analysis Results – Estimate % Tree Cover.*

Haley Lake Main Meadow	Estimated % Tree Cover
Quadrant A (1949)	15%
Quadrant A (2016)	35%
Quadrant B (1949)	60%
Quadrant B (2016)	80%
1949 Average % Tree Cover: 37.5%	
2016 Average % Tree Cover: 57.5%	
Relative change in average % tree cover: 35% increase	

Table 10. *Haley Lake Main Meadow Analysis Results - Observations on changes in tree growth patterns.*

Haley Lake Main Meadow	Canopy Closure?	Tree Ingression?
Quadrant A 1949 - 2016	Canopy closure has increased moderately from 1949 to 2016. It appears that patches of forest in 1949 were mediated by large micro-meadows that appear to be maintained by seasonal avalanche activity. This transitioned between 1949 and 2016, in which pre-existing forest patches appeared to have expanded in size and infilled towards these avalanche paths.	Tree ingression has increased moderately between 1949 and 2016 in Quadrant A. In 1949 scattered trees leading downslope towards the central gully have expanded completely towards this terrain feature.
Quadrant B 1949 - 2016	Canopy closure appears to have seen a moderate-heavy increase between 1949 and 2016. Medium sized patches of forest apparent in 1949 have infilled considerably since then, resulting in a reduction of micro-meadow size.	Changes in tree ingression was moderate-heavy between 1949 and 2016. Few scattered trees in 1949 have since transitioned to a massive expansion of pre-existing forest patches both upslope and laterally towards the central gully.

Haley Lake - Bell Creek

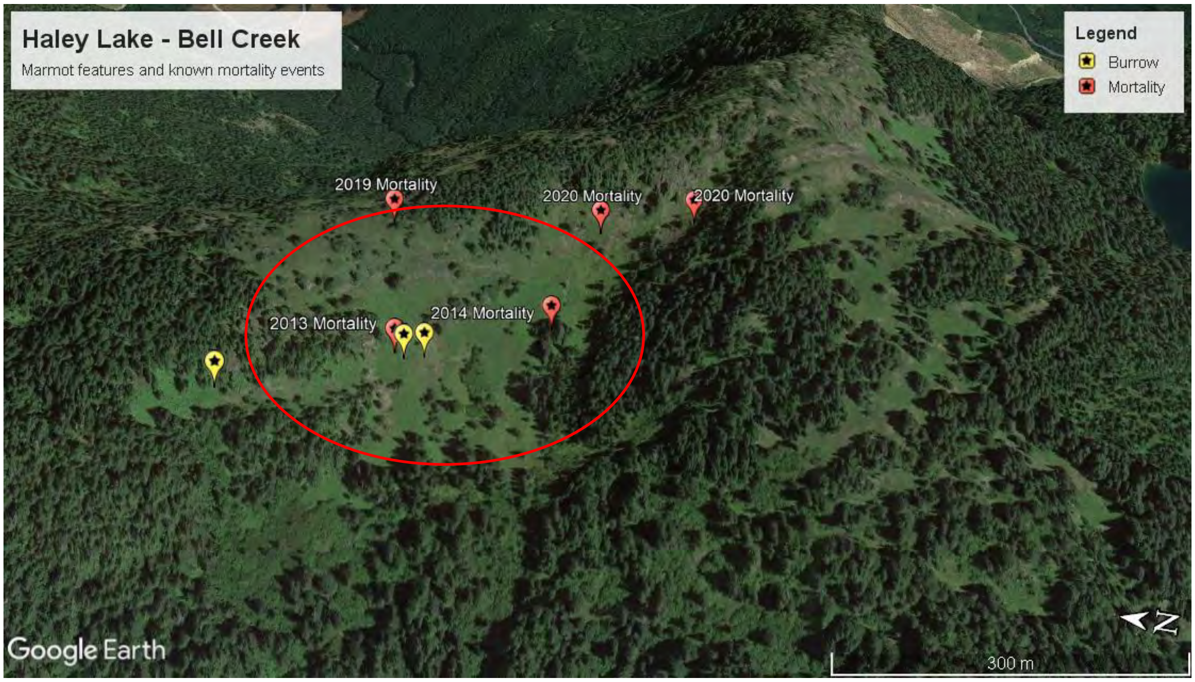

Figure 82 Haley Lake's Bell Creek present-day imagery, with marmot habitat locations and recent mortality events. Recommended priority areas for future restoration efforts circled in red. (Google Earth Pro (C) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 55% between 1951 to 2016. There are numerous patches of dense trees that appear to have expanded from tree ingression in 1949. Tree growth appears to be extending towards the centre of the sub-location from the periphery, particularly within Quadrant A (Figure 13). Canopy closure has grown moderately as scattered trees transitioned into moderately sized patches of forest. Snow cover within the historical imagery prevents a complete analysis of this sub-location (Quadrant B), however areas without snow provide strong evidence for similar tree growth patterns.

Recommendations of suitable focal areas for a future restoration project within Bell Creek could be addressing tree ingression and canopy closure occurring at the present-day meadow's peripheral edges, within Quadrant A (Figure 13). Tree ingression appears to be sourcing from these peripheral edges, and recent mortality events appear to be most concentrated at these areas (Figure 12). Restoring sightlines into these areas can hopefully allow resident marmots within the centre of this sub-location to detect predators travelling the upper ridgeline or stalking within dense cover at the meadow's peripheral edges.

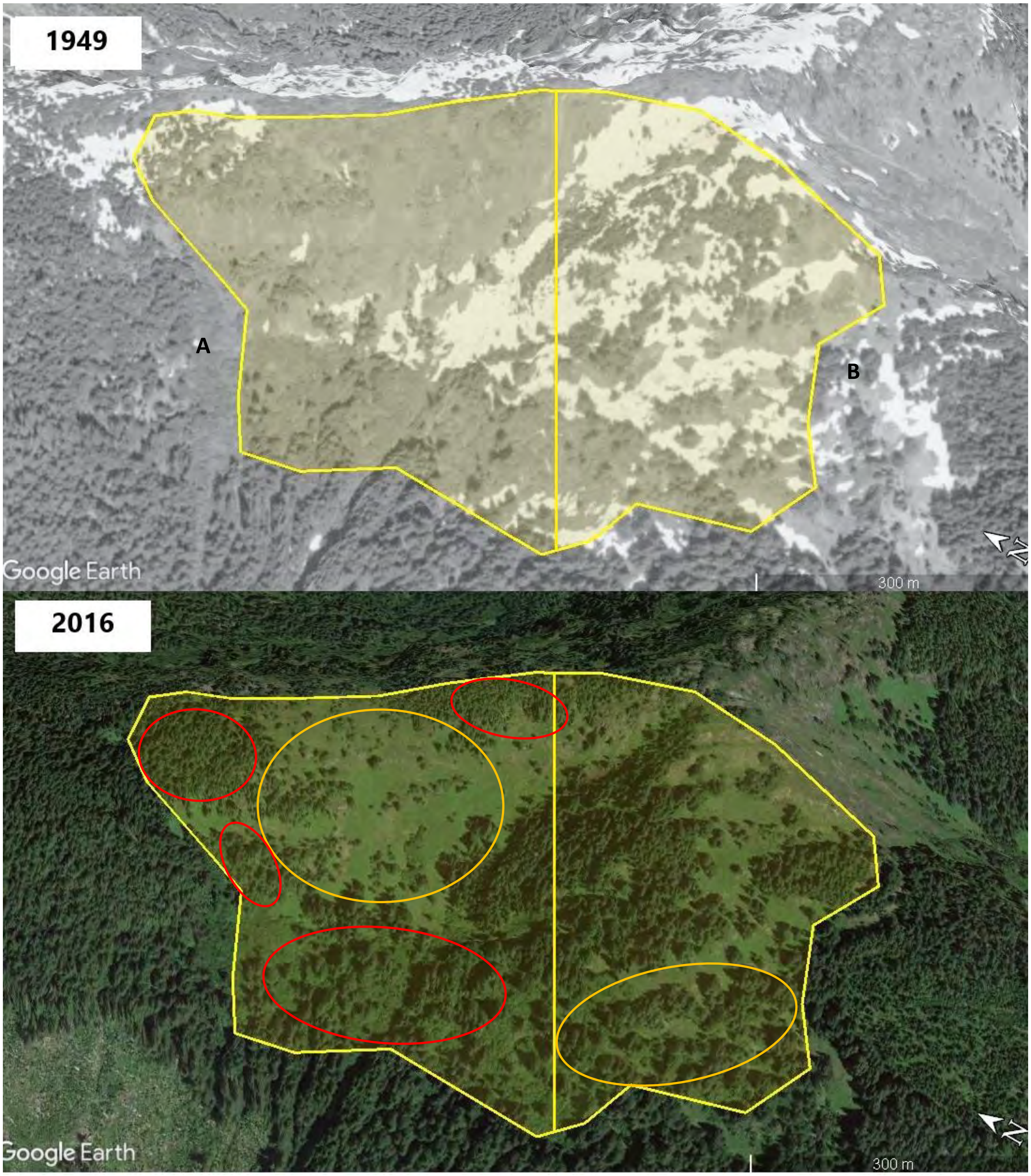

Figure 83 Haley Lake's Bell Creek Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (C) 7.3.4.8248 (64-bit) 2016) and (GeoBC Haley Lake Ecological Reserve 2021)).

__Table 11__. Haley Lake's Bell Creek Analysis Results – Estimated % Tree Cover.

Haley Lake Bell Creek	Estimated % Tree Cover
Quadrant A (1949)	10%
Quadrant A (2016)	40%
Quadrant B (1949)	30%
Quadrant B (2016)	50%
1949 Average % Tree Cover: 20%	
2016 Average % Tree Cover: 45%	
Relative change in average % tree cover: 55% increase	

__Table 12__. Haley Lake Bell Creek Analysis Results - Observations on changes in tree growth patterns.

Haley Lake Bell Creek	Canopy Closure?	Tree Ingression?
Quadrant A 1949 - 2016	Changes in canopy closure between 1949 and 2016 was moderate. Trees present in 1951 were primarily scattered individual trees along the meadow's peripheral edges. These trees have since formed discrete patches, suggesting the potential for connectivity to occur in the future.	Tree ingression has increased moderately between 1949 and 2016 in Quadrant A. In 1949 scattered trees leading downslope towards the central gully have expanded completely towards this terrain feature. An increase in scattered trees is evident towards the center of the meadow as well.
Quadrant B 1949 - 2016	Changes in canopy closure between 1949 and 2016 was minimal-moderate. Some infilling is evident, however, it is important to note that the presence of snow cover impedes our ability to analyze the entire quadrant, as only areas without snow were assessed.	Changes in tree ingression between 1949 and 2016 is difficult to assess due to the presence of snow cover in the historical imagery. Areas without snow suggest that minimal levels of scattered trees were present. When compared with 2016, tree ingression appears to be much heavier. This is revealed by larger patches of forest that appear to have expanded downslope towards the Bell Creek drainage considerably since 1949. Only areas without snow cover were analyzed.

Heather Mountain – Main Meadow

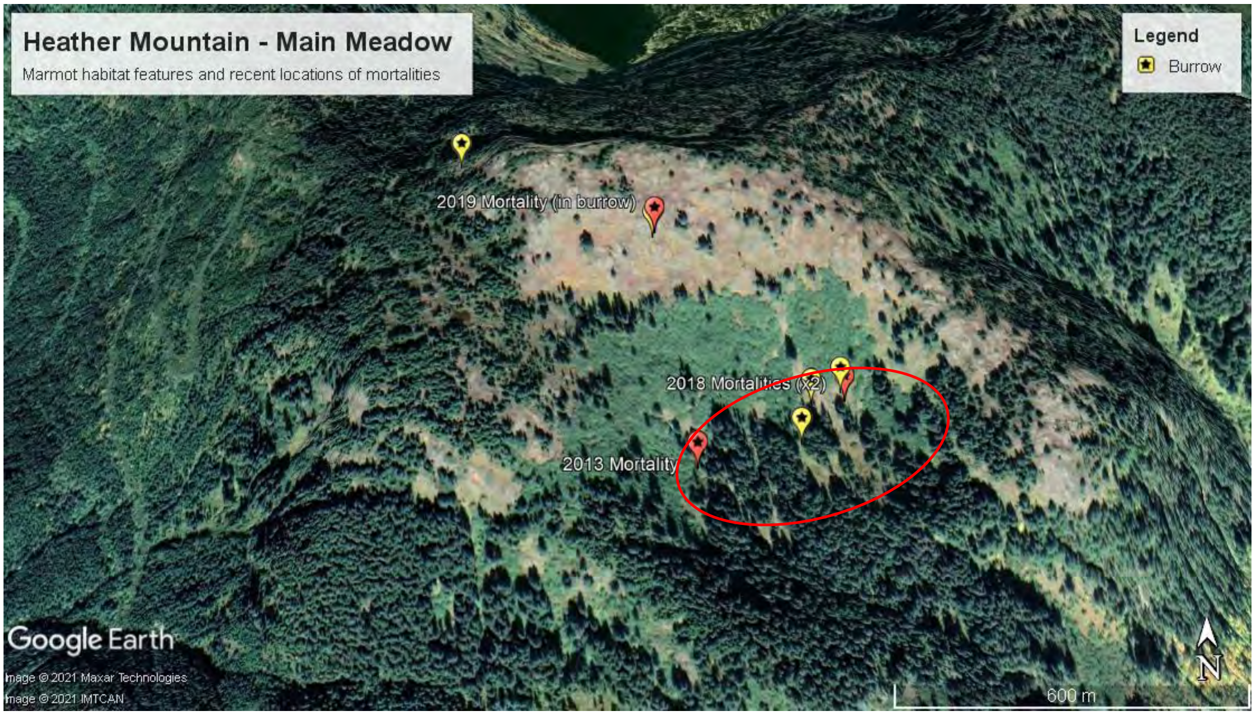

Figure 84 Heather Mountain, Main Meadow present-day with marmot habitat locations and recent mortality events. Recommended priority area for a future restoration project circled in red. (Google Earth Pro (D) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 26% between 1951 to 2016. This increase in tree cover appeared primarily as increased canopy closure within patches of open forest at lower elevations. Historical imagery suggests larger patches of trees already existed here within 1946, and appear to have increased in density.

Priorities for a future restoration project within Heather Mountain's Main Meadow should be the lowest edge of the meadow where tree ingression and canopy closure appear to be the heaviest (Figure 14). This area also includes two historical mortality locations as well as two well-known burrows. Observations from the 2021 field season suggest that this lower section of Heather Mountain is well trafficked by ungulates and could be a potential stalking hotspot for terrestrial predators.

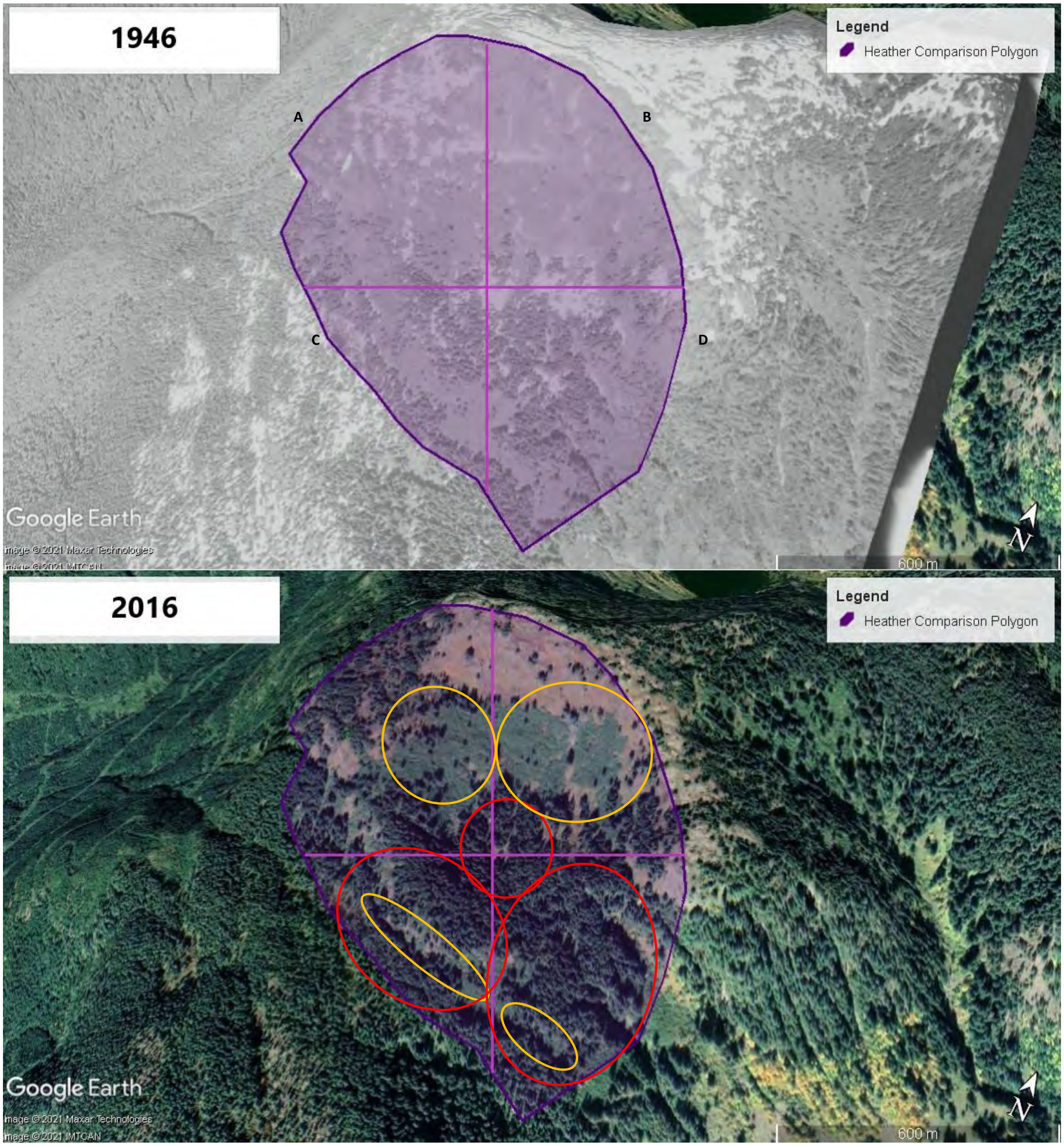

Figure 85 Heather Mountain, Main Meadow Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure encircled in red. ((Google Earth Pro (D) 7.3.4.8248 (64-bit) 2016) and (GeoBC Heather Mountain 2021)).

Table 13. Heather Mountain, Main Meadow Analysis Results – Estimated % Tree Cover.

Heather Mountain Main Meadow	Estimated % Tree Cover
Quadrant A (1946)	10%
Quadrant A (2016)	15%
Quadrant B (1946)	5%
Quadrant B (2016)	20%
Quadrant C (1946)	65%
Quadrant C (2016)	70%
Quadrant D (1946)	50%
Quadrant D (2016)	70%
1946 Average % Tree Cover: 32.5%	
2016 Average % Tree Cover: 43.75%	
Relative change in average % tree cover: 26% increase	

Table 14. Heather Mountain Main Meadow Analysis Results - Observations on changes in tree growth patterns.

Heather Mountain Main Meadow	Canopy Closure?	Tree Ingression?
Quadrant A 1946 - 2016	Changes in canopy closure between 1946 and 2016 was minimal as there are not many areas of contiguous forest within the quadrant.	Changes in tree ingression was moderate between 1946 and 2016. There appears to have been an increase in the presence of individual, scattered trees that appear to be growing upslope.
Quadrant B 1946 - 2016	Changes in canopy closure between 1946 and 2016 was heavy. What initially started off as scattered, encroaching trees have since clustered to form discrete patches of forest.	Changes in tree ingression from 1946 to 2016 was moderate. There appears to be a much higher forest line, as well as an increase of individual scattered trees at this edge.
Quadrant C 1946 – 2016	Changes in canopy closure between 1946 and 2016 was moderate-heavy. Small-medium sized patches of forest were mediated by several micro-meadows in 1946. Since then, micro-meadows in 2016 have reduced in size drastically, with an increase in scattered individual trees present throughout micro meadows.	Changes in tree ingression between 1946 and 2016 was minimal, most of the change occurred as canopy closure within micro-meadows.
Quadrant D 1946 – 2016	Changes in canopy closure between 1946 and 2016 was moderate. Patches of forest in 1946 were segregated by a complex of micro-meadows interspersed throughout the quadrant. Present-day imagery suggests fewer open patches of meadow present throughout dense forest.	Changes in tree ingression between 1946 and 2016 was heavy. Present-day imagery suggests the potential for a downslope shift of trees into drainage systems.

Mount Hooper – Main Meadow

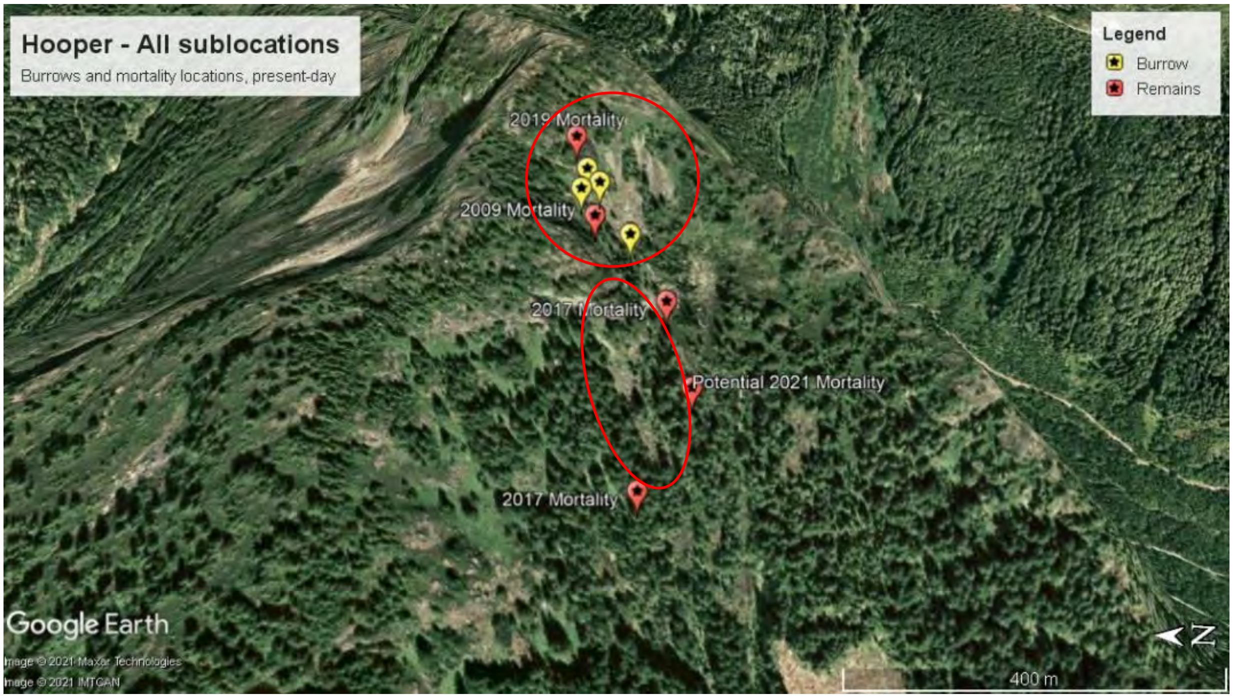

Figure 86 Mount Hooper's Main Meadow present-day with marmot habitat locations and recent mortality events. Recommended priority areas for a future restoration project circled in red. Note the second lowest mortality point "Potential 2021 Mortality" is an approximate estimation, however telemetry suggests the mortality was in this same direction. (Google Earth Pro (E) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 20% between 1951 to 2016. Due to warping in both the present-day and historical imagery of this sub-location, it was difficult to make an assessment. With that said some areas of tree ingression, such as the downslope movement of trees from the upper ridgeline in Quadrant A, is evident. There is also potential for canopy closure to be a concern particularly towards the central drainage system of this meadow within the lower half of both Quadrants A and B.

Recommendations of priority sites for a future restoration project within Mount Hooper's Main Meadow is tree ingression occurring at the periphery of the present-day talus field, in particular the upper corners of Quadrants A and B (Figure 16, Figure 17). This area hosts many marmot habitat features and present-day imagery suggests this would be the most immediate cause for concern. While warping played a considerable role in the analysis of this sub-location, it is worthwhile noting the importance of assessing canopy closure and tree ingression in person, particularly at lower elevations towards the central drainage system and within any micro-meadows nearby. Previous mortality locations (including one suspected mortality in 2021) appear to be adjacent to this drainage feature, and thus getting an accurate assessment of tree growth here can help further inform restoration priorities (Figure 16).

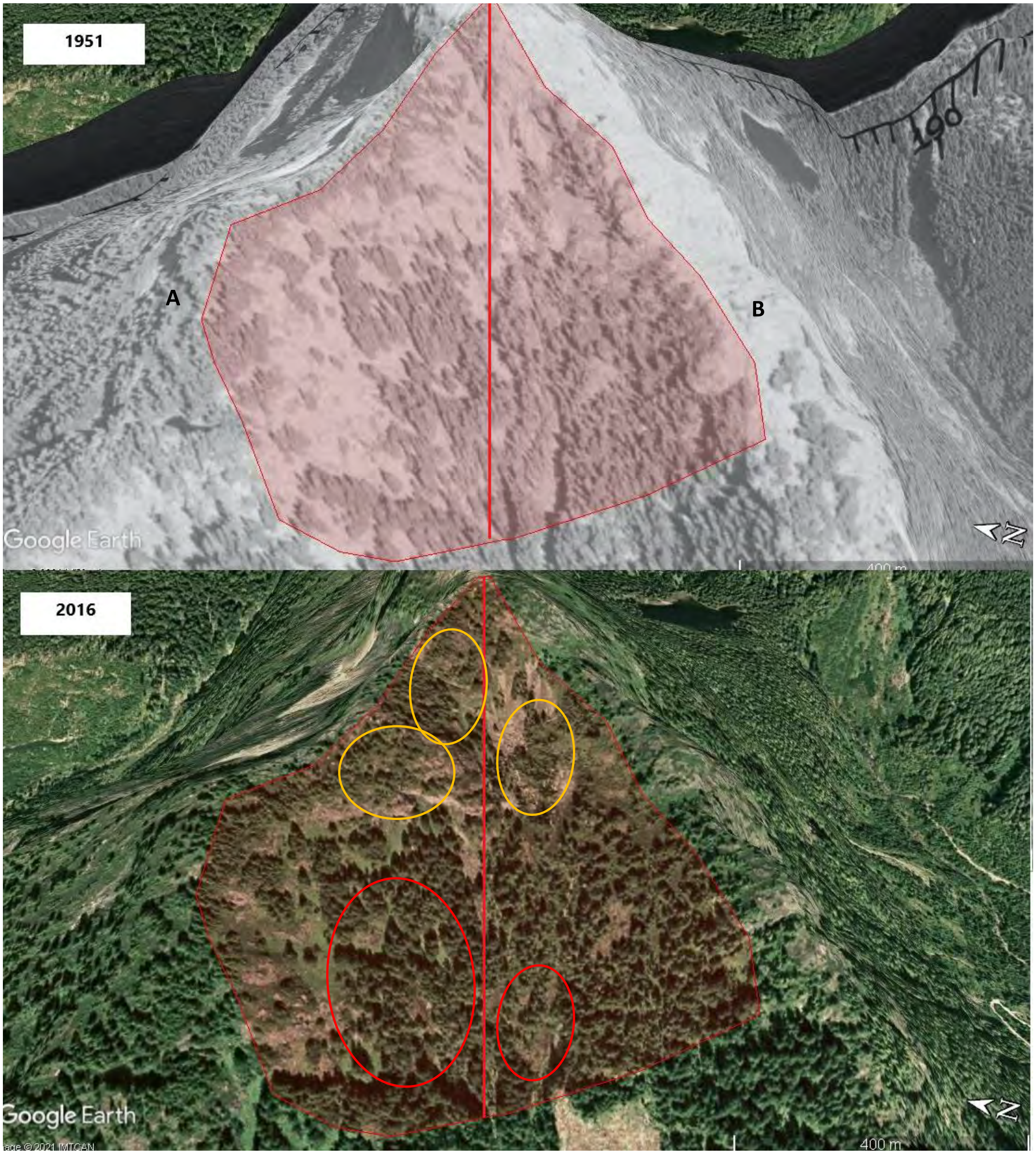

Figure 87 Mount Hooper, Main Meadow Analysis Quadrants. Tree ingression hotspots encircled in yellow, canopy closure hotspots encircled in red. ((Google Earth Pro (E) 7.3.4.8248 (64-bit) 2016) and GeoBC Mount Hooper 2021)).

Table 15. Mount Hooper, Main Meadow Analysis Results – Estimated % Tree Cover.

Mount Hooper Main Meadow	Estimated % Tree Cover
Quadrant A (1951)	30%
Quadrant A (2016)	55%
Quadrant B (1951)	70%
Quadrant B (2016)	70%
1951 Average % Tree Cover: 50%	
2016 Average % Tree Cover: 62.5%	
Relative change in average % tree cover: 20% increase	

Table 16. Hooper Mountain Main Meadow Analysis Results - Observations on changes in tree growth patterns.

Hooper Mountain Main Meadow	Canopy Closure?	Tree Ingression?
Quadrant A 1951 - 2016	Changes in canopy closure between 1951 and 2016 appears to have been minimal-moderate. There is the potential for micro-meadows within this quadrant to have filled in since 1951, particularly those towards the central drainage gully. It is important to note that warping in historical imagery for this quadrant needs to be accounted for in this assessment.	Changes in tree ingression between 1951 and 2016 appears to have been moderate. Present-day imagery suggests a moderate downslope movement of encroaching trees from the upper ridgeline.
Quadrant B 1951 - 2016	Canopy closure between 1951 and 2016 appears to have been minimal-moderate. There is potential for micro-meadows, particularly towards the bottom of the quadrant to have decreased in size. However, warping in the historical and present-day imagery for this quadrant needs to be accounted for in this assessment.	Tree ingression between 1951 and 2016 appears to have been moderate. There are some areas in the present-day imagery in which downslope movement of trees is a potential. Warping in both the historical and present-day imagery is present and thus needs to be accounted for in this assessment.

Mount McQuillan – Main Meadow

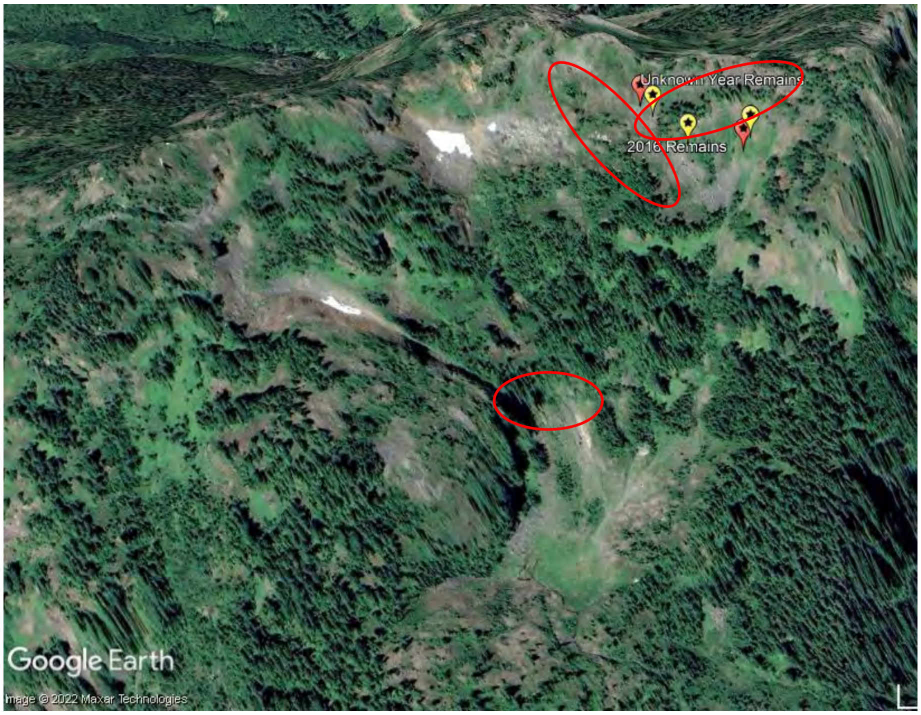

Figure 88 Mount McQuillan, Main Meadow present-day imagery with marmot habitat features and recent mortality events. Recommended priority areas for future restoration projects circled in red. (Google Earth Pro (F) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 36% between 1951 to 2016. The imagery suggests that there were moderate increases in tree ingression, as shown by the presence of small, scattered trees that grow towards drainage systems and the centre of meadows. In addition to this, canopy closure appears to have increased moderately. This has potentially resulted in canopy gaps and micro-meadows to decrease in size. It is important to note that Quadrants A and C of the present-day imagery of this sub-location was affected by warping, as well as heavy shading in the historical imagery. As a result, assessment was omitted in Quadrants A and C.

Recommended focal areas for a future restoration project within Mount McQuillan's Main Meadow could be hotspots of tree ingression growing towards the upper talus field in Quadrant B (Figure 18, Figure 19). This talus field appears to be where most of the marmot habitat features exist, and there is potential for tree ingression to increase and grow from the periphery of established forest towards the center of this meadow (Figure 18). Despite foregoing an assessment of this quadrant, it is recommended to assess the state of talus fields within the lower meadow (Quadrant C, Figure 19). 2021 surveys within this area suggest potential marmot occupation within the talus fields above this meadow, as well as the use of upper forests as travel corridors. As a result, it is recommended to confirm marmot occupation here and assess feasibility to thin out forest directly above this talus field if feasible (Figure 18).

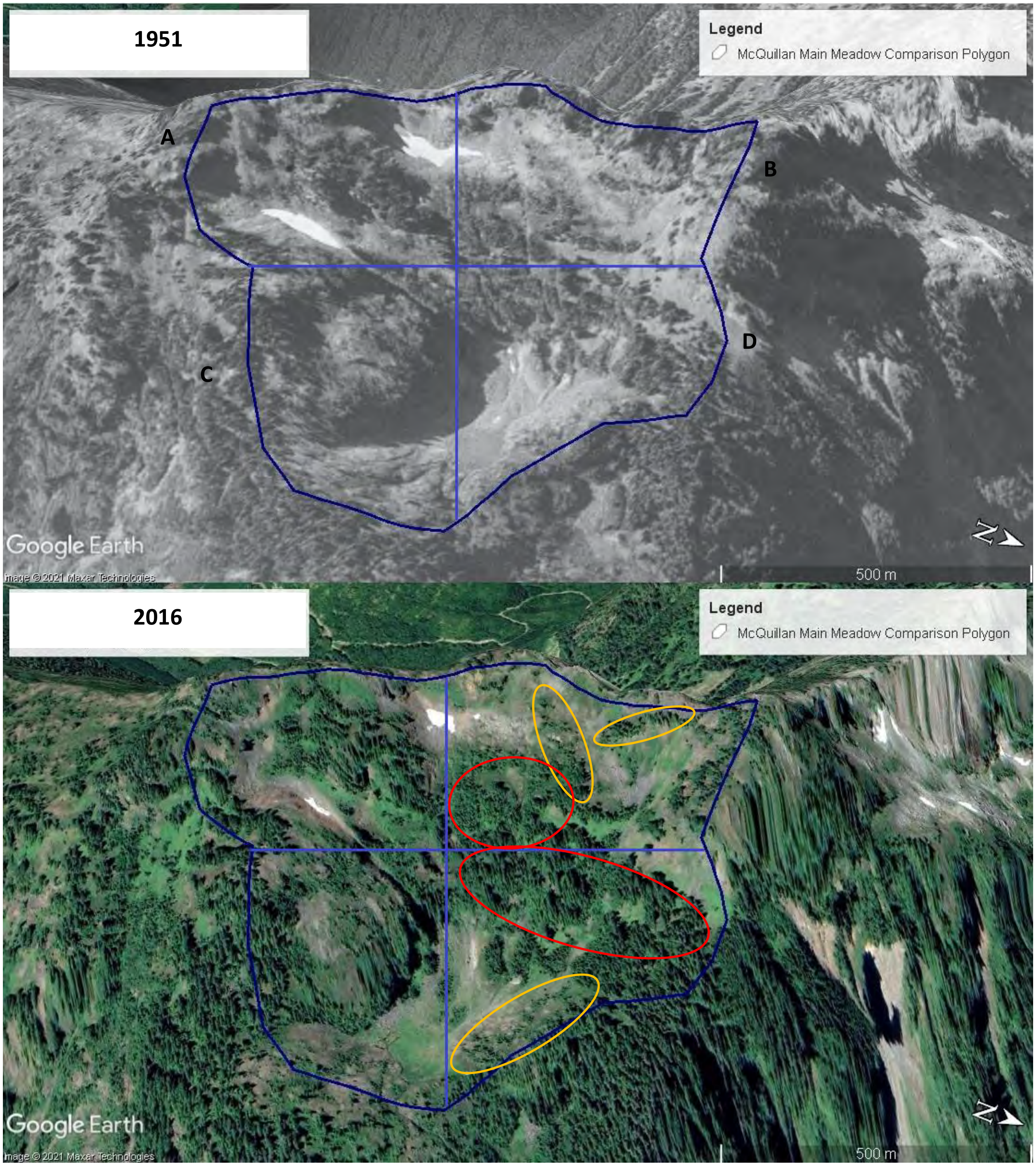

Figure 89 Mount McQuillan, Main Meadow Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (F) 7.3.4.8248 (64-bit) 2016) and (GeoBC Mount McQuillan 2021)).

Table 17. Mount McQuillan, Main Meadow Analysis Results – Estimated % Tree Cover.

Mount McQuillan Main Meadow	Estimated % Tree Cover
Quadrant B (1951)	25%
Quadrant B (2016)	40%
Quadrant D (1951)	20%
Quadrant D (2016)	30%
1951 Average % Tree Cover: 22.5%	
2016 Average % Tree Cover: 35%	
Relative change in average % tree cover: 36%	

Table 18. Mount McQuillan Main Meadow Analysis Results - Observations on changes in tree growth patterns.

Mount McQuillan Main Meadow	Canopy Closure?	Tree Ingression?
Quadrant A 1951 - 2016	Unable to assess due to warped imagery.	Unable to assess due to warped imagery.
Quadrant B 1951 - 2016	Changes in canopy closure was moderate between 1951 and 2016. This was restricted to the lower left corner of Quadrant B, in which forest patches separating upper and lower meadow habitat appear to have infilled.	Changes in tree ingression was moderate between 1951 and 2016. This was patchy in distribution throughout the sub-location, in which only two main hotspots were located. These hotspots had potential to block sightlines between marmot habitat features that were often travelled to and from, as per 2021 field observations.
Quadrant C 1951 - 2016	Unable to assess due to warped imagery and shadows.	Unable to assess due to warped imagery and shadows.
Quadrant D 1951 - 2016	Canopy closure appears to have increased moderately between 1951 and 2016, particularly within the upper forested section of this quadrant. Drainage systems within 1951 were originally much more visible, whereas these same drainage systems appear to have filled in, as suggested by the 2016 imagery.	Tree ingression has increased moderately between 1951 and 2016. Areas of tree ingression present in 1951 have since grown. 2016 imagery suggest that these trees have moved downslope into the low-lying meadow of this quadrant.

Mount McQuillan – West Talus

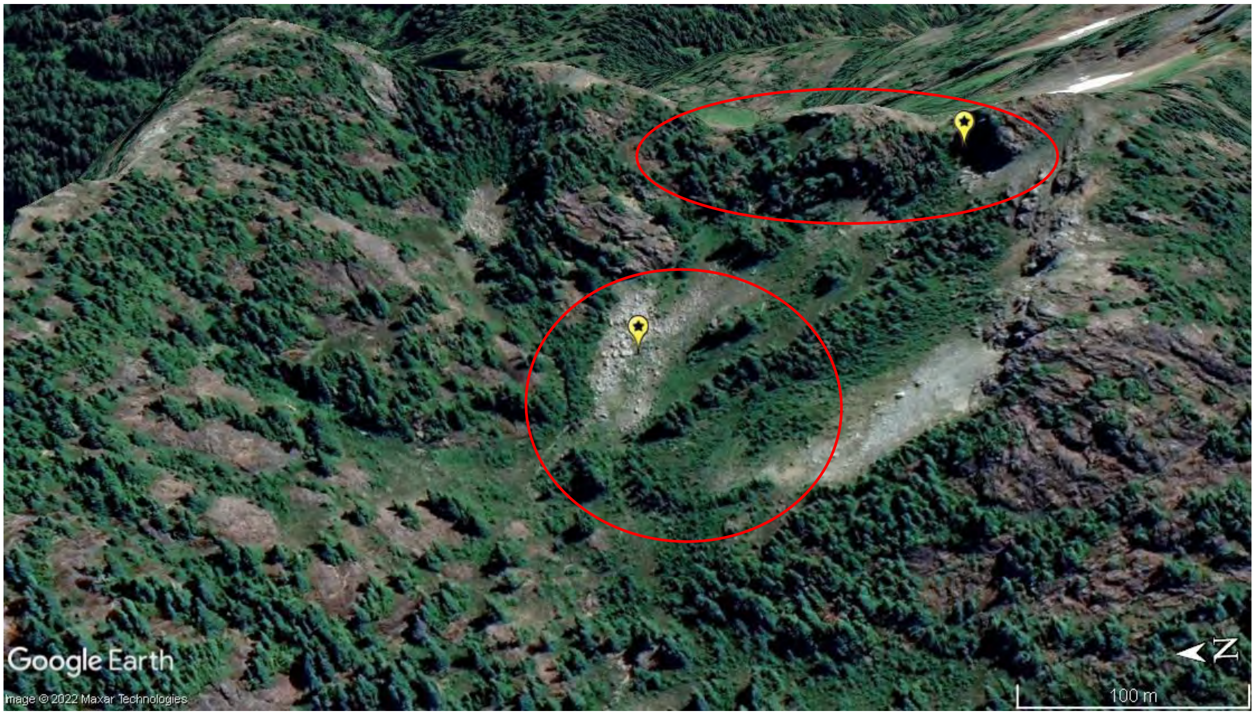

Figure 90 Mount McQuillan West Talus present-day imagery with marmot habitat features. Recommended priority areas for future restoration projects circled in red. (Google Earth Pro (F) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 32% between 1951 to 2016. Tree ingression appears to be this sub-location's largest concern at lower elevations, while canopy closure appears to be more of an issue at upper elevations along the ridgeline. Tree ingression has increased moderately, and present-day imagery suggests tree movement towards talus field habitat, particularly throughout Quadrants C and D (Figure 21). Canopy closure has increased considerably throughout this sub-location during the comparison timeframe. Many pre-existing stands, particularly those below the upper ridgeline, appear dense and more connected (Quadrant A and B, Figure 21).

Recommended focal sites for a future restoration project at this sub-location are hotspots of canopy closure within areas used as travel corridors between West Talus and the Main Meadow (Figure 20). Data from 2021 surveys suggest that marmots use talus habitat along the upper ridgeline of this sub-location between Quadrant A and B (Figure 21). These areas have shown heightened levels of canopy closure and thinning these stands could help restore sightlines for travelling marmots. Additional areas can include meadow habitat within Quadrant C and the lower edge of Quadrant A, in which marmot use was observed during 2021 field surveys (Figure 20, Figure 21). Talus field habitat in these quadrants have revealed moderate levels of tree ingression (except for the omitted Quadrant C), and so targeting small, scattered trees could be a worthwhile objective to restore sightlines for residents occupying these lower talus fields.

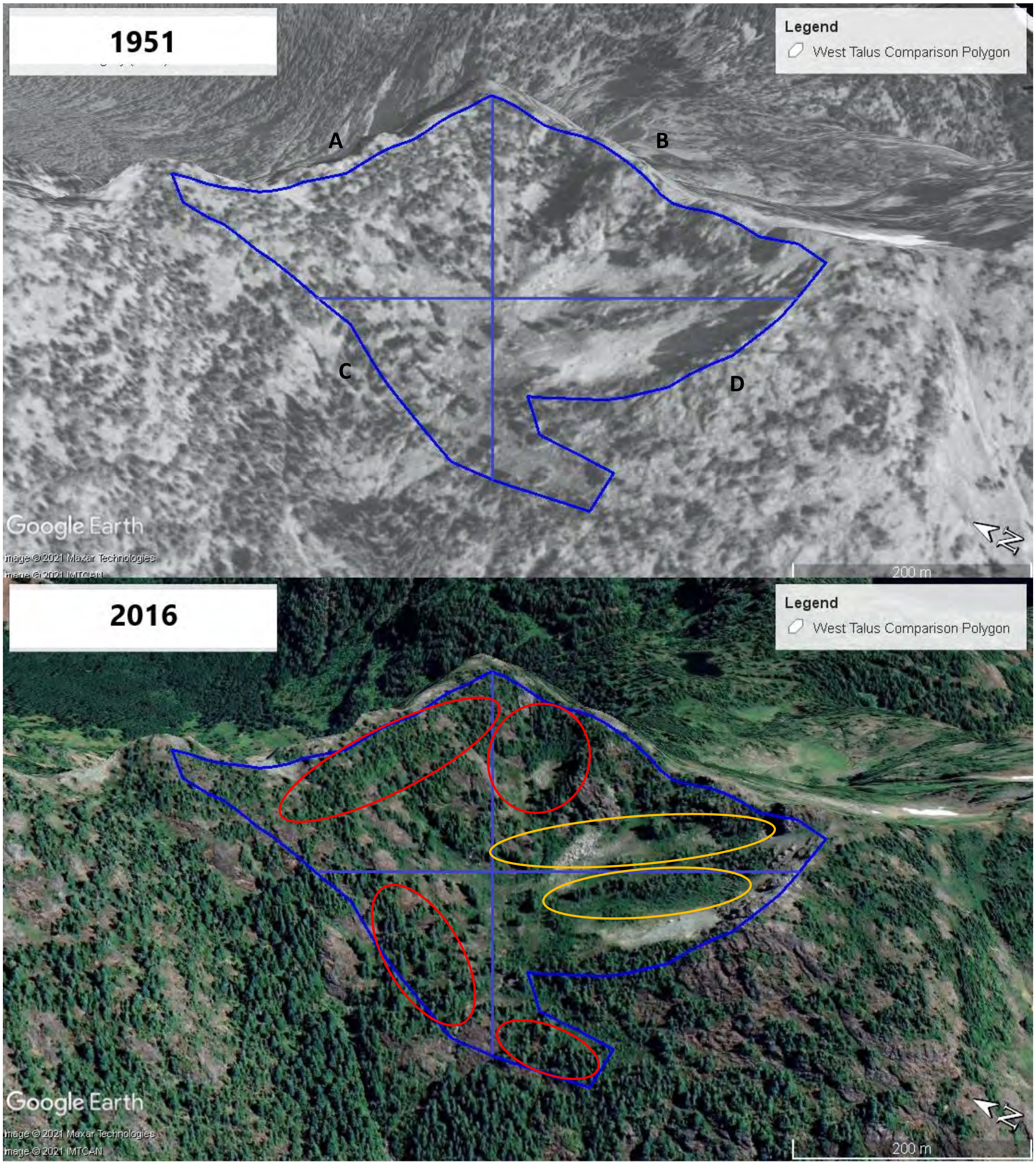

Figure 91 Mount McQuillan, West Talus Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (F) 7.3.4.8248 (64-bit) 2016) and (GeoBC Mount McQuillan 2021)).

Table 19. Mount McQuillan, West Talus Analysis Results – Estimated % Tree Cover.

Mount McQuillan West Talus	Estimated % Tree Cover
Quadrant A (1951)	45%
Quadrant A (2016)	55%
Quadrant B (1951)	30%
Quadrant B (2016)	40%
Quadrant C (1951)	10%
Quadrant C (2016)	25%
Quadrant D (1951)	7%
Quadrant D (2016)	15%
1951 Average % Tree Cover: 23%	
2016 Average % Tree Cover: 33.75%	
Relative change in Average % Tree Cover: 32% increase	

Table 20. Mount McQuillan West Talus Analysis Results - Observations on changes in tree growth patterns.

Mount McQuillan West Talus	Canopy Closure?	Tree Ingression?
Quadrant A 1951 - 2016	Changes in canopy closure was moderate between 1951 and 2016. Patches of forest in 1951 was open and scattered throughout the quadrant. Pockets of canopy closure is apparent in 2016, wherein these patches have since connected and gaps appear to be less pronounced.	Changes in tree ingression was minimal - moderate between 1951 and 2016 in Quadrant A. New trees have appeared since 1951, appearing to grow upslope.
Quadrant B 1951 - 2016	Changes in canopy closure was heavy between 1951 and 2016. Pre-existing stands from 1951, particularly those at along the ridgeline, have filled in considerably in 2016.	Changes in tree ingression between 1951 and 2016 was heavy. Areas of open talus field in 1951 have since been colonized by trees, which appear to grow upslope towards the upper ridgeline.
Quadrant C 1951 – 2016	Changes in canopy closure was moderate between 1951 and 2016. Very open forest in 1951 has since closed in, appearing more as a dense forest rather than an open forest-meadow complex.	Changes in tree ingression was moderate within this quadrant. New, scattered trees are apparent in 2016, now closer to the meadow's center.
Quadrant D 1951 – 2016	Changes in canopy closure was heavy between 1951 and 2016, however it is isolated to pockets where forest exists. In particular, the lower right corner of this quadrant.	Changes in tree ingression was heavy between 1951 and 2016 in this quadrant. New trees have grown downslope in 2016, adjacent to the open talus field. Open talus field habitat appears to have shrunk in size.

P Mountain – Main Meadow

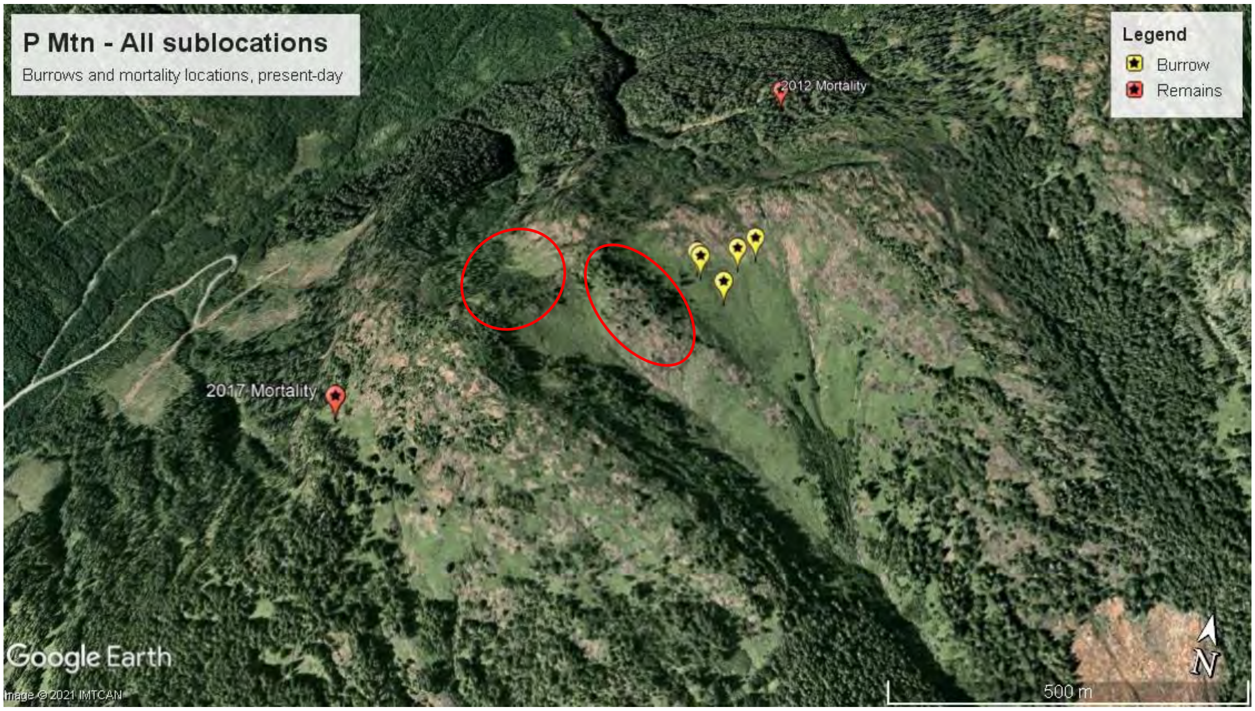

Figure 92 P Mountain's Main Meadow present-day with marmot habitat locations and recent mortality events. Recommended focal area for future restoration project circled in red. (Google Earth Pro (G) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 36% between 1951 to 2016. Present-day imagery suggests much of the change occurred as tree ingression across slope from the meadow's peripheral edges towards its center. The most dramatic changes appeared to be at lower elevations where denser forests are prevalent. It is important to note that over-exposure of historical imagery was evident, and thus may have played a role in altering analysis results. See the "Limitations" section for more details.

Tree ingression along the left/west side of the sub-location appeared to be heaviest. While this area is not the primary location of marmot habitat features, anecdotal evidence from Calgary Zoo Research team members suggests extensive travel between meadows on P Mountain. Recommendations for focal areas for a future restoration site at P Mountain's Main Meadow are the upper forest patches within Quadrant A that serves as a potential travel corridor for dispersing marmots (Figures 22 and 23). Thinning these patches of trees can allow for safe travel for marmots dispersing between sub-locations. With that being said, restoration efforts took place in this meadow in 2021, which is not shown in the photos or analysis of tree ingress, and so other areas should be considered as priority for future visits. Due to a lack of suitable imagery, P Mountain's NW Meadow was not analyzed. 2021 field observations revealed heavy tree ingression at lower elevations within this sub-location. As a result, it is recommended to also prioritize an analysis of historic change at this additional sub-location to assess the extent of change occurred over the years.

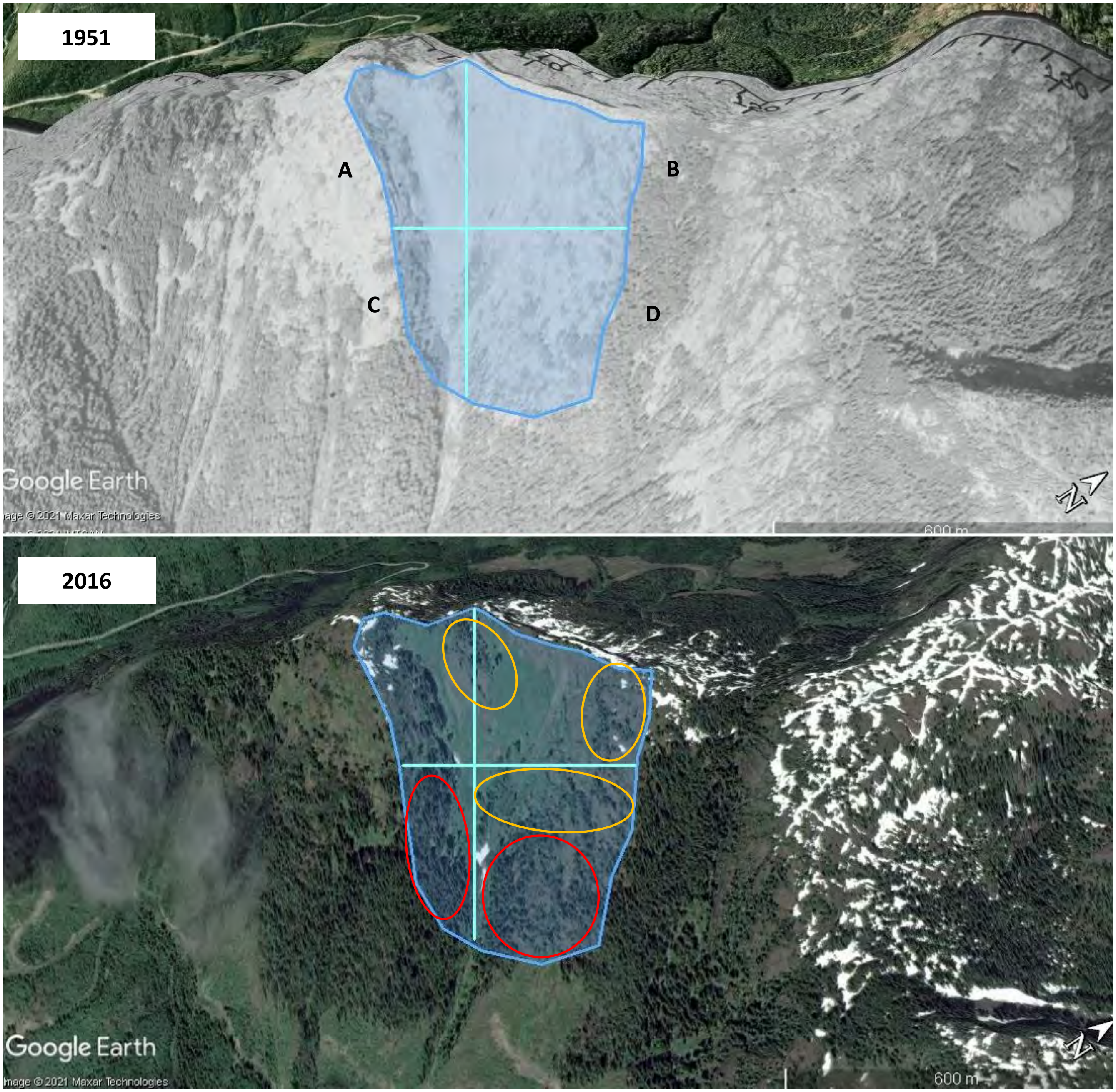

Figure 93 P Mountain, Main Meadow Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (G) 7.3.4.8248 (64-bit) 2016) and (GeoBC P Mountain 2021)).

Table 21. *P Mountain, Main Meadow Analysis Results – Estimated % Tree Cover.*

P Mountain Main Meadow	Estimated % Tree Cover
Quadrant A (1951)	7%
Quadrant A (2016)	15%
Quadrant B (1951)	5%
Quadrant B (2016)	7%
Quadrant C (1951)	20%
Quadrant C (2016)	30%
Quadrant D (1951)	20%
Quadrant D (2016)	30%
1951 Average % Tree Cover: 13%	
2016 Average % Tree Cover: 20.5%	
Relative Change in Average % Tree Cover: 36% increase	

Table 22. *P Mountain, Main Meadow Analysis Results - Observations on changes in tree growth patterns.*

P Mountain Main Meadow	Canopy Closure?	Tree Ingression?
Quadrant A 1951 - 2016	Changes in canopy closure was minimal between 1951 and 2016. Changes are isolated to a small patch of trees along the left edge of Quadrant A, in which present-day imagery suggests that infilling occurred in this stand between 1951 and 2016.	Changes in tree ingression was minimal between 1951 and 2016. There is potential for downslope movement to have occurred within the timeframe from larger stands of trees into meadow habitat.
Quadrant B 1951 - 2016	Changes in canopy closure was minimal between 1951 and 2016. No notable formation of forest patches evident between 1951 and 2016.	Changes in tree ingression between 1951 and 2016 was moderate. New trees apparent along the right edge of the quadrant, in which there are potentially new trees present within rocky bluff habitat in 2016.
Quadrant C 1951 – 2016	Changes in canopy closure between 1951 and 2016 was heavy. There is the potential for heavy infilling to have occurred within the main stand along the right edge of this quadrant.	Changes in tree ingression was heavy between 1951 and 2016. Present-day imagery suggests the potential for cross-slope movement of trees towards the meadow's drainage system to have occurred within this timeframe.
Quadrant D 1951 – 2016	Changes in canopy closure between 1951 and 2016 was heavy. A considerable infilling of trees is potentially suggested by the present-day imagery and appears widespread throughout the quadrant.	Changes in tree ingression was heavy between 1951 and 2016. The upper treeline in present-day imagery appears to have considerably more scattered, individual trees than what historical imagery suggests.

Strathcona Provincial Park – Flower Ridge, Price Pass

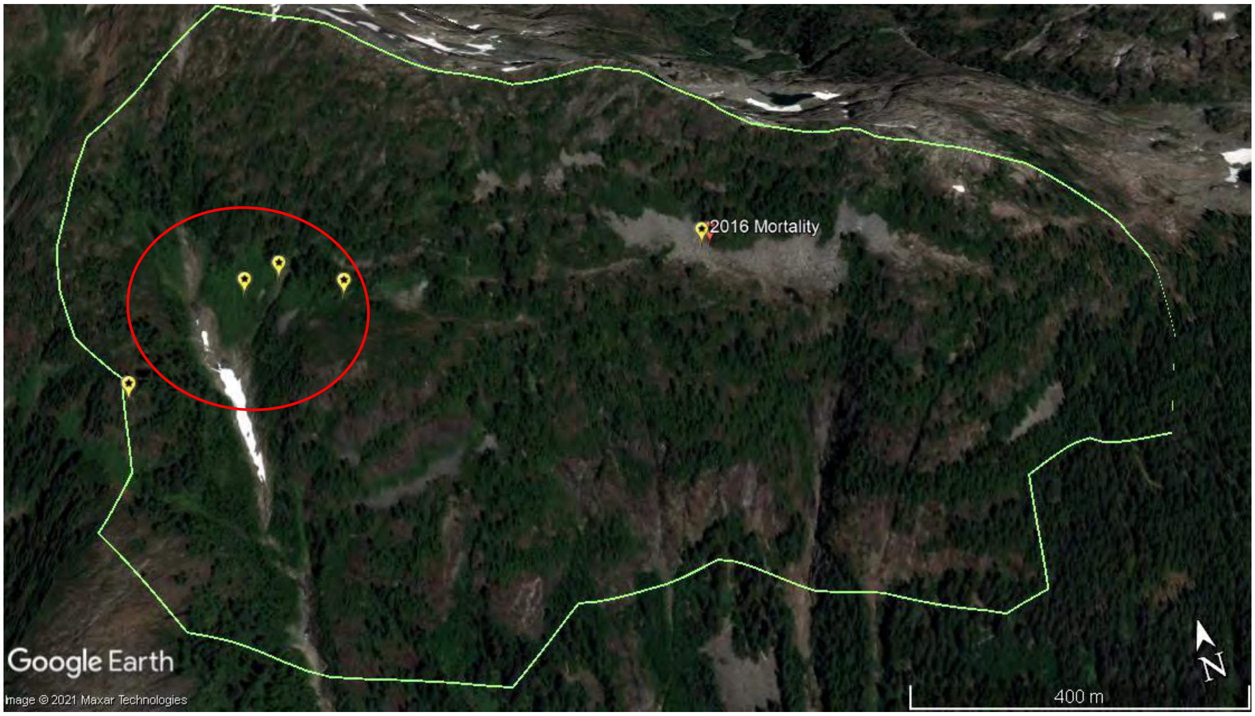

Figure 94 Flower Ridge's Price Pass present-day with marmot habitat locations and recent mortality events. Recommended focal area for future restoration project circled in red. (Google Earth Pro (K) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 26% between 1963 to 2016. Much of this change presented itself as canopy closure that favoured forested patches directly adjacent to talus field habitat and large drainage systems across the entire sub-location. Tree dynamics (as suggested by the 1963 historical imagery) appear to already have been open forest-meadow complexes widespread throughout the sub-location. This potentially attests to the present-day concern being primarily canopy closure, as the concern of tree ingression likely already occurred prior to 1963. It is important to note that there is some warping within Quadrant D, however, it was not extensive enough to warrant omitting this quadrant.

Recommended priority areas for future restoration projects should focus on Quadrants A and C, where many known marmot habitat features are located (Figures 24 and 25). This is an area that also appears to have the most intensive canopy closure. There is insufficient data available from the 2021 field season to suggest new areas of marmot occupation. As a result, it is recommended to address canopy closure within this drainage system where there is known historical marmot occupation, while updating present-day areas of occupation within the following field season. Where resources are available, assessing occupation status and present-day tree ingression within the large talus field in Quadrant B can be an additional priority (Figure 25). This talus field hosts one marmot habitat feature and one previous mortality location and is also surrounded by forests that appear to have undergone moderate levels of canopy closure within the comparison timeframe (Figure 25). Getting an accurate idea of present-day marmot occupation and the present-day extent of tree ingression here can help determine whether this talus field is at risk of shrinking in addition to the large drainage system in Quadrants A and C.

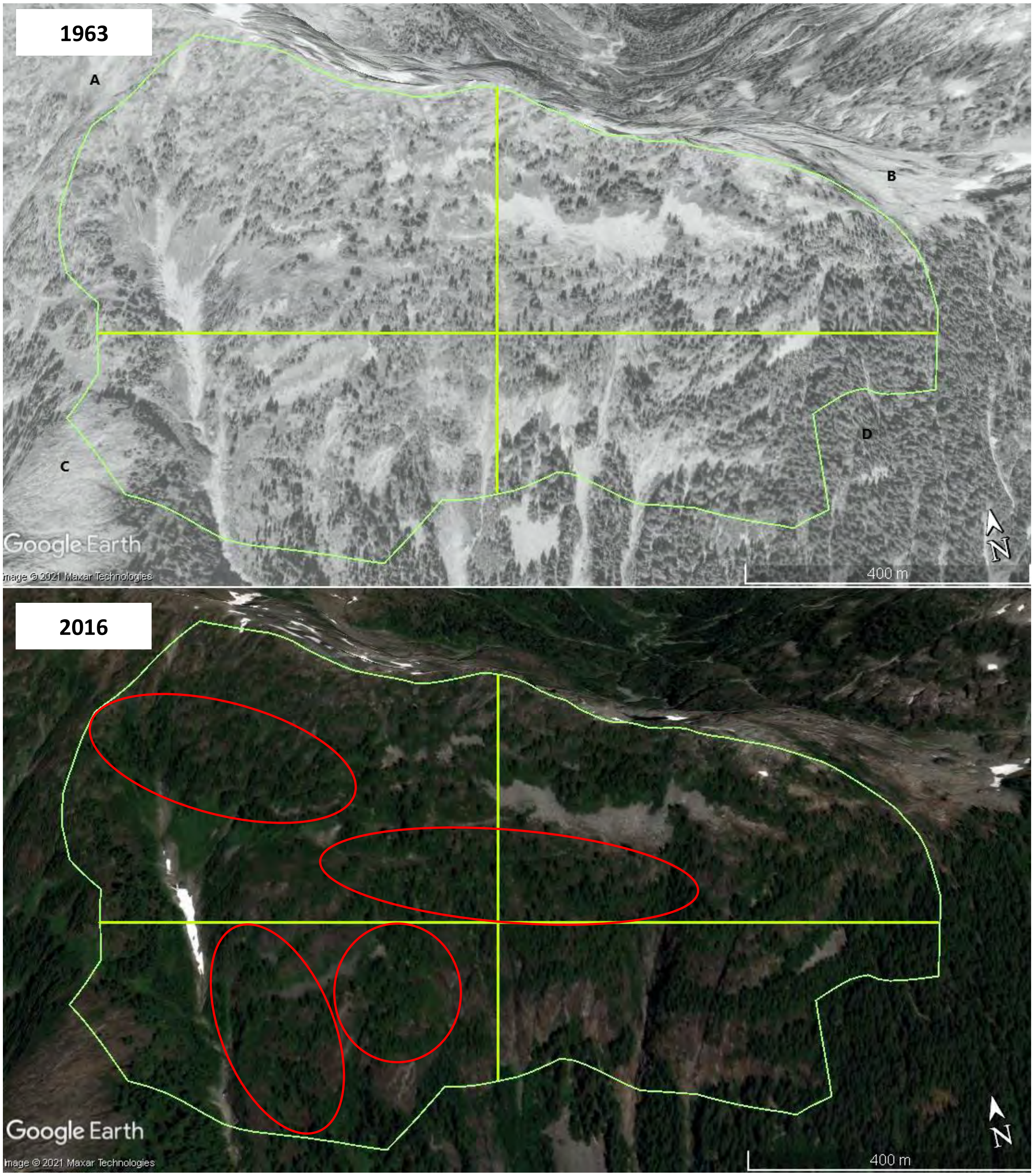

Figure 95 Flower Ridge, Price Pass Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (K) 7.3.4.8248 (64-bit) 2016) and (GeoBC Flower Ridge 2021)).

Table 23. *Flower Ridge, Price Pass Analysis Results – Estimated % Tree Cover.*

Flower Ridge, Price Pass	Estimated % Tree Cover
Quadrant A (1963)	30%
Quadrant A (2016)	50%
Quadrant B (1963)	25%
Quadrant B (2016)	40%
Quadrant C (1963)	50%
Quadrant C (2016)	70%
Quadrant D (1963)	70%
Quadrant D (2016)	75%
1963 Average % Tree Cover: 43.75%	
2016 Average % Tree Cover: 58.75%	
Relative Change in Average % Tree Cover: 26% increase	

Table 24. *Flower Ridge, Price Pass Analysis Results – Qualitative observations on changes in tree growth.*

Flower Ridge Price Pass	Canopy Closure?	Tree Ingression?
Quadrant A 1963 – 2016	Changes in canopy closure was heavy between 1963 and 2016. This was most notable within forested sections above the main drainage system in Quadrant A.	Tree ingression in the form of treeline movement or the expansion of forest patches is not notable between 1963 and 2016.
Quadrant B 1963 – 2016	Changes in canopy closure was moderate between 1963 and 2016. Canopy closure was most prominent amongst forest patches adjacent to talus field habitat.	Tree ingression in the form of treeline movement or the expansion of forest patches is not notable between 1963 and 2016.
Quadrant C 1963 – 2016	Changes in canopy closure was heavy between 1963 and 2016. Canopy closure was most notable just above the main drainage system of in Quadrant C.	Tree ingression in the form of treeline movement or the expansion of forest patches is not notable between 1963 and 2016.
Quadrant D 1963 – 2016	Slight warping in historical imagery present within this Quadrant. Changes in canopy closure appear to be moderate-heavy between 1963 and 2016. Much of this change appeared to be most prominent within forests directly adjacent to talus field habitat.	Tree ingression in the form of treeline movement or the expansion of forest patches is not notable between 1963 and 2016.

Strathcona Provincial Park – Flower Ridge, Cream Lake

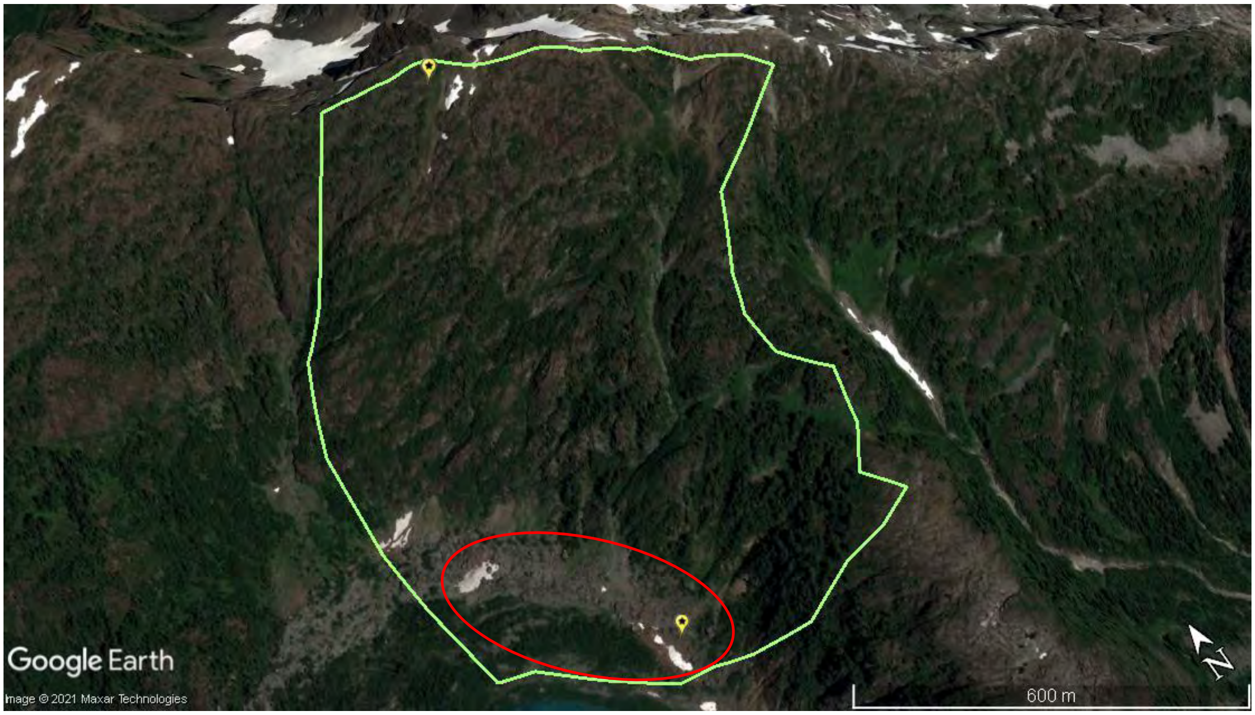

Figure 96 Flower Ridge's Cream Lake present-day with marmot habitat locations. Recommended focal area for future restoration project circled in red. (Google Earth Pro (L) 7.3.4.8248 (64-bit) 2016).

Average % tree cover was estimated to have increased by 55% between 1963 to 2016. Canopy closure was most intensive in areas of historical open forests, while tree ingression/forest expansion was heaviest in open talus field habitat. This sub-location does not have a considerable amount of data on marmot habitat features; however, previous release sites are currently surrounded by intensive tree ingression.

Recommended priority areas for future restoration projects should focus on Quadrants C and D where tree ingression appeared to be the heaviest, as well as in the vicinity of one of two previous marmot release sites (Figures 26 and 27). It is important to gain further information on additional occupied marmot habitat features to determine whether this low-lying talus field above Cream Lake of heightened tree ingression is truly the best area to focus restoration efforts.

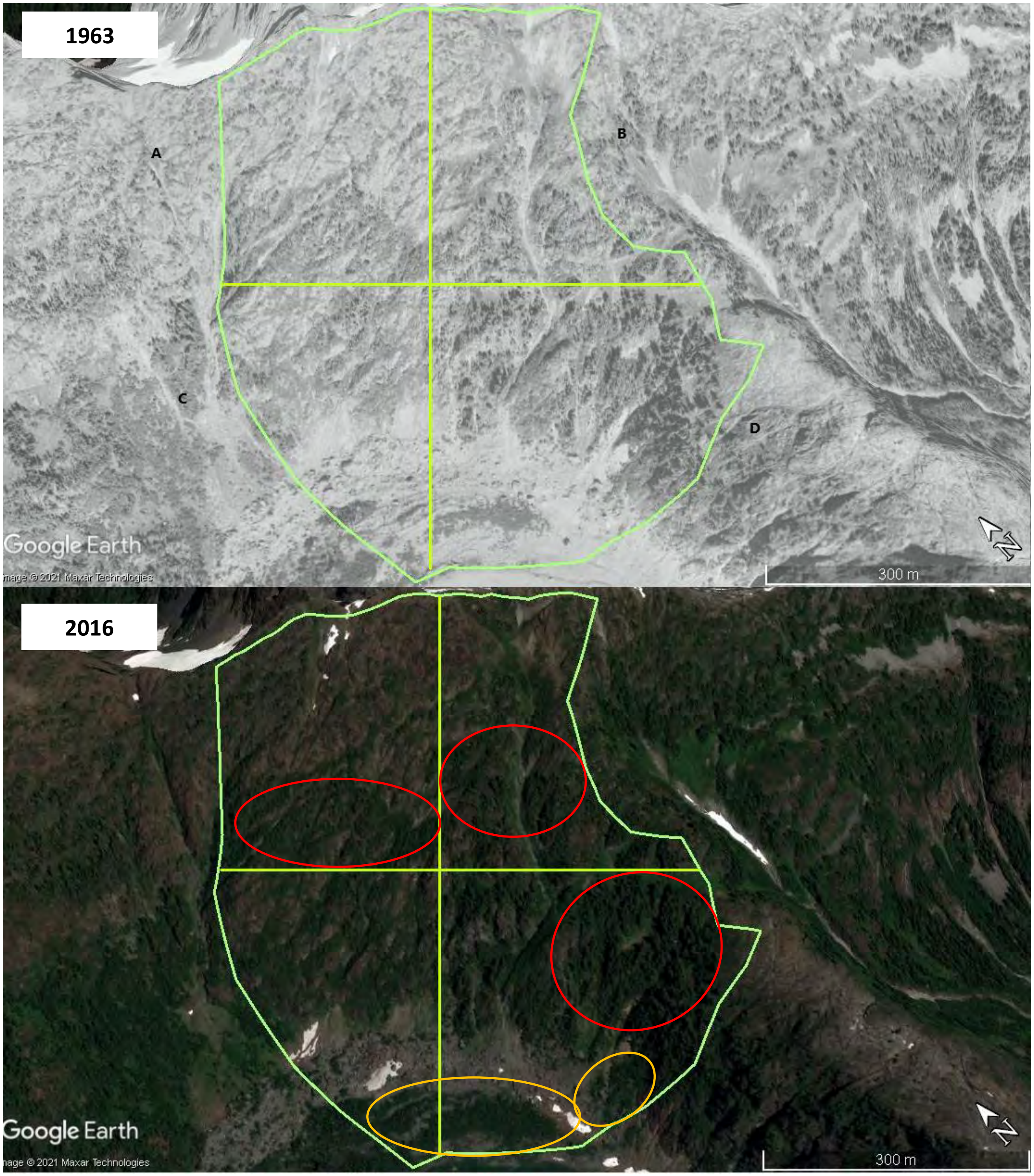

Figure 97 Flower Ridge, Cream Lake Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (L) 7.3.4.8248 (64-bit) 2016) and (GeoBC Flower Ridge 2021)).

Table 25. *Flower Ridge, Cream Lake Analysis Results – Estimated % Tree Cover.*

Flower Ridge, Cream Lake	Estimated % Tree Cover
Quadrant A (1963)	35%
Quadrant A (2016)	50%
Quadrant B (1963)	25%
Quadrant B (2016)	50%
Quadrant C (1963)	20%
Quadrant C (2016)	60%
Quadrant D (1963)	25%
Quadrant D (2016)	75%
1963 Average % Tree Cover: 26.25%	
2016 Average % Tree Cover: 58.75%	
Relative Change in Average % Tree Cover: 55% increase	

Table 26. *Flower Ridge, Cream Lake Analysis Results – Qualitative observations on changes in tree growth.*

Flower Ridge, Green Lake	Canopy Closure?	Tree Ingression?
Quadrant A 1963 – 2016	Changes in canopy closure was moderate between 1963 and 2016. Canopy closure was most intense at lower elevations of this quadrant, just below bare cliffs.	Changes in tree ingression was moderate-heavy between 1963 and 2016. Tree ingression is most notable within the upper half of this quadrant.
Quadrant B 1963 – 2016	Changes in canopy closure was moderate between 1963 and 2016. This was most concentrated just above a large drainage feature within Quadrant B, in which patches of trees standing in 1963 appear to have filled in considerably since then.	Changes in tree ingression was minimal between 1963 and 2016. No notable areas of forest movement/expansion due to tree ingression was observed, however, there is room to suggest a slight increase in the presence of scattered, individual trees.
Quadrant C 1963 – 2016	Changes in canopy closure was moderate between 1963 and 2016, but was isolated to a very small portion of Quadrant C, just above a low-angle talus field at the bottom of Quadrant C.	Changes in tree ingression was moderate-heavy between 1963 and 2016, most notable within the low-angle talus field at the bottom of Quadrant C. This patch of trees has expanded considerably between 1963 and 2016.
Quadrant D 1963 – 2016	Changes in canopy closure was moderate between 1963 and 2016. Much of the change occurred within upper forested reaches of Quadrant D. Forests in 1963 appeared to be open - consisting of patchy, well-spaced trees. Since then, forests appeared to have infilled to create dense, contiguous forest.	Changes in tree ingression was heavy between 1963 and 2016. The area of the most intensive change was the low-angle talus field at the bottom of Quadrant D. This patch of trees has expanded considerably.

Strathcona Provincial Park – Castlecrag Mountain, Main Meadow/West Talus

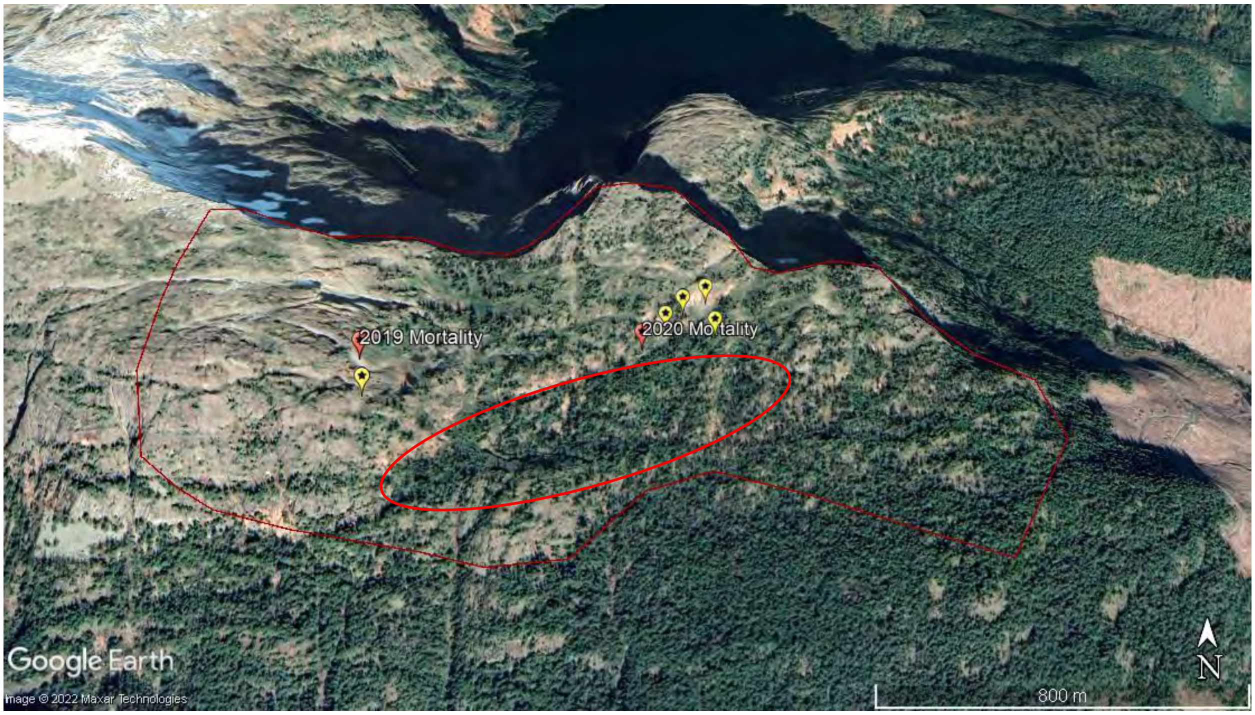

Figure 98 Castlecrag Mountain's Main meadow and West Talus present-day with marmot habitat locations and recent mortality locations. Recommended focal area for future restoration project circled in red. (Google Earth Pro (I) 7.3.4.8248 (64-bit) 2018).

Average % tree cover was estimated to have increased by 35% between 1977 to 2018. West Talus is within Quadrant A, while the Main Meadow is within Quadrant B. Canopy closure appeared to be the largest concern for these two sub-locations, as several micro-meadow features at lower elevations are now filled within 2018. Tree ingression is evident, but the historical imagery suggests moderate levels of change has occurred within the comparison timeframe. Canopy closure appears to be the most prevalent issue.

Recommended priority areas for future restoration projects should focus on canopy closure hotspots where forests appear to have filled in the most between 1977 and 2018 (Figure 28). In particular, the shelf feature spanning across Quadrants A and B has experienced heavy levels of canopy closure and is located just below all marmot habitat features and mortality locations (Figures 28 and 29). Addressing this location can hopefully enhance sightlines into areas of dense forest where terrestrial predators may be concentrated and sourced.

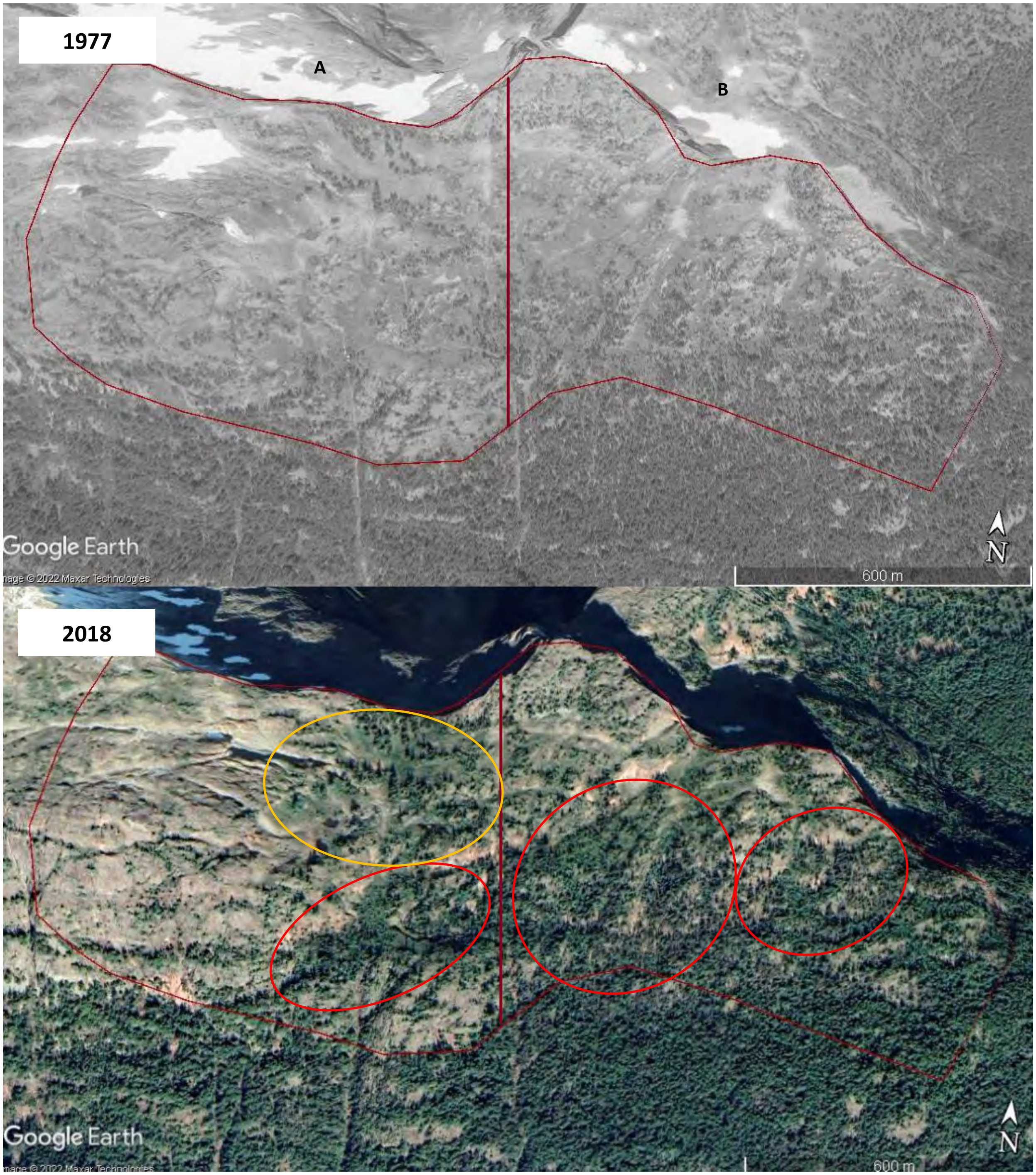

Figure 99 Castlecrag Mountain, Main Meadow and West Talus Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (I) 7.3.4.8248 (64-bit) 2018) and (GeoBC Castlecrag Mountain 2021)).

Table 27. Castlecrag Mountain, Main Meadow & West Talus Analysis Results – Estimated % Tree Cover.

Castlecrag Mountain, Main Meadow & West Talus	Estimated % Tree Cover
Quadrant A (1977)	25%
Quadrant A (2018)	40%
Quadrant B (1977)	40%
Quadrant B (2018)	60%
1977 Average % Tree Cover: 32.5%	
2018 Average % Tree Cover: 50%	
Relative Change in Average % Tree Cover: 35% increase	

Table 28. Castlecrag Mountain, Main Meadow & West Talus Analysis Results – Qualitative observations on changes in tree growth.

Castlecrag Mountain, Main Meadow & West Talus	Canopy Closure?	Tree Ingression?
Quadrant A 1977 – 2018	Changes in canopy closure between 1977 and 2018 was heavy. A relatively open drainage system within 1977 has nearly filled in within 2018.	Changes in tree ingression between 1977 and 2018 is minimal-moderate. A slight increase in the number of individual trees scattered throughout the upper meadow in Quadrant A is apparent.
Quadrant B 1977 – 2018	Changes in canopy closure between 1977 and 2018 was heavy. Many micro-meadow features within 1977 have since been infilled in 2018.	Changes in tree ingression between 1977 and 2018 appeared to not be a large concern within Quadrant B.

Strathcona Provincial Park – Castlecrag Mountain, Talus Bowl

Figure 100 Castlecrag Mountain's Talus Bowl present-day with marmot habitat locations and recent mortality locations. Recommended focal area for future restoration project circled in red. (Google Earth Pro (J) 7.3.4.8248 (64-bit) 2018).

Average % tree cover was estimated to have increased by 51% between 1977 to 2018. Canopy closure appeared to be the largest concern for this sub-location, wherein several micro-meadow features at lower elevations are now filled in 2018. Tree ingression is evident, however historical imagery suggests that treeline dynamics already consisted of well-established scattered trees widespread throughout the sub-location in 1977. This suggests that much of the tree ingression within this sub-location has occurred prior to 1977, and potentially explains why much of the changes in tree growth occurred as canopy closure after this year.

Recommended priority areas for future restoration projects should focus on present-day areas of tree ingression hotspots, rather than canopy closure. This is because canopy closure appears so advanced that addressing tree ingression hotspots around marmot habitat features would be the fastest way of partially restoring sightlines. Actions should target tree ingression occurring within Quadrant A, where much of the canopy closure has yet to occur and tree ingression (as evidenced by young, scattered trees) are closest to marmot habitat features (Figure 30 and Figure 31). Where resources are available, it would be worthwhile moving downslope from this area into Quadrant B where canopy closure is most concerning, however, triaging tree ingression is recommended as a first priority (Figure 31).

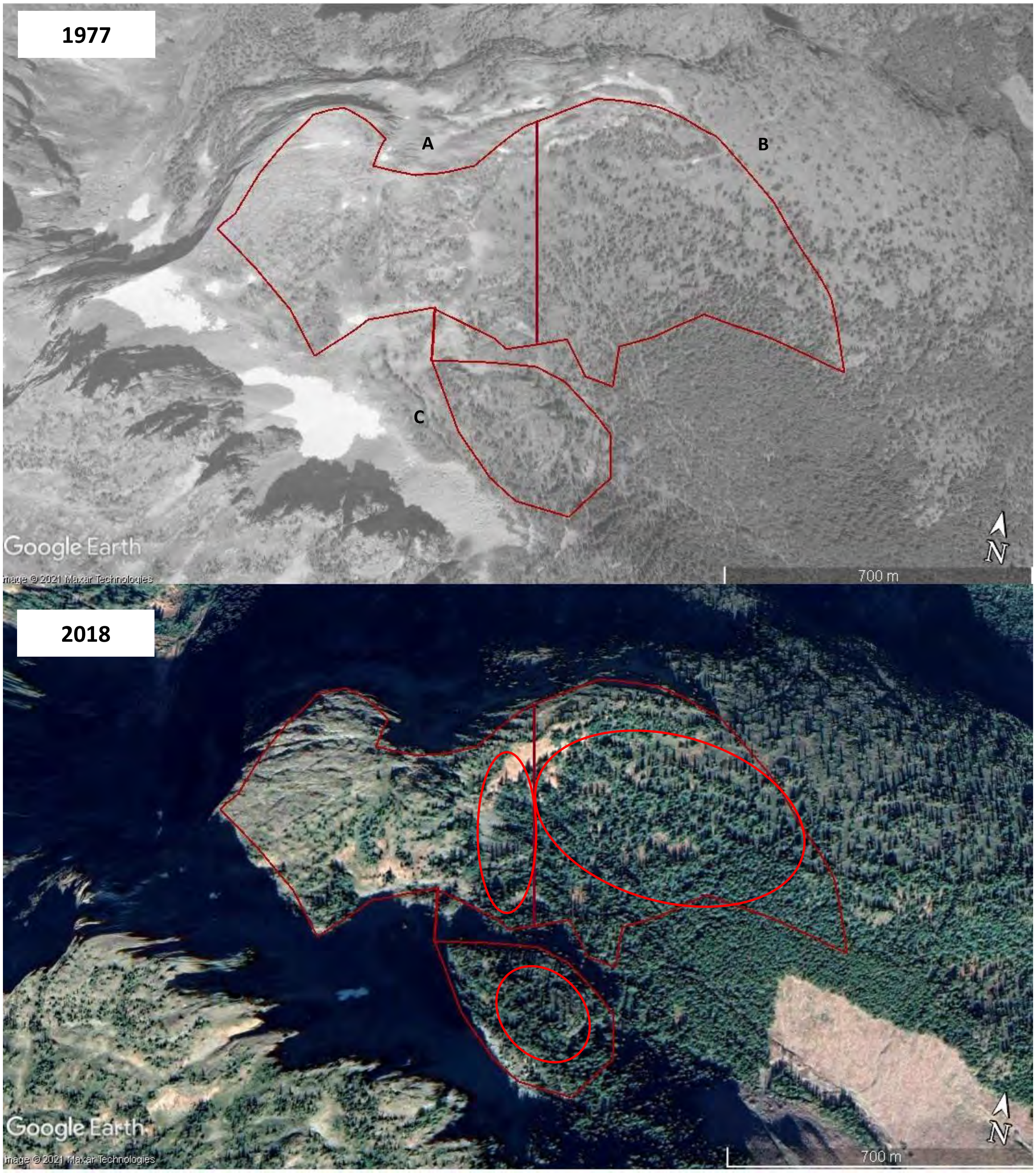

Figure 101 Castlecrag Mountain, Talus Bowl Analysis Quadrants. Tree ingression hotspots encircled in orange, canopy closure hotspots encircled in red. ((Google Earth Pro (J) 7.3.4.8248 (64-bit) 2018) and (GeoBC Castlecrag Mountain 2021)).

Table 29. *Castlecrag Mountain, Talus Bowl Analysis Results – Estimated % Tree Cover.*

Castlecrag Mountain, Talus Bowl	Estimated % Tree Cover
Quadrant A (1977)	15%
Quadrant A (2018)	30%
Quadrant B (1977)	40%
Quadrant B (2018)	75%
Quadrant C (1977)	25%
Quadrant C (2018)	60%
1977 Average % Tree Cover: 27%	
2018 Average % Tree Cover: 55%	
Relative Change in Average % Tree Cover: 51% increase	

Table 30. *Castlecrag Mountain, Talus Bowl Analysis Results – Qualitative observations on changes in tree growth.*

Castlecrag Mountain, Talus Bowl	Canopy Closure?	Tree Ingression?
Quadrant A 1977 – 2018	Changes in canopy closure between 1977 and 2018 was heavy. Canopy closure was most concentrated along the right edge of this quadrant, wherein several micro-meadows have infilled during this timeframe.	Changes in tree ingression between 1977 and 2018 was moderate. Tree ingression was most notable along the right edge of this quadrant, wherein the upper forest line of dense, contiguous forest is notably higher in elevation.
Quadrant B 1977 – 2018	Changes in canopy closure between 1977 and 2018 was heavy. Forests dominating this quadrant within 1977 were primarily open and intermixed with meadow habitat. In 2018, this has since infilled, creating contiguous forest that is now widespread throughout the quadrant.	Changes in tree growth between 1977 and 2018 appeared to primarily occur as canopy closure within Quadrant B.
Quadrant C 1977 – 2018	Changes in canopy closure between 1977 and 2018 was heavy. Open sections of scattered trees have since been filled in, thus being replaced by contiguous, dense forest.	Changes in tree growth between 1977 and 2018 appeared to primarily occur as canopy closure within Quadrant C.

Table 31. Results summarized, in order of highest average change in % tree cover to lowest.

Colony/Sub-location	Core Marmot Habitat Elevation (estimate)	Aspect	Average change in tree cover %	Focal problems
Green Mountain / Snowbowl	1400 m	E Facing	68%	Heavy tree ingression reducing available talus field habitat.
Mount Arrowsmith / South Meadow	1450 m	W Facing	68%	Significant forest line expansion upslope into meadow habitat due to tree ingression.
Green Mountain / Summit West	1450 m	W Facing	63%	Rapid tree ingression throughout entirety of meadow resulting in large, contiguous forests.
Haley Lake / Bell Creek	1200 m	W Facing	55%	Tree ingression from peripheral edges of meadow descending into central meadow habitat and drainage systems.
Flower Ridge / Cream Lake	1200 m	SW Facing	55%	Heavy tree ingression directly adjacent to Cream Lake. Heavy canopy closure at mid-elevations.
Castlecrag Mountain / Talus Bowl	1550 m	SE Facing	51%	Heavy canopy closure in lower elevation forest-meadow complexes. Present-day tree ingression directly adjacent to marmot habitat.
Mount McQuillan / Main Meadow	1400 m	SE Facing	36%	Tree ingression sectioning off areas of high marmot use and travel. Potential for tree ingression to impact lower talus field habitat wherein 2021 field observations suggest marmot occupation.
P Mountain / Main Meadow	1250 m	S Facing	36%	Tree ingression expanding into core marmot habitat. Canopy closure of pre-existing stands throughout potential travel corridors between meadows.
Castlecrag Mountain / Main Meadow and West Talus	1600 m	SW Facing	35%	Heavy canopy closure directly below marmot habitat features.
Haley Lake / Main Meadow	1200 m	S Facing	35%	Canopy closure reducing micro-meadow availability and size. Tree ingression upslope into areas with highest concentration of marmot habitat features and historical mortalities.
Green Mountain / North Green	1400 m	N Facing	32%	Canopy closure reducing micro meadows in size.
Mount McQuillan / West Talus	1400 m	NW Facing	32%	Canopy closure in areas of known marmot traffic/travel. Tree ingression encroaching lower elevation talus field habitat, wherein 2021 field observations suggest marmot occupation.
Flower Ridge / Price Pass	1500 m	SW Facing	26%	Canopy closure is heavy within drainage systems, especially where marmot habitat features are located.
Heather Mountain / Main Meadow	1200 m	S Facing	26%	Tree ingression upslope into meadow habitat.
Mount Hooper / Main Meadow	1400 m	W Facing	20%	Tree ingression downslope from summit ridgeline into marmot habitat.

Discussion

Due to a variety of site-specific factors that determine favourable tree growth conditions, it is difficult to tease out specific direction and/or patterns within changes in percent tree cover. With that said, analysis results undoubtedly suggest that tree growth patterns over the past 70 years have considerably altered core marmot habitat for in ways that likely increase marmot mortality. Incidental observations during the 2021 field season saw several abandoned marmot habitat features found in densely forested areas. This strongly attests to the level of change that has occurred within VIM habitat. Across many of the analyzed sites between the comparison timeframes, there has been at the very least a 25% increase in tree cover within core marmot habitat, with many sites seeing upwards of 35-50% increase in tree cover. Without appropriate action, these numbers are expected to increase within the coming years as climate change progresses.

Regarding tree ingression specifically, analyses at several different sites suggest that the spatial distribution of encroaching trees favours movement of marmot occupation towards the center of meadows as well as downslope into drainage systems. This pattern was observed at sites such as Green Mountain's Snowbowl, Haley Lake's Bell Creek, Mount McQuillan's West Talus, as well as Flower Ridge's Price Pass and Cream Lake. Assessments in canopy closure across all sites suggest that historically forested areas at low elevations saw the most dramatic increases within the comparison timeframes. For example, the lower half of Mount Arrowsmith's South Meadow historically consisted of open forest intermixed with large micro meadows. Upon analysis, canopy closure appeared to be heaviest and isolated within this area. Present-day imagery showed this area to now be comprised of dense subalpine forest with very few micro meadows. The same patterns were seen at sites such as Castlecrag Mountain's Talus Bowl, Haley Lake's Main Meadow, and Green Mountain's Summit West.

As a result of these findings, additional increases in stalking cover within core marmot habitat at lower elevations, at the peripheral edges of meadows, and within open forest-meadow complexes can be reasonably expected within the coming years.

While climate change is known to be a driving force in enhanced tree growth within subalpine meadows, it is important to also consider the synergistic role anthropogenic disturbance plays in further accelerating tree growth. An example of this is Green Mountain's Summit West, which historically operated as a ski resort. The development and subsequent deactivation of roads and ski runs may have played a role in the widespread expansion of forests within this sub-location. This may suggest heightened risk to marmots in areas with historical logging. Additional examples in which new clearcuts have developed between 1946 and 2018 include Mount Hooper's Main Meadow, P Mountain's Main Meadow, Castlecrag Mountain's Talus Bowl, and Haley Lake's Bell Creek.

Similarly, it is possible that fire suppression has also contributed to tree ingress. The role of fire in maintaining marmot habitat is unknown. Given the relatively low volume of fuel in marmot habitat, it is possible that irregular low intensity fires contributed to maintaining tree free areas in the sub-alpine, while not impacting marmots who could effectively shelter underground. Fire suppression may therefore have contributed to tree ingress.

Limitations

During the image overlay process, all historical imagery was inspected for a series of conditions that consider whether the image is appropriate for analysis. The following was assessed during the overlay process: overexposure in photographs, seasonality of image/presence of snow, and warping at the sub-location level. These are the primary limitations that were encountered during this project. The following addresses the limitations, where they were seen, and the mitigations taken to counteract their effect on imagery analysis.

1) *Overexposure in photographs*: In which historical imagery was overexposed during some stage of image processing. This results in overly bright areas and reduces the ability to see finer details such as individual trees within an image. This limitation was only seen within the historical imagery for P Mountain's Main Meadow. Mitigations included turning down screen brightness during imagery analysis, as well as altering the brightness of the image during assessment of lighter areas.

2) *Image seasonality/snow presence:* The presence of snow depends on what time of year the image was taken. As well, historical snowpack levels often stay high well into the growing season, and so there is a very small window during which imagery is suitable to compare with present-day imagery (which typically lacks snow). Snowpack makes it difficult to infer the extent of tree ingression, as snow presence only reveals larger trees. Areas such as Haley Lake's Bell Creek had an issue of snow presence. This was mitigated by assuming more trees are present and altering tree cover % based on this. As well, the amount of snow in Bell Creek was manageable, as there were many other areas in the sub-location without snow that provided a representative estimate of tree cover %.

3) *Warping:* This is a prevalent error across both GeoBC's historical aerial imagery and Google Earth's base map imagery. This is because the imagery used by both institutions has not been orthorectified, otherwise known as raw aerial imagery. The process of orthorectification involves correcting all pixels within a given image to the real-life position of the features within that pixel as if it were viewed directly overhead. This process accounts for the warping in aerial imagery due to aircraft movement and tilt, flights over mountainous terrain, light refraction, and other known sources of error in raw imagery (McCarty 2014). As a result, warping in raw aerial imagery covering marmot habitat is inevitable. Areas that featured manageable levels of warping included: Mount McQuillan's Main Meadow (present-day imagery, Quadrants A and C) and Mount Hooper's Main Meadow (historical imagery, Quadrant B). Orthorectification is outside of the scope of this project, therefore the Foundation has decided upon an "acceptable" amount of warping. As well, a series of mitigations were added to ensure the highest possible accuracy in an overlay of historical and present-day imagery. This includes adjusting overlays to a larger scale (i.e. adjusting image overlays to each sub-location, rather than per colony), as well as using non-warped, unchanging terrain features (prominent gullies, ridgelines, lakes) as landmarks where available.

Future Recommendations

Broadly speaking, future restoration efforts should focus on the peripheral edges of meadows, infilling trees within micro-meadows, and obvious draws (such as the center of meadows or drainages), particularly if these features are present at lower elevations and adjacent to marmot habitat features within a given sub-location. It is suspected that these areas would see the leading edge of tree ingression, and thus be primarily made up of densely packed young trees. As a result, these areas would make for an efficient means to restore sightlines. Travel corridors between sub-locations could be an additional priority focus for future restoration efforts. Thinning out stands with heavy canopy closure through travel corridors (for example, the recommended focal areas for Mount McQuillan's West Talus) could help mitigate potential mortality events for travelling marmots. Overall, future restoration efforts should always be site-specific and present-day tree distribution should be verified prior to restoration activities.

Future analyses should focus on high-priority sub-locations that were not analyzed this year due to poor historical imagery. This includes Green Mountain's SE Talus and P Mountain's NW Talus. Recent year observations at these sites saw dense forests and tree growth, as well as an increase in the number of predation events directly in core marmot habitat. While imagery between 1940-1950 is not available for these sites, analyzing imagery from later years would still be worthwhile to adequately document change. Additional sites suitable for future analyses would be medium and low priority sites, as per Appendix D. Documenting changes in tree growth patterns amongst these sites could provide a holistic overview of change to core marmot habitat across the entire range of *M. vancouverensis*, as this would include all 3 metapopulations.

Improving baseline knowledge should be the next step to inform future restoration efforts. First, the implementation of an ongoing photo monitoring program would be suitable to increase aerial imagery inventory. Sites suitable for this program would include any area that lacks historic imagery, such as colonies within Strathcona Provincial Park. This includes Tibetan Mountain, Mount Phillips, and Mount Henshaw (Appendix D). Additional sites suitable for a photo monitoring program due to poor historic imagery include Green Mountain's SE Talus, Mount McQuillan's Main Meadow (some quadrants omitted), Hooper Mountain's Main Meadow (warping), P Mountain's Main Meadow (over-exposure) and P Mountain's NW Talus.

LIDAR mapping of marmot habitat would provide detailed baseline information about the height of vegetation. If repeated in future years, this technology would allow more detailed comparisons of changes in tree growth and vegetation structure than can be achieved with aerial photograph or satellite imagery alone.

Secondly, addressing knowledge gaps surrounding mitigation actions is necessary to appropriately inform how to undertake future restoration projects. For instance, there is a need to understand how seasonal avalanche cycles influence marmot habitat features. To address this knowledge gap, it is recommended to measure snow energy annually within marmot habitat, with the goal of quantitatively estimating how avalanches may influence burrow integrity.

Overall, there is undoubtedly ongoing change occurring within the critical habitat of *Marmota vancouverensis*. Restoration of sub-alpine meadows to re-introduce historical sightlines is likely to increase individual survival. It is imperative to improve efforts through an ongoing update of restoration methods and mitigation actions. This guide recommends future actions to address knowledge gaps, monitor the efficacy of restoration, and broaden analyzed sites across all 3 metapopulations. Additionally, each sub-location's analysis results aim to provide guidance on areas to be prioritized for future restoration projects at each site. These results serve to further augment on-the-ground assessments that determine areas of concern at a given sub-location when considering sightline restoration to historical baselines.

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Appendices

Appendix A – Guiding Principles for Clearing Work

A. Objective for clearing VIM habitat: To improve the survival of individual marmots and the persistence of colonies. Clearing work may help to accomplish this by improving the ability of marmots to detect approaching predators, thus lowering predator success. An additional anticipated benefit is the restoration of conditions conducive to the re-establishment of natural subalpine/alpine vegetation, which will provide additional forage options for Vancouver Island marmots.

B. Short-term measures of success:

1. Increase in number of sightlines within marmot habitat.
2. Increase in length of sightlines, especially between high-use areas.
3. Increase in % of marmot habitat within a sublocation that is estimated to have high visibility.

C. Target vegetation:

1. Small trees (diameter <15cm).
2. Low-lying branches (0-120cm off the ground) of large trees (diameter >15cm).

D. Restrictions on clearing activities

1. Trees within 10m from an entrance to a hibernaculum will not be removed or modified. This minimum buffer distance will be expanded on a case-by-case basis to include any trees with likely influence on the form or function of a marmot hibernaculum.
2. Trees upslope of marmot hibernacula will not be removed or modified.
3. Shrubs and other tall, non-arboreal vegetation will not be targeted in clearing efforts.
4. When tree removal is planned for a site and the growth of invasive species may be a concern, consider using a two-stage approach in which the lower limbs of trees are removed the year prior to the tree being cut down.

E. Disposal of cleared materials

Materials created by clearing activities should be disposed of in such a way as to minimize any negative impacts on marmots.

- a. When controlled burning is considered by landowners to be a safe and reasonable activity, this would be the preferred disposal method.
  - i. Newly-cut materials should be gathered and made into small piles (in terms of both width and height), and situated as far from marmot areas as is possible/reasonable.
  - ii. A controlled burn can be conducted the year after the materials were cut, and will be coordinated through the landowners.
- b. When controlled burning is not an option, materials should be:
  - i. Scattered in a thin layer around the site, with care not to cover potential marmot forage species or create new piles of stalking cover; or
  - ii. Wedged into areas that already provide significant stalking cover on or outside the fringes of marmot habitat.

F. Recommended actions:

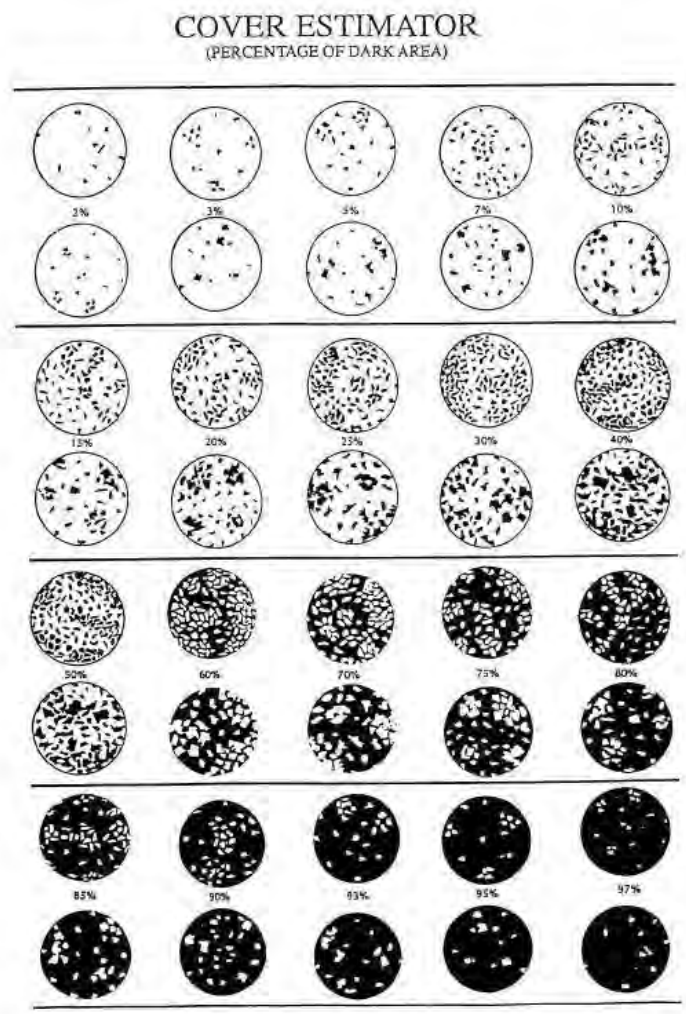
1. Pre-work assessment to evaluate vegetation composition and cover in target areas.
2. Identification of hibernacula and sensitive areas.
3. Removal of small trees.
4. Limbing of lower branches of large trees.
5. Disposal of the materials created during clearing activities.
6. Post-work assessment to record status of areas most likely to change.
7. Future monitoring, to document the timing and magnitude of changes.

Appendix B – Focal sites for imagery analysis

Meta-population	Colony	# of sub-locations	Priority	Reason for analysis	Rationale for sub-location analysis	Colour-code	Jurisdiction
Strathcona Provincial Park	Castlecrag Mountain	3	High	Anecdotal accounts of dense tree growth directly in marmot habitat. High numbers of previous mortalities	All sub-locations analyzed.	Burgundy	BC Parks
Strathcona Provincial Park	Flower Ridge	2	High	Potential for heavy tree growth in area. Data deficient colony, aiming to get as much information as possible.	All sub-locations analyzed.	Light green	BC Parks
Nanaimo Lakes	Mount Arrowsmith	4-5	High Priority	Anecdotal accounts of heavy tree growth encroaching upwards into south meadow.	Only one sub-location analyzed (South Meadow). Extent of colony required more than one image, out of project scope. Re-ordering required as initial roll/frame combination featured heavy warping in targeted sub-location area.	Pink	Mount Arrowsmith Massif Regional Park
Nanaimo Lakes	Heather Mountain	1	High Priority	Heavy wildlife area, particularly at risk to terrestrial predation due to large elk and deer population.	All sub-locations analyzed (Main Meadow) – imagery suitable. Re-ordering required as initial roll/frame combination did not cover Heather Mountain.	Purple	Mosaic Forest Managemen t
Nanaimo Lakes	Haley Lake Ecological Reserve	2	High Priority	Heavy wildlife area and increased mortalities over recent years.	All sub-locations analyzed. Imagery suitable. Bell Creek and Main Meadow.	Yellow	BC Parks

Meta-population	Colony	# of sub-locations	Priority	Reason for analysis	Rationale for sub-location analysis	Colour-code	Jurisdiction
Nanaimo Lakes	P Mtn	3	High Priority	Heavy wildlife area, anecdotal observation of heavy tree growth in NW meadow over recent years.	Only one sub-location analyzed (Main Meadow). NW Meadow was not analyzed due to heavy warping in this area of the image.	Light blue	Mosaic Forest Management
Nanaimo Lakes	Mount McQuillan	3	High Priority	Heavy wildlife area with increasing accounts of predation events near core marmot habitat.	Only two sub-locations analyzed (Main Meadow and West Talus). East Steeps was not analyzed due to observed lack of trees (N facing)	Dark blue	Mosaic Forest Management
Nanaimo Lakes	Green Mountain	4	High Priority	Increasing observations of heavy tree ingression within sub-locations.	Only 3 sub-locations analyzed (Summit, N Green, and Snowbowl). Unable to analyze SE Talus due to heavy warping in this area of imagery.	Green	Ministry of Forest, Lands, Natural Resource Operations and Rural Development.
Nanaimo Lakes	Hooper Mountain	2	High Priority	Increasing observations of mortalities across new releases within main meadow.	Only one sub-location analyzed (main meadow) due to heavy warping in other sub-location.	Red	Mosaic Forest Management

Appendix C – Cover Estimator



(Barry 1994)

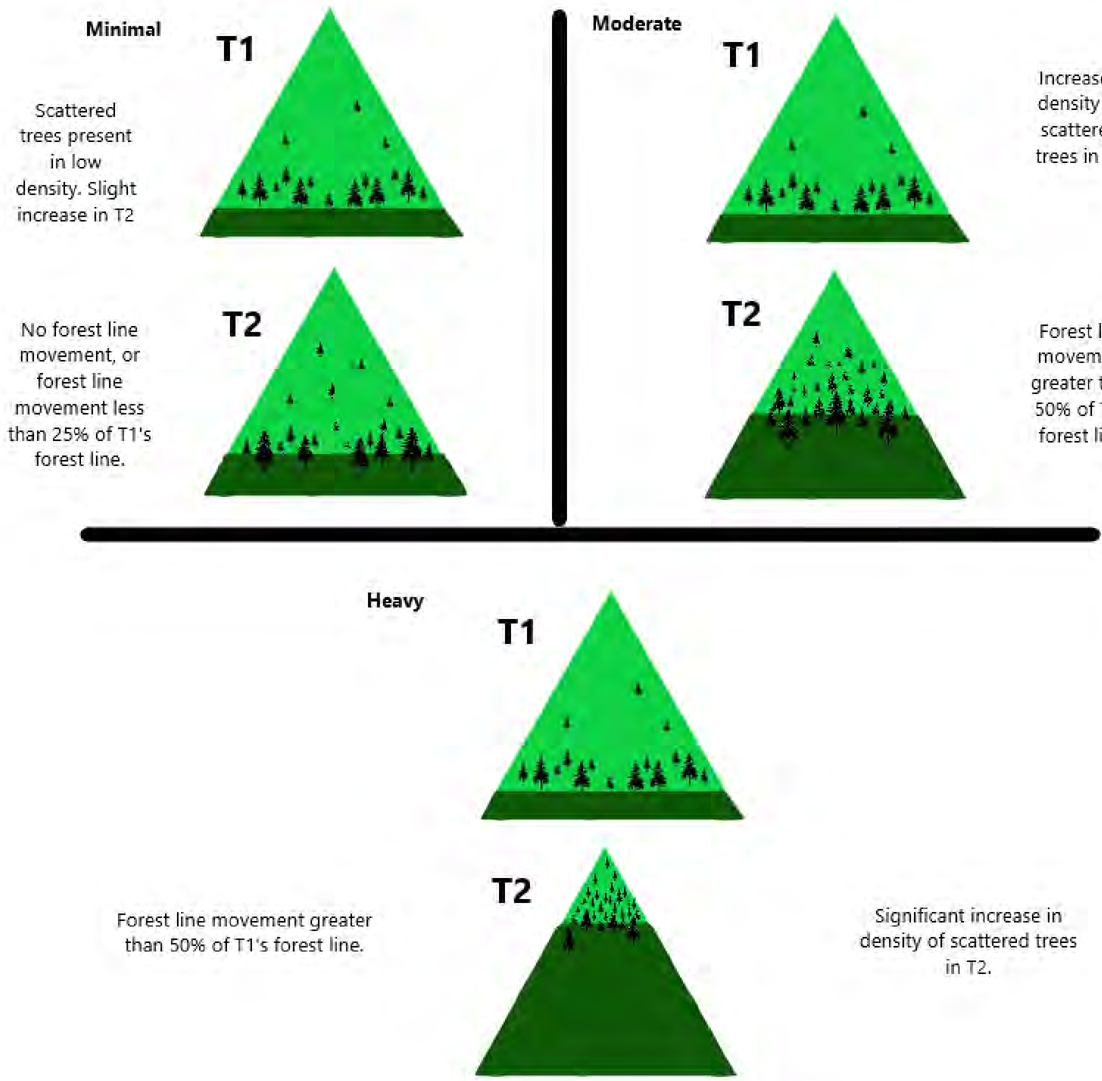
Appendix D – High, Medium and Low Priority Sites

Sites for tree ingress analysis were prioritized by Marmot Recovery Foundation staff based on an assessment of reported tree ingress observations by field teams, the number of predator related mortalities at each site, and the number of marmots at each site.

Colony	Metapopulation	Priority
Mount Arrowsmith	Nanaimo Lakes	High
Castlecrag Mountain	Strathcona	High
Heather Mountain	Nanaimo Lakes	High
Haley Lake	Nanaimo Lakes	High
P Mountain	Nanaimo Lakes	High
Mount McQuillan	Nanaimo Lakes	High
Green Mountain	Nanaimo Lakes	High
Mount Hooper	Nanaimo Lakes	High
Tibetan Mountain	Strathcona	Medium
Flower Ridge	Strathcona	Medium
Sadie Mountain	Nanaimo Lakes	Medium
Mount Moriarty	Nanaimo Lakes	Medium
Mount Becher	Strathcona	Medium
Mount Phillips	Strathcona	Low
Mount Henshaw	Strathcona	Low
Butler Mountain	Nanaimo Lakes	Low
Steamboat Mountain	Clayoquot Plateau	Low
Mount Douglas	Nanaimo Lakes	Low
Mount Gemini	Nanaimo Lakes	Low

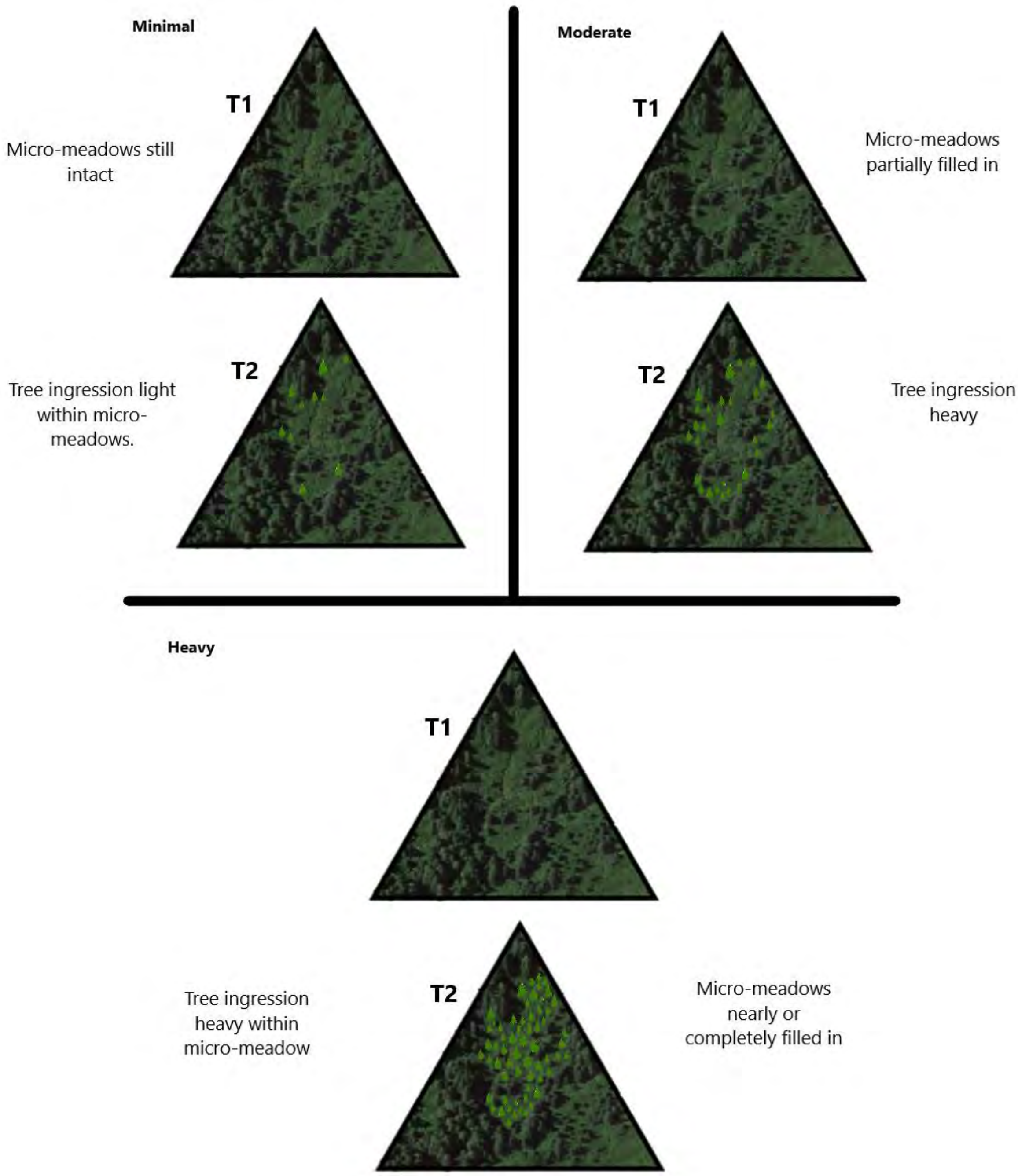
Appendix E – Tree ingression ranking

Minimal, moderate, and heavy rankings, wherein T1 represents historical conditions, and T2 represents present-day conditions. Forest line refers to the upper elevational extent of contiguous subalpine forest. Forest lines can move upslope, downslope, or across slope towards obvious draws (e.g. gullies or drainages).



Appendix F – Canopy Closure ranking

Minimal, moderate, and heavy rankings wherein T1 represents historical conditions and T2 represents present-day conditions. Micro-meadows refers to meadow habitat segregating what otherwise would have been dense forest. Canopy closure rankings would occur per quadrant. If a quadrant does not hold patches of dense forest and/or contiguous forest, there is no ranking applied for canopy closure.



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