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Ministry of Forests, Lands, Natural Resource Operations and Rural Development

Health of Young Stands: The challenge, the science, the future.

Science to Policy Forum-Part 2

A *Virtual Symposium* held November 17-18, 2020

Compiled by J.E. Brooks

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Goals

The first Science Policy Forum, in collaboration with Natural Resources Canada (NRCan), was held at the Pacific Forestry Centre, Victoria, B.C., on November 19 and 20, 2019. In a Discussion Group held at this Science Policy Forum the need for a second forum on the Health of Young Stands was proposed and the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) Forest Health group and NRCan organized and delivered the Health of Young Stands Forum. The goal of the Health of Young Stands Forum was to bring together forest managers, scientists and practitioners to share the most current science and field expertise available on the health of regenerating forests, to discuss potential implications for policy and decision makers, and to identify a road map to healthy and productive future forests.

Forest regeneration represents a significant financial investment and to ensure the health of young stands, we must address current knowledge gaps and challenges. Identifying and quantifying biotic and abiotic impacts, developing strategies to mitigate these impacts through science-based decision-making tools, reviewing provincial reforestation guidelines in the context of climate change, are all part of a process to ensure future forests are resilient and meet a range of values identified by British Columbians.

Subject area specialists spoke on a wide range of topics and two facilitated breakout sessions provided an opportunity for participants to discuss management practices, science/knowledge gaps and other critical issues facing forest regeneration in British Columbia.

The forum was held virtually due to the ongoing Covid-19 pandemic and associated restrictions. Presenters pre-recorded their talks, which were made available to participants on a public YouTube channel (https://www.youtube.com/channel/UCnYcsCYbBAEsfwQnClCFmnQ) that went live on November 17, 2020. The following week, on November 24, 2020, two Discussion Groups were hosted online. Tim Ebata (FLNRORD) moderated the first discussion group, *Science and Research*, and Stefan Zeglen (FLNRORD) moderated the second discussion group, *Policy*. There was a total of 131 registrants and up to 100 individuals participated in one or both of the Discussion Groups.

Acknowledgements

We would like to acknowledge the Lekwungen speaking-peoples, and the Songhees and Esquimalt Nations whose historical relationships with the land continue to this day.

Many thanks to all the presenters who took the time to assemble and present their talks in this virtual forum.

Thank you to FLNRORD and CFS managers and Executive for their support of this forum: in particular, Shane Berg, Deputy Chief Forester, Diane Nicholls, Chief Forester, and Judi Beck, Director General, Canadian Forest Service, Pacific Forestry Centre, Victoria, B.C.

Francesco Cortini, Research Management Lead, Office of the Chief Forester, acted as the facilitator of the Discussion Groups and Ann Lockley, Senior Extension Lead, Office of the Chief Forester, coordinated and ran the technical aspects of the Discussion Groups. Their help was immensely appreciated.

Session 1: The Challenge and the Science

The Silviculture Challenge

Neil Hughes

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For over 100 years, B.C. has been known around the world for supplying high quality timber, and an awful lot of it. For those of us in the business however, we know that to be able to keep on doing this for another 100 years is going to be a very big challenge. We are rapidly moving from an industry based upon harvesting natural stands, whether as old growth or incredible naturally regenerated second growth on the Coast, to forests that we are growing and managing through our silviculture practices. The question is whether these are going to provide a seamless transition in terms of quality and value.

Our area of young seral forest is growing rapidly, especially where impacts from mountain pine beetle and recent wildfires have exacerbated things. These two issues alone account for approximately 1.75M hectares of the THLB that is now in a denuded or severely damaged state. Across the province, we have a declining timber harvest and mounting challenges to the extent of the THLB from a host of non-timber focused requirements, some of which are exacerbated by the large area of young seral forest.

Therefore, silviculture and silviculture foresters must improve both the systems and practices that are carried out. Preparing detailed silviculture prescriptions focused on the site conditions; getting more uniform stocking across the block with higher densities (in many places) and achieving canopy closure faster by utilizing the best seed source available and using proactive brushing regimes; and planning for and recognizing the increasing levels of forest health issues and drought stress encountered today will all be essential as we move forward. Finding opportunities to bring forward harvests into the mid-term will also be important and so a resurgence in incremental silviculture such as juvenile spacing and fertilizing may well be necessary.

All of this may sound "old school" but it is tried and tested in terms of being able to produce the timber yields and value we need. However, the province is also pushing forward with using new science and innovation to improve our efforts to manage our young forests. Linking silviculture outcomes to full rotation regimes that are directed by landscape level plans will move us forward from block by block prescriptions and should enable better overall resource management decisions to be made. The goal of all of this will be to create a focus on managing for resilient forests in an age of rapidly changing climate, initially through utilizing such tools as climate based seed transfer (CBST) and species selection based upon projections of future climates.

Ultimately, success in managing our young forests in a healthy and resilient state will come from ensuring we invest enough resources into the human capital currently working for government and industry in whose hands the decisions lie.

Young Stands in B.C: Silviculture Records

Dan Turner

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Silviculture records provide us stand level treatment history and treatment outcomes for an ever-increasing amount of crown land in B.C. There is a massive amount of survey data available that may be of value to support forest management decisions beyond the measure of success against a silviculture obligation.

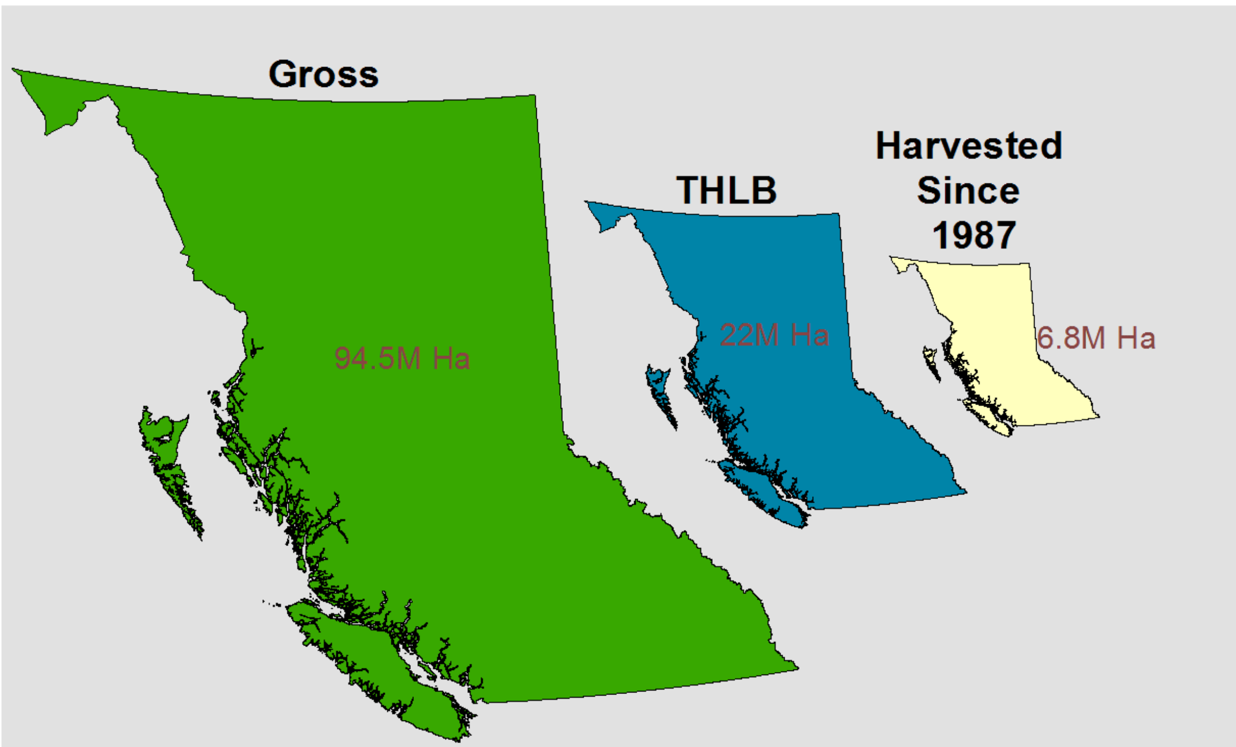

Figure 1. Summary of area harvested on crown land in BC since 1987. Source - RESULTS database October 1, 2020.

The presentation provides a brief history of silviculture record keeping in BC, then a high-level summary of what young stand and forest health information is included in our silviculture records. The presentation ends with a summary of which forest health information is collected, how this information can be accessed, and a few example projects using forest health silviculture records.

Table 1. Example of forest health data available in our silviculture records.

Layer 1 Inventory Layer					
	Species		%	Average Age	Average Height
1	PLI-lodgepole pine		90	12	2.6
2	AT-trembling aspen		10	10	0.9
Crown Closure	7		Basal Area		
Stems/ha Total	4,767		Total Well Spaced	Well Spaced	Free Growing
Damage Agent				%	Area
DMP-Lodgepole pine Dwarf Mistletoe (L. *Arceuthobium americanum*)				1	
DSC-Comandra Blister Rust (L. *Cronartium comandrae*)				3	

KEY QUESTIONS

1. What opportunities are available to use silviculture survey data to better inform forest health decisions?
2. What improvements can be made to silviculture surveys to better inform forest health decisions?
3. What improvements can be made to silviculture record systems to better inform forest health decisions?

Forest Health Impacts to Young Stands

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British Columbia (B.C.) prides itself on being a world leader in sustainable forest management and since the province's reforestation programs began in the 1930's, close to 8 billion trees have been planted. British Columbia uses a mix of over 20 different native tree species in its reforestation programs with the intent to establish resilient and diverse forests for the future, and to maintain and restore proper ecosystem function. As highlighted in the Health of Young Stands Symposium, there are more young stands on the land base than ever before and considering the challenges we are facing in light of climate change, the impacts of native forest health factors (abiotic and biotic) on young stands are becoming increasingly important. A host of forest health factors can impact stand establishment and stand productivity, with respect to timber volume and quality, and their occurrence and impact vary across the land base and only select factors will result in mortality or significant decreases in yield. However, it is important to note that although a single forest health factor may not result in mortality, the cumulative sum of different factors can significantly impact stand establishment and productivity at a stand or landscape level.

This two-part talk introduced select abiotic and biotic forest health factors affecting young stands in B.C., highlighted the need for long-term monitoring data that are required to mitigate current and emerging forest health factors, and discussed potential consequences of not amending current government policies that drive forest management. The first part of this talk introduced select insect and animal forest health factors.

Climate-mediated disturbances are one of the greatest threats to young stands. Increasing temperatures and changing precipitation regimes will and have had adverse impacts on host tree vigour and in some cases increased pest success. However, the greatest impacts most recently and in the future will likely be the result of landscape level disturbances such as wildfire, which have the ability to cause extensive mortality. For example, approximately 2M ha were burned over 2017 and 2018. Catastrophic disturbances such as wildfire in the interior of the province will not only result in economic losses from losing regeneration and silvicultural investments, but also impact future timber supply and carbon sequestration. Considering anticipated increases in frequency and intensity of catastrophic events with a warming climate and changes to precipitation patterns, landscape level forest management and landscape level wildfire management, which go beyond community or interface fuel management, are extremely important as a means to mitigate wildfire related losses to our silvicultural investments and to mitigate ecological and community impacts. Additionally, forest health factors that have historically not been an issue may become pests as we see changes in climate and host vigour. Typically, innocuous pests such as black army cutworm or secondary pests are, or could become agents of tree mortality in predisposed stands. There is the risk of range expansion and possible establishment and impacts of non-native pests (i.e., white pine blister rust or gypsy moth) with increasing globalization. For example, the black army cutworm, which is a native insect, has not generally been a common pest of recently planted stands since the 1980s, when prescribed burning was broadly used for site preparation; however, following recent landscape level wildfires and high intensity wildfires, the cutworm has caused low incidence mortality and impacts on productivity at a stand level. Although the impacts are generally not extensive, consideration of the risk and hazard of this pest is important to minimize losses to regeneration investments in recently burned areas.

In many parts of the province, drought has become one of the most limiting factors for tree species establishment. Drought has and will continue to be one of the leading causes of young stand mortality related to a warming climate. Drought will also result in growth reduction at the stand level due to induced carbon starvation. Select species are more susceptible to drought stress (e.g., western redcedar on the Coast) and generally younger or suppressed stands are more susceptible to succumbing to drought related mortality, especially if there is a predisposing factor such as lodgepole pine dwarf mistletoe (in the Cariboo) or hemlock dwarf mistletoe (on the Coast). Additionally, drought stress (especially cumulative stress/back-to-back years) not only reduces host vigour and increases susceptibility to other factors (i.e., defoliators & bark beetles), but typically innocuous pests such as secondary pests are becoming agents of tree mortality in these stressed stands.

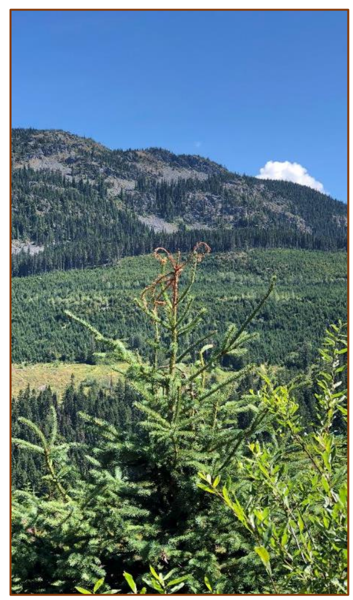
Although frost does not impact young stands to the extent that drought or wildfire does, the stand level impacts in regenerating Douglas-fir on cleared areas due to frequent summer frosts are significant throughout the Cariboo Chilcotin. Summer frosts throughout this region are a significant factor in reducing initial stand establishment and growth of planted Douglas-fir, and highlights the importance of implementing silvicultural tools that can be employed to minimize adverse effects to establishing stands (i.e., silviculture systems such as single tree selection or volume retention). Additionally, late spring frosts can result in frost heaving (typically high elevation stands or mounded areas) and these frost events can lead to seedling mortality at a stand level. From a management perspective, it is important to understand which sites are susceptible to drought or frost events and develop strategies, including species selection, to minimize impacts on newly established plantations and young stands. The use of tools such as the Climate Based Seed Transfer and CCISS applications for species selection, and timing of planting, in addition to microsite selection are some of the tools we can use to mitigate drought and frost impacts. Heavy snowfall and hail can also cause mortality or growth losses when foliage and/or buds are removed and cause deformities, which affect wood quality. Impacts from snow press and hail typically occur in patches or are scattered throughout plantations.

A mountain pine beetle outbreak started in the early 1990s and impacted 18M ha of forest. Typically, mature pine (> 50 yrs. old, larger diameter trees) are attacked by mountain pine beetle; however, during the unprecedented outbreak, young pine stands or smaller diameter pine stands were also impacted throughout the province, primarily in the central interior (Maclauchlan 2006).

Table 1. Summary of data from mountain pine beetle in young stands in central B.C. (Maclauchlan 2006).

Stand Age	Mountain Pine Beetle Occurrence from Aerial Overview Survey	Mean % Green Attack
20 – 25	28%	5
26 – 30	33%	7
31 – 40	62%	12
41 - 50	83%	23

This outbreak had significant landscape level impacts on young stands and our mid-term timber supply, and although we do not anticipate an outbreak of the same magnitude to occur in the future, we anticipate future impacts to young stands with future outbreaks and our best option to mitigate impacts is to manage pine stocking on the land base. Past and potential future impacts highlight the importance of collecting inventory data at layers below the canopy level.



Terminal weevils are found on pine and spruce throughout most regions of the province. Although they generally do not cause tree mortality, they do impact timber volume and wood quality by causing stem deformation and height loss. Stem deformation occurs when lateral branches below an attacked leader compete for dominance, causing a forked or dwarfed tree form. Repeated attacks on new dominant laterals will cause severe stem deformation over time. We anticipate that young stand pests such as spruce weevil or lodgepole pine terminal weevil incidence and impact will continue to increase due to more frequent drought events and consequently, increased host stress. Efforts to mitigate weevil impacts have focused on risk assessment and reduction, which can further be facilitated by planting mixed stands or alternate species in high hazard areas; by increasing stand density; and using resistant seed, which is available for Sitka spruce on the Coast. An additional tool, which is not as commonly used, is the shading of planted regeneration in high hazard areas.

Warren's root collar weevil can be a pest of lodgepole pine and spruce in stands that are mixed with pine, and less frequently of Sitka spruce on the Coast. Weevil attacks are most evident on 5 – 20 year old trees or young plantations with small diameter trees. Severely affected trees of this age class exhibit aboveground growth reduction, decreased root diameter growth and occasionally mortality. Warren's root collar weevils can live up to five years, and this longevity is a concern during the regeneration of host trees. A planting delay of two to three years in areas where large pre-harvest weevil populations are present may reduce the impact on susceptible stands. Prescribed burning was used in the past. An alternate method would be site preparation to reduce the duff layer and an increase in planting density.

There are four main disease factor categories: root diseases, stem cankers and rusts, dwarf mistletoes, and foliage diseases. Root diseases account for the greatest losses in terms of impacts to timber supply. In some high hazard Interior Cedar Hemlock (ICH) ecosystems in southern B.C., Armillaria root disease has an incidence greater than 15% in 20% of stands, based on above ground symptoms (Fig. 1). Intensive forest health management can result in increases in root disease over time, through an increase in amount of inoculum present in the soil and availability of susceptible hosts. The major root diseases in B.C. are *Armillaria ostoyae*, laminated root disease, Black stain, and Tomentosus root disease. Except for Tomentosus that occurs throughout B.C., root diseases occur in the southern half of the province, where they are often found together. Management controls include stumping or planting less susceptible species. Major licensees can apply for a stumping allowance to cover the cost of stumping. However, it is difficult to set conditions for when and where stumping can occur under a professional reliance framework and there have been problems with stumping being used inappropriately or ineffectively by some licensees. Proper management of these diseases often requires detailed pre-harvest information about the root disease species present, its distribution, and severity (FLNRORD 2018). This information is only rarely collected. Root disease is one of the more difficult forest health factors for surveyors to identify and map, and is under represented in most forest health monitoring surveys. Free Growing declarations should be delayed until stands reach age 15 to allow root disease adequate time to be expressed in young stands.

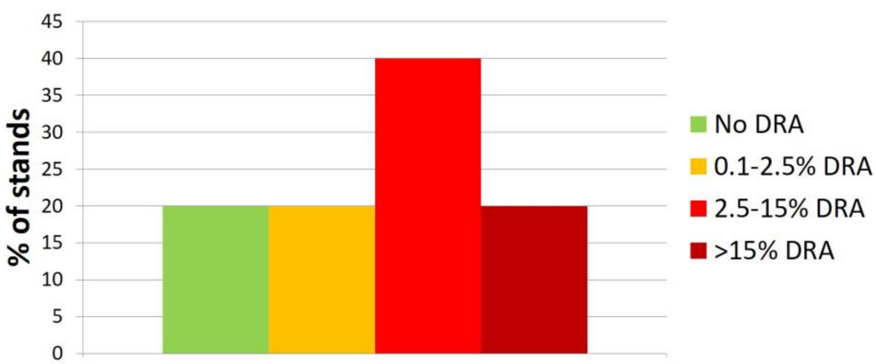


Figure 1. Severity distribution for Armillaria in the Thompson Okanagan ICH.

The major stem rusts include the hard pine stem rusts: western gall rust, comandra rust, stalactiform rust and the introduced white pine blister rust. White pine blister rust is an excellent example of the risks posed by exotic forest health factors. Western white pine was once a very important species throughout the southern part of B.C. Today, more than 100 years after the introduction of white pine blister rust and extensive breeding efforts to increase resistance to the disease, western white pine comprises a very small component of our current planting program. The hard pine stem rusts are major sources of mortality in young lodgepole pine stands (Fig. 2). These stem rusts kill their hosts by girdling the main stem. The main methods of control are planting alternate species and planting high densities in high rust hazard areas to help offset losses. Breeding programs are currently underway to reduce the susceptibility of improved seed. As with high hazard root disease areas, Free Growing declarations should be delayed until age 15 in high hazard areas to ensure adequate stocking levels. Atropellis canker, an ascomycete, infects tissues older than 15 years of age, usually on the north side of the tree, and is more frequent in high-density lodgepole pine stands.

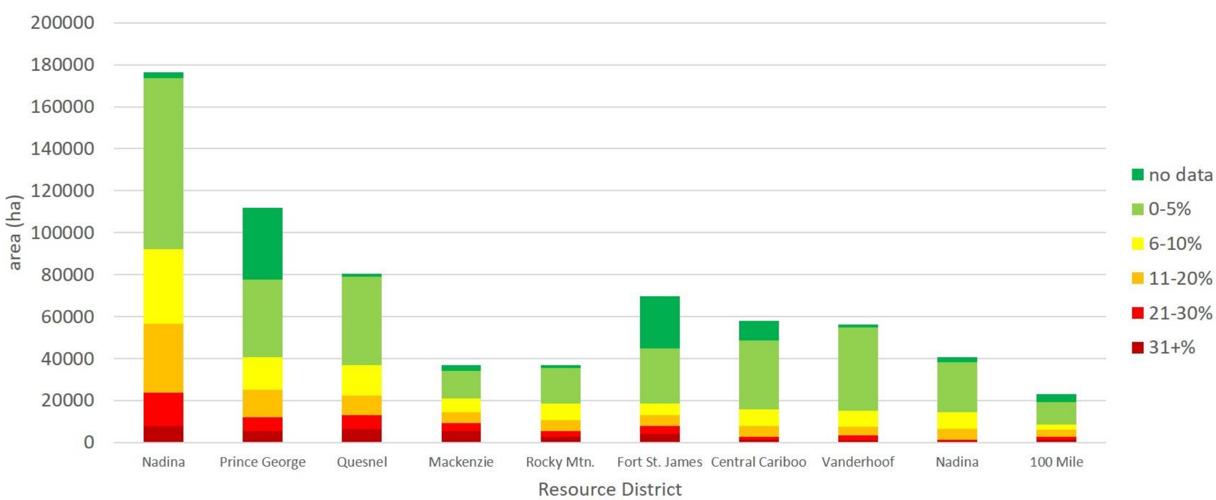


Figure 2. Stem rust affected area (all rusts combined) for the 10 most affected resource districts. Information is based on RESULTS data collected by Richard Reich, 2010, published 2013.

There are four species of dwarf mistletoe in B.C., each with its own primary host (Rusch et al. 2019). Lodgepole pine dwarf mistletoe and hemlock dwarf mistletoe cause the greatest impacts, while larch and Douglas-fir dwarf mistletoes have much more limited ranges. The main control method is to plant non-susceptible trees or to remove all overhead seed sources using clear-cut harvesting systems and removal of all overtopping residuals. An ongoing issue in dwarf mistletoe management has been the retention of infected residuals along pre-existing roads and trail right of ways. A dwarf mistletoe spatial statistical model attached to the Forest Vegetation Simulator (Robinson and Geils 2006) was used to project impacts at different rotation ages in the 100 Mile House TSA, by comparing mean merchantable volume at rotation, with the dwarf mistletoe mode turned on and off (Table 2).

Foliage diseases have become increasingly important due to climate change. Dothistroma outbreaks in northwestern B.C. (Woods et al. 2005), and increased severity of Swiss Needle cast on the Coast are good examples. Silvicultural practices have partially contributed to the problems. In northwestern B.C., an increase in Dothistroma has resulted from planting lodgepole pine above historical levels, while in the southern Cariboo, mixed Douglas-fir and lodgepole pine stands have been converted to pure lodgepole pine plantations, resulting in high levels of Elytroderma Needle cast. Elytroderma is a systemic needle cast that can have severe impacts on stand height growth and knot size in lodgepole pine.

Table 2. Modelled impacts of lodgepole pine dwarf mistletoe at different rotation ages.

Age	Merchantable Volume (m^3/ha)		% Change
	DM	No DM	
40	61	62	-1.7
50	89	90	-1.9
60	119	122	-2.6
70	144	146	-1.3
80	165	168	-1.9
90	181	185	-1.9
100	193	198	-2.2
110	204	209	-2.7
120	211	219	-3.3
130	218	226	-3.3

The second part of the talk focused on the importance of forest management in the context of increased forest health risks to young stands. These risks have highlighted the need for better forest health monitoring data; better mitigation of future forest health risks and climate change, through stand and landscape level planning; better forest health policies and management; and better understanding of how current levels of forest health factors in young stands will affect future timber and non-timber values over time.

Forest health data is currently being collected in two widespread and systematic ways: through the RESULTS Free Growing database and through inventory plots, such as vegetation resource inventory temporary sample plots, permanent young stand/change monitoring plots, and growth and yield plots. The reliability of RESULTS forest health data has been questioned due to a lack of quality assurance once the data are submitted. Inventory staff has a good quality assurance program in place for the ground sampling programs and young stand monitoring holds great promise in collecting reliable long-term forest health data. The young stand monitoring program has been recently developed and is used to monitor stands 15-50 years of age. As such, there are a limited number of plots with repeat forest health measurements. At present, forest health data from these sources are not well summarized or accessible to the public; however, steps are underway to change this.

Changes in forest policy have resulted in fewer requirements around site plans and the collection of detailed site information prior to harvesting, in favour of professional reliance. For some forest health agents such as root diseases and dwarf mistletoes, it is vital to collect pre-harvest data for planning and evaluating future forest health treatments. The consistency and level to which these pre-harvest data are collected vary widely among licensees. These problems are exacerbated when harvesting and silviculture are divided into separate and distinct activities performed by separate groups or individuals.

Planting a diversity of species and managing for multiple age classes and forest structures is an important aspect of mitigating future forest health risks and climate change. Often, decisions around stocking and species are made at the stand level and are motivated by efforts to reduce costs and relieve obligations as soon as possible. The following came out in a 2020 Forest Practices Board report on reforestation in the IDF:

"No formal reporting mechanisms are in place to assess whether provincial goals and management unit objectives and targets for species composition and longer term stocking are being met."

Decisions around stocking, species selection, and forest health may be influenced by unintended consequences of government policy. A good example of this was the overplanting of lodgepole pine resulting from Free Growing policies. Early Free Growing delays were eliminated in favour of minimum heights to encourage prompt reforestation, which often results in better regeneration outcomes. An unintended consequence was that high hazard stands for root disease and stem rust could be declared Free Growing before the diseases were fully expressed, thereby reducing a licensee's obligation to deal effectively with them. Additionally, there is a trend to survey for Free Growing declaration using drones, which could mean that forest health factors are not adequately assessed on the ground. It is up to individual licensees to determine the most appropriate method of measuring whether a stand meets the minimum Free Growing requirements set by the government.

Forest health is not currently a requirement of forest stewardship plans other than through approved stocking standards, which are written with healthy stands in mind. Once approved, there is no formal monitoring to ensure that the standards are suitable for mitigating forest health risks and hazards present on the site.

Considerable effort must go into determining the impacts of forest health factors on timber supply. Growth curves determined in TASS/TIPSY are based on optimum growth in healthy stands. To address this oversight, fudge factors or operational adjustment factors (OAFs) are built in, which are difficult to estimate and often have little or no value outside of TASS/TIPSY. Models are developed that use the incidence and severity of forest health factors in young stands projected forward to rotation. On their own, most forest health factors have a small impact on future volumes (root disease can be an exception); however, the cumulative impacts could be substantial. For most forest health factors, specific adjustment factors have not been determined, so default OAFs that only account for non-productive areas (OAF1) and decay waste and breakage (OAF2) are used in most timber supply modelling. Where OAFs are developed, they are often based on random or systematic sampling. However, on volume-based tenures, harvesting priority is likely to be in healthy, high volume stands. This can result in increasing OAFs over time (deferred OAFs), especially true of root disease, which can have a major impact on stand volume.

To conclude, climate change will result in increasing mortality and growth loss in our young stands due to reduced host vigour and impacts of a range of biotic and abiotic forest health factors. As forest managers, it is imperative that we ensure our management decisions and forest policies adequately address the future health of our forests.

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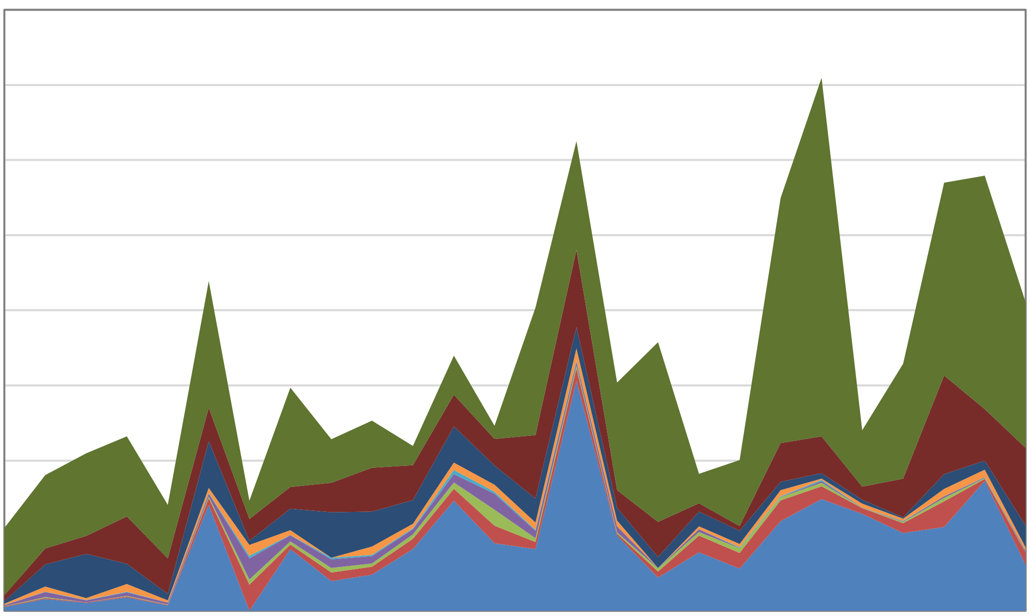
Session 2: A Scattergram of Data



Young Stand Forest Health Data: What do we have and what can we do with it?

Tim Ebata

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Detecting forest health damaging agents in young stands is generally a difficult task. Although recent mortality is relatively easy to observe, most of the damage encountered during silviculture surveys is non-lethal. Rarely are there circumstances where young stand damage can be detected operationally from airborne (remote) sensing platforms unless the damage is widespread. Identification of the damaging agent is very difficult and requires training, including periodic refreshing. Furthermore, severity information combined with incidence data is vital to estimate potential impact. Damaging agents vary by host species, host age, crown position and many other factors. Damage is rarely evenly distributed, thereby increasing the probability of missing observations if the sample number is low. In summary, well-trained surveyors must ground survey stands to collect forest health data, using enough sample points to account for the variability to obtain accurate estimates of the incidence and severity of damage.

Young stand forest health data were collected by the CFS's Forest Insect and Disease Survey (FIDS) unit until 1995, when CFS disbanded FIDS and the responsibility for monitoring forest health was passed onto the province. Annual regional FIDS reports document the findings from summer survey activities conducted by FIDS rangers. Over the 40-year history of the provincial forest health program, many attempts have been made to assess the health of young stands through various survey initiatives led by regional and provincial forest health specialists. A wide variety of surveys and trials, including establishment of temporary and permanent sample plots, were utilized as the program sought to assess the extent and severity of young stand damage observed throughout the province. This information led to the development of the initial pest hazard and risk ratings that were used to inform stocking standards and silviculture investment decisions. Products like the series of forest health Forest Practices Guidebooks, Stand Establishment Decision Aids, and other guidance documents resulted. Unfortunately, much of the data and supporting documentation has not been archived in easily accessed digital records and many of the installations have been lost to fire or harvesting or have been simply abandoned.

Some examples of early survey work done in young stands involved extensive root disease strip surveys, including "pixel surveys" in both the Interior and the Coast. Surveys for spruce weevil, Warren's root collar weevil, lodgepole pine terminal weevil, pitch moth, dwarf mistletoe and stem rusts were also conducted. General Pests of Young Stands (POYS) surveys were also conducted by FIDS, the former Prince Rupert Forest Region (now Skeena Region), and McBride District – all funded by the BC/Federal Forest Resource Development Agreement (I and II) in the early 1990's. Summary reports can be found on the web on the FLNR forest health FTP site https://www.for.gov.bc.ca/ftp/HFP/external/!publish/Forest_Health/internal_pubs/

As noted above, these older installations and survey initiatives were rarely documented in a format that is easily accessible. Furthermore, the patchwork of surveys and trials were not part of a provincial sampling strategy and offer limited utility when attempting to use their information at a TSA level. Many of the projects had specific objectives, so the sampling designs and sample populations were highly variable. Very few were re-measured plots or samples, which meant they only represent a point in time estimate of the conditions at the time of sampling. Despite these limitations, these data provide insight into forest health conditions over much of the province and it may be worth the effort to collate and convert some of these data into a modern, web-accessible spatial format.

The following table summarizes the attributes of various general large-scale pests of young stands surveys that have been conducted over the last three decades.

PROVINCE- WIDE POYS				
	Years Sampled	Target Population	Type of Sample	Data Collected
FIDS	1991-1995	FRDA investments; 1,132 randomly selected stands. All trees >0.5 m.	TSP; 10 fixed r plots/ stand + 5m strip survey for root disease	Incidence and severity, summarized by damage type/pest/ guidebook thresholds
SPI	1996-1998, more?	Proportion of inventory type group; 10-25 yrs.	TSP +100m long strip plots for root disease	Incidence and severity
SDM	1.0 - 2011 2.0 - 2017	Managed stands post-FG; 15-50 yrs.	TSP; v1-10 x 3.99 m circular plots; v2-up to 6 5.64 m plots	Incidence and severity based on modified FG damage criteria
YSM	2013-ongoing; some on second re-measurement	All stands (Nat and Art) in 20-50 yrs.; > 1300 plots (TSA and TFL	PSP; 1 x 11.28 m circular plots; 5 yr. re-measurements	Incidence and detailed severity measurements

Not included in this table, but a very important source of young stand data are the incidence data collected during Free Growing (FG) surveys and stored in the silviculture database, RESULTS. More information about FG surveys and FAIB's YSM program will be covered in the presentations by Dan Turner, and Rene De Jong and Scott MacKinnon, respectively. There have also been many Forest and Range Evaluation Program (FREP) Stand Development Monitoring plots sampled (and the pilot Effectiveness Evaluation plots) that have targeted post-Free Growing stands and data summaries are available. Much of the SDM survey data have been uploaded into RESULTS. It is important to note that for both Free Growing and SDM surveys, incidence was only tallied for damage that exceeded a specific severity threshold, whereas other young stand surveys generally tallied incidence regardless of severity.

Recent surveys have been done to target specific forest health questions focussing on hard pine stem rusts, Swiss needle cast and balsam woolly adelgid in B.C.

Most surveys collect basic information on the number or proportion of stems damaged by species (incidence) and some surveys collect severity data. These data have been used for many purposes. However, one main challenge to interpreting the data is the limited knowledge about the relationship of young stand damage to final impact at rotation age for both volume and log / lumber quality. Other presentations in this symposium will provide examples of modelling efforts to estimate impacts; however, this relationship remains a high priority research question.

Specific products generated directly or through interpretation of forest health data collected to date include hazard and risk ratings for priority forest health agents that guide reforestation decisions, from site preparation to stocking standards, silviculture investment decisions, and priorities for FIRM's tree breeding program. Timber supply analysis uses these data to estimate forest health impacts through modified operational adjustment factors and pest specific model extensions for TASS and other growth and yield models. Other presenters will discuss more about these impact estimation methods.

Looking to the future, there are opportunities to improve the utility of past forest health data collection efforts, and those currently underway through obligatory silviculture surveys and inventory sampling. Priority forest health questions may require development and implementation of specific surveys. Obtaining additional resources to support these new survey initiatives would require justification through a well thought out implementation plan directed by a provincial forest health data management strategy.

Data are vital to answer critical questions about the status and management of young stands in B.C. Our challenge is obtaining the right data and ensuring that it is distributed to the people who need it.

KEY MESSAGES

1. Data have been collected about forest health conditions in young stands for at least 40 years by different methods and over different areas across the province. However, this information is not widely available through a standardized provincial database.
2. Several initiatives to conduct young stand forest health surveys were done in the 1990's and data summaries are available.
3. The obligatory Free Growing survey has sampled nearly every opening since 1988. It has collected basic forest health information as a part of the sampling process designed to determine if the stand is stocked with healthy, free growing trees.
4. Recent survey initiatives through the FREP Stand Development Monitoring and FAIB Young Stand Monitoring programs have collected young stand forest health data at a provincial scale in post-Free Growing stands.
5. Forest health data have been used to guide forest management decisions by providing hazard and risk ratings and practice recommendations designed to minimize potential impacts.
6. The data have been used in a limited manner to project forest health impacts on timber yield through the Timber Supply Analysis process.
7. Data collection methods could be improved and enhanced, and the data management process needs to be standardized to ensure better utilization of the information.

The Young Stand Monitoring Program and Applications to Estimate Stem Rust Impacts: Preliminary Results

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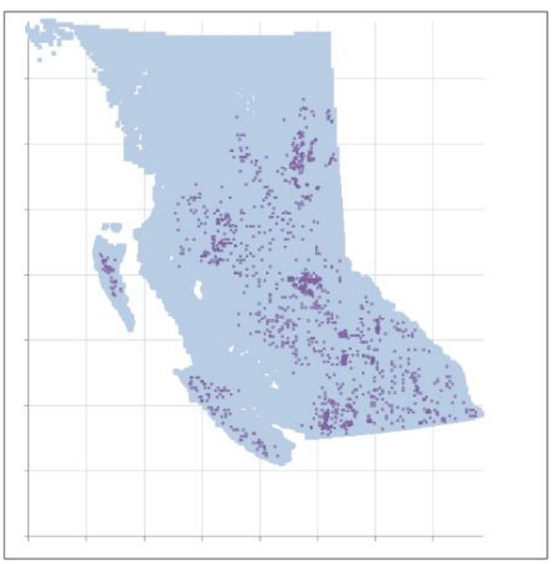
The Forest Analysis and Inventory Branch (FAIB) includes about 10 full time staff that manage the ground sampling program, coordinate and audit field measurements done by certified contractors, and compile and analyze the data. Over 700 ground sample plots are measured annually across five different ground sampling programs, including the young stand monitoring (YSM) program.

FAIB implemented a provincial young stand monitoring program in 2011 to monitor the change of young stands across the province. The sampling framework, forest attributes, and estimates of change are based on traditional concepts in forest inventory. These include ground sample plots established on a systematic grid to provide statistically sound, point in time and change estimates of forest attributes. These monitoring data also support other uses: testing the accuracy of spatial map coverage, tracking forest health, and testing management plan assumptions in TSR.

Over the past nine years, FAIB completed YSM program establishment across a majority of interior TSAs (Figure 1). The first five-year remeasurements have also just been completed on some units. Current and planned priorities are to expand YSM coverage to include coastal and northern TSAs.



Ground Samples: YSM

BC Totals

	TFL	TSA	Total
# Samples	449	963	1,412
# Sample Msmts	622	1,239	1,861

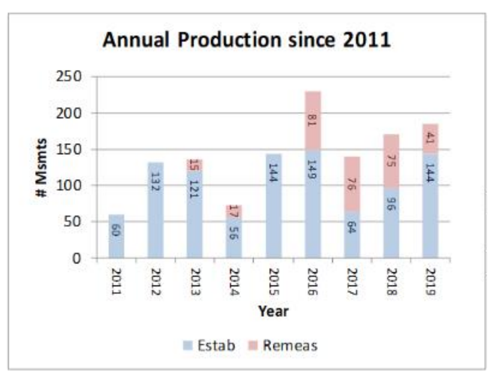


Figure 1. YSM sample establishment to date.

The YSM population is defined by the VRI Phase 1 spatial layer and includes all stands between 15 and 50 years old in the crown forested land base. The 5 x 10 km sampling grid is an intensification of the National Forest Inventory grid. Ground samples are established at every grid point that intersects with the YSM population. At each re-measurement cycle, stands previously too young (<15 yrs. old) are also established with new plots. This sampling framework is simple, repeatable, and helps ensure the program can be maintained over the long term.

The establishment of ground samples follows documented standards and procedures. In addition, forest health training is offered most years by regional forest health specialists to contractors awarded field sampling contracts. Each YSM ground sample is established as a nested circular plot, where trees at least 4 cm DBH are permanently tagged and re-measured (Figure 2). Every tree is stem mapped, measured for DBH and height, and is assessed for forest health damage agents and severity. Sample trees are selected to obtain site index estimates for all major species. Small tree plots are used to quantify trees < 4 cm DBH. A subset of measured ground sample plots undergoes independent audits to ensure quality measurement standards are met.

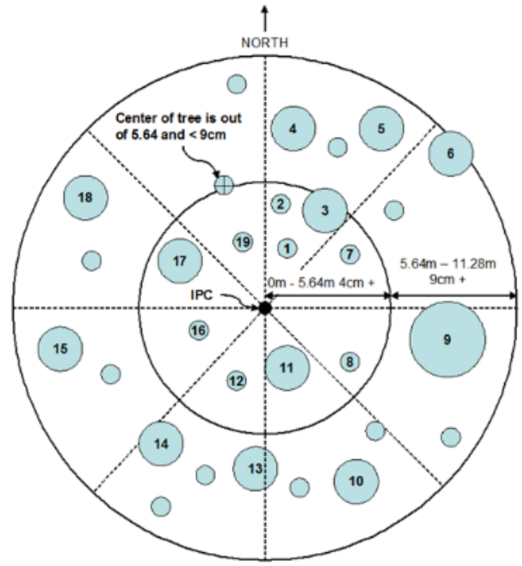


Figure 2. YSM ground sample layout.

Figure 3 illustrates an example of an established YSM ground sample plot, with the stem mapped trees located in the plot, and four documented photos taken at time of measurement in the four cardinal directions from plot center.

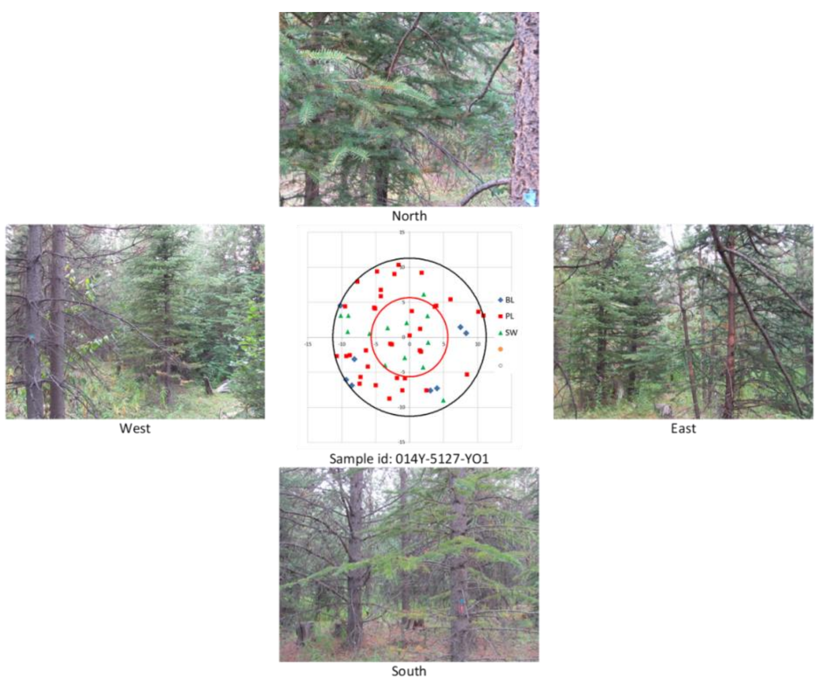


Figure 3. Example YSM layout, with photos taken at four cardinal directions.

Forest health damage agents and severity are assessed on all tagged trees, based on the provincial list of pest species codes managed by Resources Practices Branch. Up to five damage agents are recorded for each tree in descending order of severity for multiple occurrences. This also includes previously tagged trees, which subsequently become dead fallen at time of re-measurement. Special consideration is given for three stem rusts Comandra Blister Rust (DSC), Western Gall Rust (DSG), and Stalactiform Blister Rust (DSS), where additional measurements include the rust height from the ground and % circumference measured for each stem rust on the tree. These added measurements feed directly into the TASS growth and yield model, which also includes the GRIM and CRIME forest health modules.

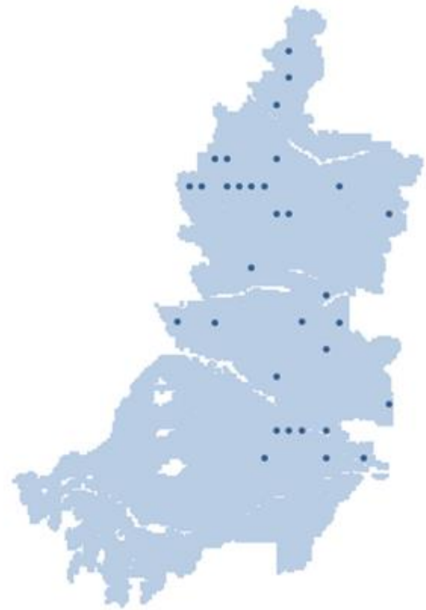


Figure 4. YSM sample grid layout in Lakes TSA.

The YSM program for the Lakes TSA helps illustrate the design and methods used to quantify stem rust impacts across a management unit (Figure 4).

In 2017, 32 YSM ground sample plots were established on a 5 km x 10 km grid network across the young stand population. Parks and protected areas located in the southern portion of the TSA were excluded from the YSM population.

From the collected forest health data, the incidence of all forest health damage agents are summarized for each ground sample, as a percentage of the total number of trees affected (Figure 5). This figure illustrates the incidence of the three stem rusts of interest (DSC, DSG, and DSS) within each YSM sample plot. Out of a total 32 YSM sample plots, 26 plots had some level of rust present.

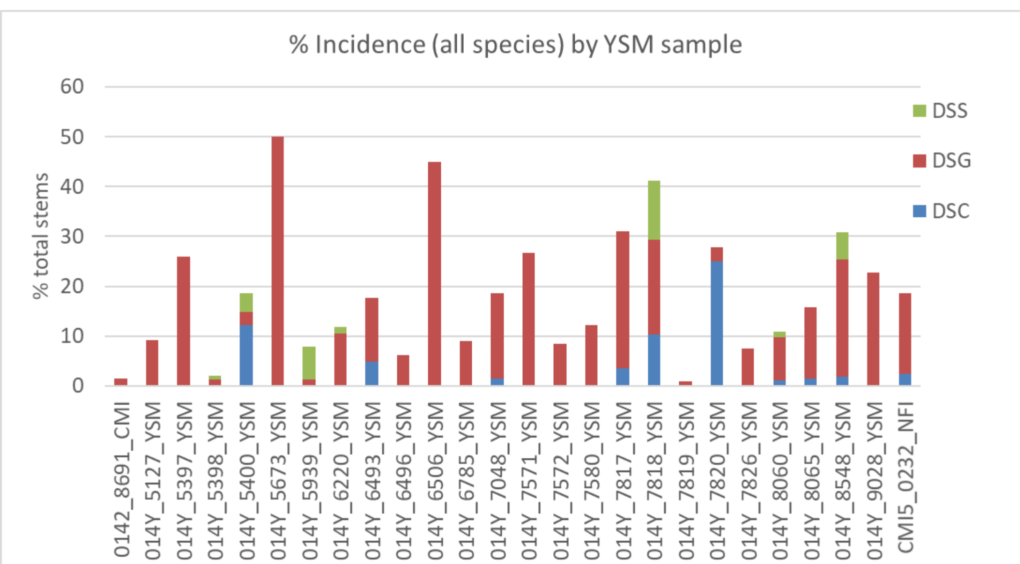


Figure 5. Stem rust incidence recorded by YSM sample in the Lakes TSA.

When averaged across all YSM samples in the Lakes TSA, the measured stem rust incidence shown in blue dots is 2% for DSC, 12% for DSG, and 1% for DSS, for a combined 15% stem rust incidence (Figure 6). The 95% confidence intervals around the average percent incidence are shown as red bars.

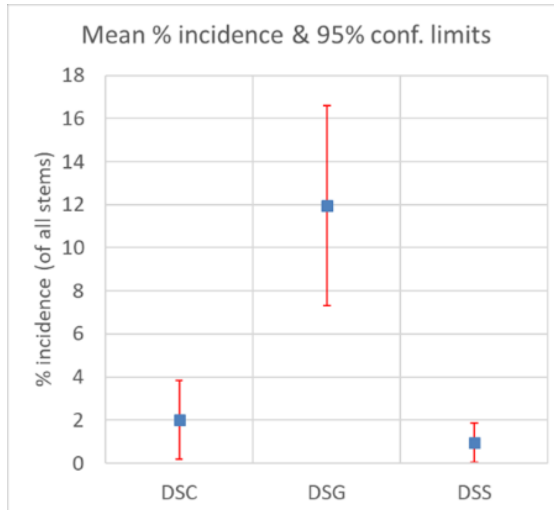


Figure 6. Average incidence of stem rusts in the Lakes TSA.

Ideally, every YSM ground sample would be re-measured up to a desired rotation age, and then the true impact of forest health pests would be known. The YSM program is only just completing a first 5-year re-measurement cycle. As an interim step, TASS is used to project the growth of each YSM tree list to rotation.

In these cases where additional stem rust data are collected (including rust heights and % encirclement), TASS projections together with GRIM and CRIME forest health modules are used to estimate the future volume impacts of stem rusts from measured YSM data.

Further detail is provided for an example YSM ground sample, to illustrate the stem rust data collected in the field and subsequently used in TASS projections. Plot #014Y-9028 was 27 years old at time of measurement in 2017, comprising 100% PL, with a density of 1,426 stems/ha. DSG was recorded from this plot @ 23% measured incidence of the total number of trees. Looking at the gall height chart (Figure 7), galls were measured up to 5 m high, with most galls between 1-2 m high. Looking at the gall encirclement chart (Figure 8), the majority of galls were at 30% encirclement or less. The nested stem mapped YSM plot was then used to run TASS projections (Figure 9). TASS runs indicate that when projected to 80 years old, there is a 2% merchantable volume impact due to stem rusts (expressed as a percent volume loss relative to a non-infected stand). This process has been repeated for each YSM ground sample plot.

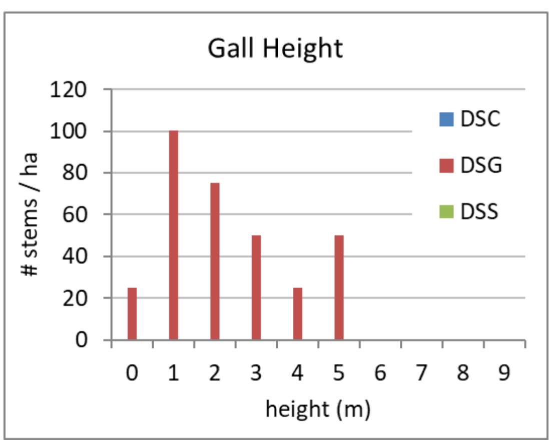


Figure 7. Distribution of gall rust heights for YSM sample 014Y-9028.

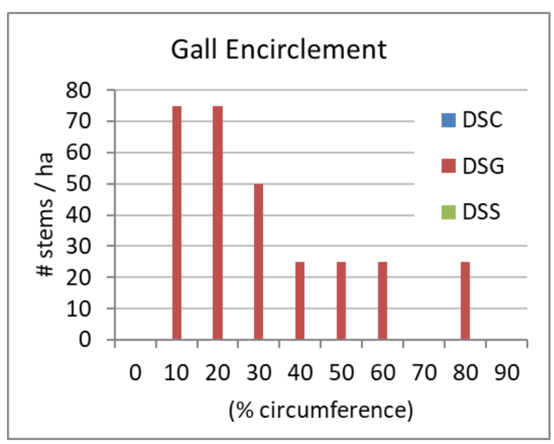


Figure 8. Distribution of gall % encirclement for YSM sample 014Y-9028.

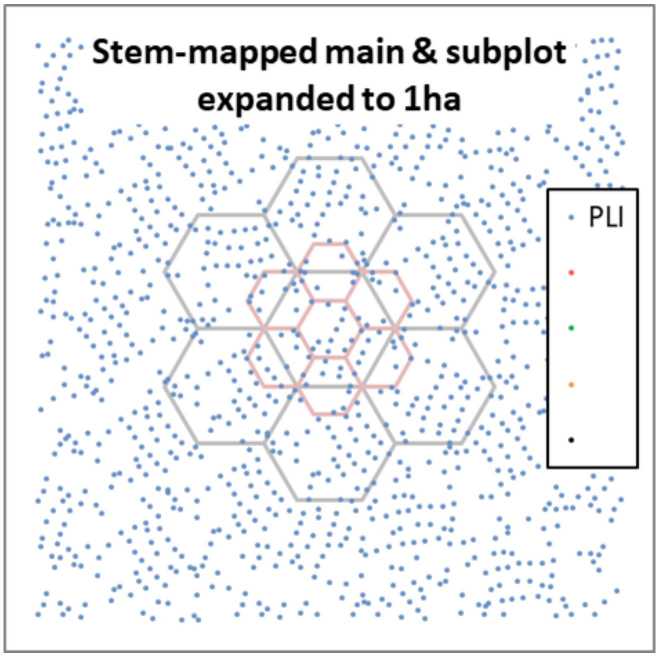


Figure 9. Nested stem mapped YSM sample 014Y-9028, expanded to 1 ha for TASS runs.

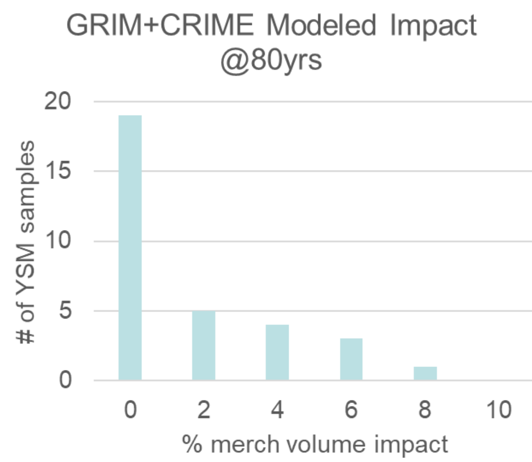


Figure 10. Average volume impact of all YSM samples in the Lakes TSA projected to 80 yrs.

Each YSM ground sample is projected in TASS from its current age, to estimate future stem rust impacts. Across all 32 YSM sample plots, the impact ranges from zero to 8% volume loss when projected to a rotation age of 80 years (Figure 10). The average volume impact for young stands in the Lakes TSA is projected to be 1.6%.

This same process described for the Lakes TSA has been repeated for other management units with ongoing YSM programs. This table summarizes preliminary results across seven TSAs, including YSM sample size, average current age of the YSM sample population, the current measured incidence of stem rusts, and the estimated volume impact (Table 1).

Table 1. Average % incidence and associated projected stem rust volume impact at 80 yrs., across seven management units with ongoing YSM programs.

Sampled Management Unit	Measurement Year	# YSM plots	Average Age	% Incidence	% Impact
Bulkley TSA	2018	12	40	3.5	0.3
Kispiox TSA	2017	19	35	1.3	0.7
Lakes TSA	2017	32	31	15.0	1.6
Mackenzie TSA	2019	51	35	6.9	0.1
Morice TSA	2017	31	35	3.8	0.5
Prince George TSA	2019	79	35	3.6	1.0
Williams Lake TSA	2018	100	35	4.5	0.7

There are some points that should be considered when evaluating these results. The stem rust incidence is based on the current stand age (in the case of Lakes TSA, the average age is 31 yrs.). So while growth loss before the first recorded measurement is unknown, the current measured stand does reflect past losses that have already occurred. Overall, rust impact depends on the proportion of host species. In the Lakes TSA 60% of the overall species composition is PL, with 40% attributed to other species. All YSM samples in the population are included in analyses, whether rust is present or not. In the case of the Lakes TSA, 81% of the YSM samples had some recorded rust, while 19% had zero incidence. Future impacts are dependent on modeled projections. To help minimize these risks and provide the growth model with as much measured information as possible, additional tree detail are collected from all ground samples. These include measuring the stem mapped locations of every tree, 100% tree height measurements, and detailed stem rust severity measurements. Over time, modeling risks will be reduced as YSM samples continue to be re-measured on a regular cycle.

In summary, this study demonstrates a viable method to estimate future stem rust impacts by management unit using TASS together with CRIME/GRIM forest health modules, based on future projections of designed-based YSM ground samples with current stem rust incidence and severity recorded. This information has utility for checking and evaluating future expectations of young stand growth projections used in TSR. There is an increasing need to develop new forest health modules for additional damage agents, which can then be integrated with TASS managed stand yield table projections.

As a related information resource, all ground sample plot data maintained by FAIB on public lands have recently been designated as OpenData under the BC open government license. These compiled data (including YSM) are available to the public either from the BC Data Catalogue, or via GIS Web App that allows users to spatially review and export data from custom areas of interest. The Web App is located at: [https://bcgov-env.shinyapps.io/ground_sample_deploy\](https://bcgov-env.shinyapps.io/ground_sample_deploy/)

Session 3: The Science and the Future: Uncertainty and Climate Change

Better Forest Health Through Better Seed Transfer

Greg O'Neill

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Background

For over a century, foresters have recognized the importance of using 'local' seed sources to help ensure that plantations are productive (Langlet 1971). This understanding is derived from provenance trials, where seed sources from a range of climates are grown in one or more test sites. Provenance trials typically reveal that seed sources with the greatest survival and growth are those from climates similar to that of the test site (i.e., local seed sources) (Savolainen 2007). Like Darwin's finches, trees are adapted to their local environments. By relating height or survival to the climate distance each seed source is transferred in a provenance trial, one can estimate a 'safe seed transfer distance' (SSTD) – the maximum climate distance one can transfer seed and still expect to obtain acceptable growth or survival (Ukrainetz et al. 2011).

The preceding view of local adaptation stems from a growth-centred focus of production forestry. However, as demand grows for greater forest resilience, and pest epidemics become more frequent, severe and extensive as the climate changes (Weed et al. 2013), there is an increasing awareness of the need to consider adaptation from a broader perspective. Including forest health traits in provenance test analysis can help reveal the contribution of health traits to fitness, and potentially indicate the need for health-based SSTDs that might differ from those calculated from tree height or survival. Therefore, I sought to examine the degree of local adaptation and calculate SSTDs for B.C. tree species using forest health traits available in B.C.'s provenance data.

Methods

Transfer functions for forest health traits were developed for lodgepole pine using data from the Illingworth provenance trial (EP 657.06) (140 range-wide populations grown at 60 test sites in B.C. and Yukon). (See O'Neill et al. 2008 for details regarding the trial materials and design.) Data from a report of the IUFRO Douglas-fir provenance trial (9 populations from western USA and B.C.) at Malcolm Knapp Research Forest were also used to develop a transfer function (McDermott and Robinson 1989).

Annual climate values for the period 1961-1990 were obtained for the lodgepole pine and Douglas-fir provenances and test sites from ClimateBC (B.C. provenances and test sites) and ClimateNA (non-B.C. provenances) (Wang et al. 2016). Transfer distances were obtained by subtracting provenance climate from test site climate. Pooled quadratic transfer functions were developed relating live crown percent and years of needle retention, both potential indicators of *Dothistroma septosporum* infection in lodgepole pine in northwest B.C. (Woods and O'Neill 2006), western gall rust (*Endocronartium harknessii*) infection score, and *Lophodermella concolor* infection percent to transfer distances of the 8 geoclimatic variables used in B.C.'s Climate-Based Seed Transfer System: latitude, mean annual temperature (MAT), mean coldest month temperature (MCMT), temperature difference (TD, between mean warmest month temperature and mean coldest month temperature), mean annual precipitation (MAP), mean summer precipitation (MSP), degree-days above 5°C (DD5), and precipitation as snow (PAS). (See O'Neill et al. 2017 for details on the geoclimatic variable selection). The transfer functions displaying the smallest mean squares error for each response trait were retained and safe seed transfer limits were estimated from the retained functions by interpreting the climate transfer distance associated with a 15% increase in symptom or disease incidence relative to the local seed source. A transfer function was also developed for Swiss needle cast (*Phaeocryptopus gaeumannii*) using data presented in McDermott and Robinson (1989).

Results

Dothistroma needle blight on lodgepole pine

When selecting seed sources for reforestation, limiting losses in live crown % to 85% of the live crown % observed the local population (i.e., to 72% X 0.85 = 61%) would necessitate procuring seed from locations with summer precipitation no more than 110 mm drier than the plantation. (Fig. 1A). Similarly, to limit losses in years of needle retention to 85% of the years of needle retention observed in the local population (i.e., to 94% X 0.85 = 80%), seed must not be procured from locations that are more than 9.5°C MCMT warmer or 14°C MCMT colder than the plantation (Fig. 1B).

Swiss needle cast on Douglas-fir

To limit increases in Swiss needle cast incidence to 15% greater than incidence levels observed on local populations (i.e., to 52% X 1.15 = 60%), Douglas-fir seed should not be procured from locations that are more than 280 mm MAP drier than the plantation (Fig. 1C). Establishing a plantation with seed from locations that are slightly wetter than the plantation may result in a plantation with incidence levels of Swiss needle cast that are lower than levels expected in local populations.

Western gall rust on lodgepole pine

To limit increases in western gall rust incidence to 15% greater than incidence levels observed on local populations, lodgepole seed should not be procured from locations that are more than 1.2 °C MAT warmer or 2.8° MAT colder than the plantation (Fig. 1D).

Lophodermella needle cast on lodgepole pine

To limit increases in Lophodermella needle cast to 15% greater than incidence levels observed on local populations, lodgepole pine seed should not be procured from locations that have 800 DD5 more or 300 DD5 less than the plantation (Fig. 1E).

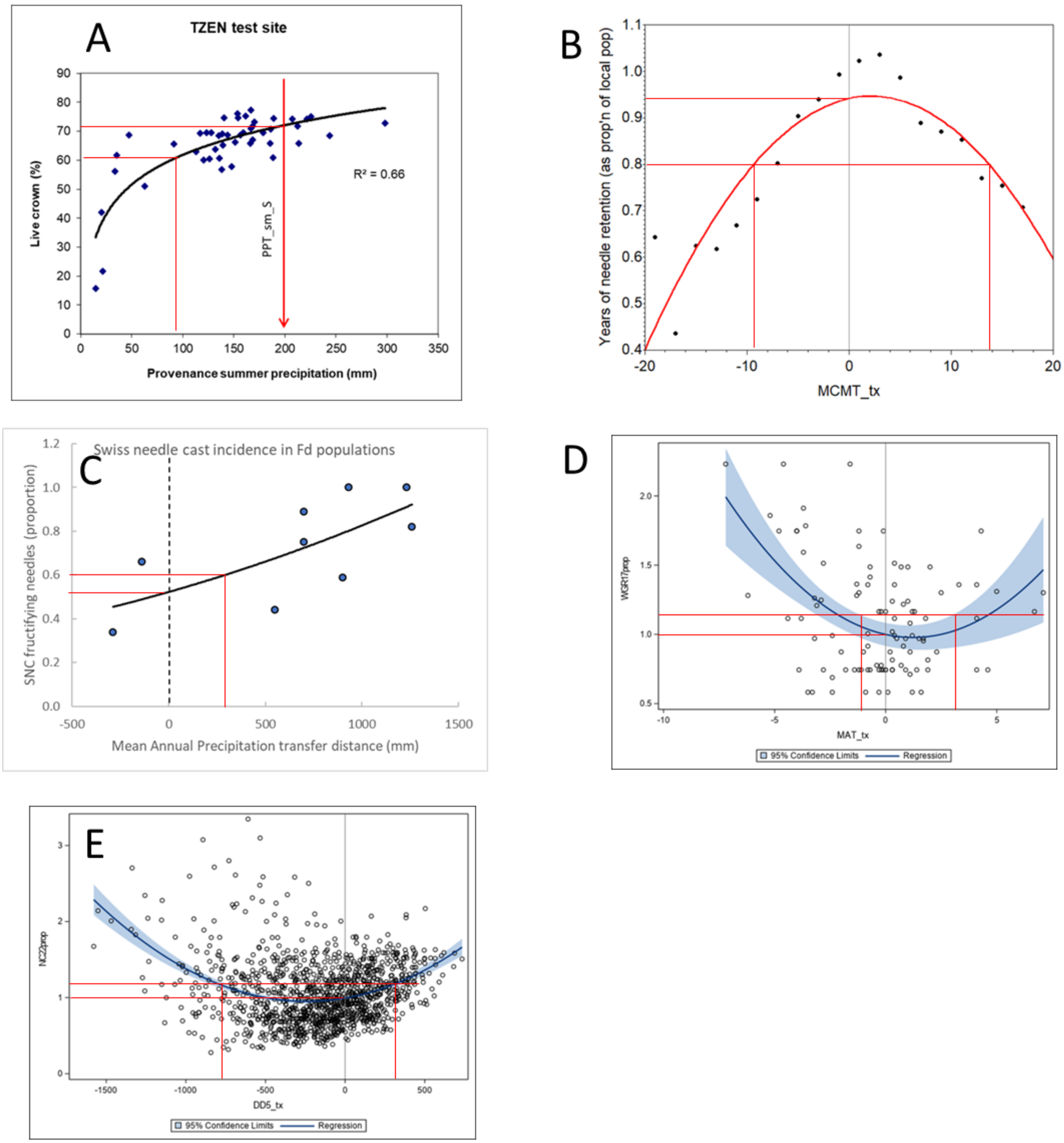
Discussion

Constraining seed movement appears to provide a low-cost strategy to help control the incidence of pest infection in forest plantations. While the degree of acceptable seed movement is typically determined using growth-based transfer functions, we observed moderately strong transfer functions – evidence of local adaptation - in all four host-plant systems that we examined (Dothistroma needle blight, western gall rust and Lophodermella needle cast in lodgepole pine, and Swiss needle cast in Douglas-fir). Minor health concerns were observed among populations transferred short distances, and a moderately steep decline in tree health was noted among populations transferred moderate or long climate distances in one or both climate directions (Fig. 1).

These findings support the contention that a carefully developed seed transfer system can help ensure that plantations are both productive and healthy (O'Neill et al. 2017). They also highlight the potential for improving B.C.'s seed transfer system by broadening the scope of evaluated traits to include forest health, and demonstrate again the value of B.C.'s provenance test legacy in continuing to provide forest management solutions.

RECOMMENDATIONS

1. Greater consideration should be given to forest health traits in provenance test analysis to develop a better seed transfer system and improve plantation outcomes especially in a changing climate.
2. Incorporating forest health traits into provenance test evaluation will require close collaboration between geneticists and forest health experts to identify 1) host-plant systems of greatest concern and 2) specific traits that are most informative and cost-effective to assess.
3. B.C.'s extensive provenance test system warrants continued attention and investment to ensure that it remains effective.



	Tree species	Response variable	Predictor variable	Author/source
A	lodgepole pine	Live crown %	Summer mean precipitation of the provenance	A. Woods (unpublished)
B	lodgepole pine	Years of needle retention	Mean coldest month temperature transfer distance	G. O'Neill (unpublished)
C	Douglas-fir	Swiss needle cast fructifying needles	Mean annual precipitation transfer distance	McDermott & Robinson. 1989
D	lodgepole pine	Western gall rust infection score	Mean annual temperature transfer distance	N. Ukrainetz (unpublished)
E	lodgepole pine	Lophodermella needle cast attack score	Degree-days above 5 transfer distance	N. Ukrainetz (unpublished)

Figure 1. Fitted transfer functions for forest tree health traits with interpreted safe seed transfer distances associated with 15% increase in pest incidence or symptom severity relative to incidence or severity in a local population.

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A Retrospective Look at Pests in Young Stands: the 1990's vs. 2020. Changes and Implications?

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Abstract

The previous two mountain pine beetle outbreaks of the 1970's and 2000's have dramatically accelerated lodgepole pine harvesting and reforestation efforts in B.C. The 2000's outbreak was a clear response to climate change. Have there been parallel responses by pests affecting young stands over the past two decades? In 2019, a project was initiated whereby young pine stands (age 15-20 years) were surveyed for incidence of damaging agents and mortality in the Southern Interior Region and compared to data collected in similar aged stands and locales in the late 1990's. The results show that more young stands are being affected today by damaging agents than 20 years ago. In addition, the percentage of stems affected by specific pests was higher in the recent surveys and the density and structure of these new stands have changed. Many damaging agents have minimal long-term impacts to regeneration but others, such as lodgepole terminal weevil and western gall rust, can have serious implications in terms of stem form and tree survival. Drought events are more common and severe, and have impacted regeneration, with over 100,000 hectares affected by the 2017 drought. I will highlight the changes in pest occurrence over the past two decades and the long-term damage caused by the most prevalent and important pests found in young pine stands.

Background

Over the past century, interior forests of British Columbia have experienced numerous landscape level disturbances. Many pests affect lodgepole pine, *Pinus contorta* Dougl. ssp. *latifolia* (Engelm.), throughout its rotation, with the dominant natural disturbance agents being the mountain pine beetle, *Dendroctonus ponderosae* Hopk. (Coleoptera: Curculionidae: Scolytinae) (Safranyik and Carroll 2006; Amoroso et al. 2013; Westfall and Ebata 2017; Negron and Cain 2019), and stand replacing fires (Lotan et al. 1985; Klutsch et al. 2011; Kulakowski et al. 2012). Mountain pine beetle (MPB) populations periodically erupt, killing thousands of hectares of mature, or nearly mature pine trees (Safranyik and Carroll 2006; Alfaro et al. 2015; Maclauchlan et al. 2015; Walton 2016; Axelson et al. 2018). At least four large-scale MPB outbreaks have occurred in western Canada in the past 120 years (Alfaro et al. 2004; Taylor et al. 2006; Axelson et al. 2010; Westfall and Ebata 2017; Axelson et al. 2018). The most recent outbreaks in B.C. occurred in the 1970-1980's and again, in the late 1990's through 2000's, when almost 14 million hectares of pine forests were ultimately affected (Safranyik et al. 2010; Walton 2016; Westfall and Ebata 2017).

The 1970-1980's MPB outbreak triggered the targeted harvest and reforestation of lodgepole pine in B.C. In the late 1990's through 2000's, MPB returned, precipitating record-breaking harvest and reforestation efforts. During this outbreak, young stands (aged 20-50 years) were also attacked and killed by MPB. Coupled with this vast and unprecedented MPB outbreak, drought and wildfire also challenged the survival of B.C.'s interior forests. Cumulative disturbances on B.C.'s land base have resulted in extensive landscapes of young forests, many composed of pure lodgepole pine or mixtures with other species.

There are numerous ways to evaluate the health of young stands. In this summary report, I describe methods used to investigate and describe the health of young lodgepole pine stands in the Thompson Okanagan Region (TOR), including:

- a comparison of pest abundance and complexity in stands (age approx. 15 years) 20 years ago (resulting from the 1980's MPB harvest) to that seen in present day stands of the same age (resulting from the 1990-2000's MPB harvest) growing in the same ecosystems/locations;
- identification and incidence of pests (damaging agents) at distinct points in time; and,
- impact of pests over the development of the stand (following individual trees and pests over time).

The impact and dynamics of insects, diseases and other damaging agents change as new climatic and stand conditions present themselves. Pests can target trees throughout their development or at a very specific time (age or size) in stand development. Some pests have a negligible effect on host tree, whereas others can seriously compromise survival, growth and tree form.

Methods

Retrospective study: From 1995-2001 (referred to as 1998), 186 young lodgepole pine stands, with an average age of 15 years, were surveyed in the Thompson Okanagan Region. In 2019-2020 (referred to as 2020), 130 lodgepole pine stands of the same age, and located in the same ecosystem (ESSF, MS, IDF, ICH)[1] and geographic location as the 1998 stands, were surveyed. The Survey for Pest Incidence protocol (Joy and Maclauchlan 2000) was used to assess the selected stands.

	Total number of surveys	
	1998	2020
ESSF	43	9
ICH	41	25
IDF	26	17
MS	76	72
SBS	0	7
	186	130

Drought study: In 2017, a significant drought event occurred in the TOR. Mortality was mapped during the 2018 Aerial Overview Survey (AOS). In addition to the AOS, a detailed aerial survey using rotary-wing aircraft, augmented with ground surveys, was conducted in 2018, to further quantify and investigate the repercussions of this widespread drought event in young stands. The Vegetation Resource Inventory (VRI) was used to identify candidate stands. A sub-sample was

[1] ESSF=Engelmann Spruce – Subalpine Fir Zone; MS=Montane Spruce; IDF=Interior Douglas-fir; ICH=Interior Cedar-Hemlock

surveyed by air, then ground surveyed to identify pests and those responding to drought stressed trees. A full description of the 2018 drought study can be found at:

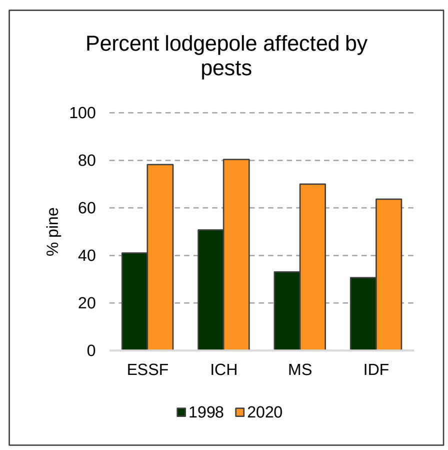
https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/monitoring/aerial-overview-survey-documents/2018_south_overview_report_web.pdf

Long-term plots: Seventeen fixed area long-term plots were established in young lodgepole pine stands throughout the Thompson Okanagan Region. These plots have been monitored for ±30 years for the incidence, severity and long-term impact of pests (damaging agents).

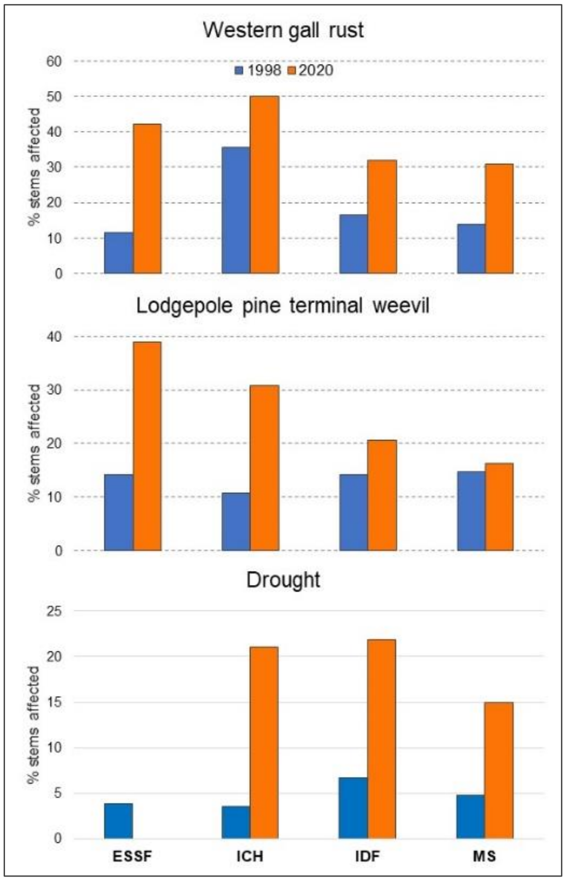
Results and Discussion

Retrospective and Drought Study: Young, lodgepole pine stands are more complex today than 20 years ago. On average, the total stem density (stems per hectare=sph) was higher in 2020 (2,000-6,000 sph) than in 1998 (<1,000-4,000 sph). However, 30% to > 40% of stems in the 2020 surveys were classified as suppressed ingress, and not likely to become crop trees. In addition, up to 81% of the potential crop trees and 68% of ingress trees were affected by at least one or more pests.

In 1998, the average number of pests identified per stand was 5, compared to an average of 7 pests per stand in 2020. There was also a much higher percentage of pine affected by one or more pests in 2020 compared to 1998; sometimes more than double the number observed 20 years ago. A few pests are cyclical and are not easily identified unless there is an ongoing outbreak e.g., *Lophodermella concolor* (Dearn). Serious pests, including stem rusts, cankers and lodgepole pine terminal weevil, *Pissodes terminalis* Hopping, were found in more stands, and affected more lodgepole pine per hectare in the most recent surveys.



Lodgepole pine terminal weevil is one of the most common insect pests of lodgepole pine (Drouin et. al. 1963; Retnakaran and Harris 1995; Maclauchlan and Borden 1996; Heineman et al. 2010). However, there was little information on long-term damage caused by the terminal weevil, nor were we certain whether there was a higher incidence of attacks today than in the past. Whereas, the effects of Sitka spruce weevil, *Pissodes strobi* (Peck.), on Sitka spruce, *Picea sitchensis* (Bong.) Carr, and Norway spruce, *Picea abies* [L.] Karst. are well described (Alfaro 1989; Alfaro and Omule 1990; Daoust and Mottet 2006), and we understand how a warming climate can increase the success and proliferation of the weevil (Seiben 2000) in spruce regeneration.



In the retrospective study, the incidence of lodgepole pine terminal weevil in 2020 was significantly higher across all biogeoclimatic zones compared to1998, most notably in the ESSF and ICH. The ESSF had a low sample size but the trend across all ecosystems suggests that the weevil is influenced by longer, warmer summers and increasingly mild winters. Incidence of western gall rust, *Cronartium harknessii* (J.P. Moore), was also significantly higher in the ESSF and ICH in 2020, indicating more favourable springtime conditions when infections occur. Comandra, *Cronartium comandrae* Peck, and stalactiform blister rust, *Cronartium coleosporioides* Art., were more frequently found at ESSF sites in the 2020 surveys, infecting on average 30% and 10% of lodgepole pine, respectively. There was variability in the percentage of trees infected by these rusts in the IDF and MS zones. Given that these stands are still very young, it is possible that the infection rate and incidence of pests may increase over the next decade.

Major drought events occurred in the TOR in 1998 and 2017. Both caused visible symptoms of drought stress (sub-lethal) and significant mortality in young and mature trees. Drought affected all tree species and was more widespread and severe in 2017. Drought effects were recorded at much higher levels in the 2020 surveys than during the 1998 surveys. The average mortality due to drought, and the subsequent attack by secondary insects or pathogens, exceeded 42% in the MS, 39% and 15% in the ICH and IDF zones, respectively.

Drought affects host trees, insects and their interactions (Mattson and Haack 1987). Translocation is lowered, which leads to decreased resin pressure and reduced ability to expel attacking insects. Drought stress can lead to increased plant attractiveness to insects by altering cues used to identify hosts. Drought will kill trees directly and causes increased susceptibility to insects and pathogens for several years after the event.

In 1998, trees showing drought symptoms were observed across all BECs, ranging from 3% to 7% stems affected. In 2020, drought mortality ranged from 15% to 22% stems affected, except in the ESSF where no drought-related mortality was observed. A similar pattern of drought mortality was captured in the 2018 Aerial Overview Survey, where less than 9% of the total area mapped occurred in the ESSF (Maclauchlan and Buxton 2019).

Stand density and tree diversity were higher in 2020. The question is – what is the health of non-pine species, which are often ingress (natural regeneration)? Interior spruce (*Picea glauca* (Moench) Voss), *Picea engelmannii* Parr and their crosses), was the most abundant secondary species in the

surveyed stands. Cooley spruce gall adelgid (*Adelges cooleyi* (Gill.) was the most prevalent pest recorded on spruce and was present across all BECs, affecting up to 93% of spruce. However, this insect has negligible impact. Another spruce-specific pest, the spruce weevil, was present across all BECs surveyed in 2020, affecting on many of the spruce in a stand. Spruce weevil can cause severe stem defects and suppress height growth. Multiple attacks over a tree's development can even prevent a tree from reaching the main canopy. With increasing summer temperatures and milder winters, sites normally considered low hazard for spruce weevil are now considered moderate to high hazard. Warmer and longer summers allow more weevils to complete development, emerge from attacked leaders and overwinter as adults in the duff, where they are protected from winter temperature extremes and predation. Therefore, we are likely to see increasing levels of spruce weevil attack in higher elevation stands (e.g. ESSF). In the ESSF, 18% of layer 3 and layer 4 (2019-2020 surveys) spruce had one or more weevil attacks and, in the ICH and MS, 23% and 10% of layer 3 and 4 spruce, respectively, had weevil attack.

Many of the ingress trees in the stands surveyed in 2020 were suppressed, impacted by pests and unlikely to develop into main canopy trees.

Long-term plots: Long-term pest data from 17 permanent sample plots had similar damage agents as those noted in the retrospective study. Most trees in the plots are now 40-45 years old. Lodgepole pine terminal weevil and western gall rust were the most prevalent pests and were present in all plots, affecting on average 32% and 18% of pine respectively, with a range of incidence and impact among individual plots. Comandra blister rust occurred in over 50% of plots, causing significant mortality within some stands. Atropellis canker, *Atropellis piniphila* (Weir) Lohman & Cash, occurred in 43% of plots, with an average of 11% pine infected.

Both the type of pest (insect, disease, animal, or abiotic) affecting a tree and the number of pests per tree can be important in regards to tree growth, form and survival. In the ESSF, IDF and MS plots, 30% to 40% of stems were affected by only one pest. Trees in the MS were more likely to have multiple pests per tree; 23% had two pests; 12% had 3 pests; and 10% had 4 or more pests per tree. Plot trees within the ESSF had the lowest occurrence of multiple pests per tree, with fewer than 9% of trees affected by 2 or 3 pests.

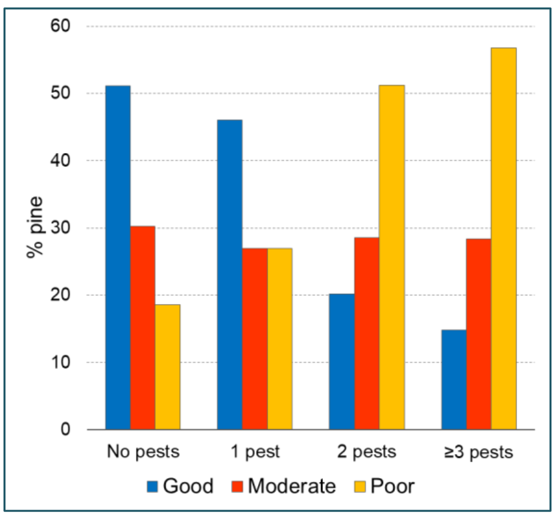
Comandra blister rust was the most serious mortality agent in these plots. Comandra was active in 10 of the 17 plots, with an average of 12% pine infected. I highlight one plot in the IDFdm as a case study, showing how comandra affected trees in a plot over time. In 1995, 287 stems per hectare (sph) were infected: 114 sph had branch infections; 173 sph had stems infections; and, there was no mortality. By 2014, 559 sph were dead due to comandra and 91 sph still had active stem infections. Very few trees had only branch infections.

Comandra blister rust

Lodgepole pine terminal weevil (old attack)

Western gall rust and squirrel feeding

Lodgepole pine terminal weevil and western gall rust were present in all 17 plots, affecting on average 32% and 18% of the pine, respectively. Both pests can seriously affect tree form and western gall rust can kill trees. I followed all weevil attacks on trees in the plots over time, noting the defect at the point of attack in each assessment year. In the few years following attack, it was unclear how a tree would react, and many trees appeared to have multiple leaders competing for dominance. However, with time, it became clear how a weevil attack would affect bole form. Using the same IDFdm plot as above, I divided all attacks into two categories: minor defect (stem crease at the point of weevil attack); and, major defect (stem crook, fork or staghead at the point of weevil attack). Initially, 29% of attacks resulted in a minor defect and 71% a major defect; predominantly crooks and forks. By the 2014 assessment, 46% of attacks were classified as a minor defect and 54% as a major defect, causing the tree to have poor form.



In 2014, I conducted a qualitative evaluation of tree form (good, moderate, poor) based on the presence of a stem defect, broken top or branchy growth form, and compared to the number of pests per tree. There was a clear trend showing that the more pests there were per tree, the higher the likelihood that the tree would have poor form. Very few trees with 3 or more pests per tree had good form.

In summary, young stands in 2020 have a higher species mix and more stems per hectare than was observed in the late 1990's. However, more stands are being impacted by damaging agents today than 20 years ago. Some pests, such as comandra blister rust, are being observed at a much higher incidence in higher, colder ecosystems (e.g. ESSF) than in the past, suggesting conditions for infection are becoming more favourable. Similarly, the incidence of both western gall rust and lodgepole terminal weevil is increasing across all BECs studied. Not all pests impact tree form, growth or survival. Therefore, it is critical to have clear goals in mind for young stands in order to plan for, and minimize the various impacts of pests. The data presented from the 17 long-term installations clearly showed the impact of some mortality-causing agents such as comandra blister rust, and the effect on tree form when trees are afflicted with multiple pests over time.

This report highlights the value of having multiple sources of information to evaluate pests and damaging agents on young stands over time. Incidence surveys are valuable for identifying patterns over a landscape and at a point-in-time, and can highlight where more intense monitoring is needed. Long-term installations provide impact data for individual pests over the life of a tree or stand. Both types of monitoring are required to make accurate forest yield projections for mid- and long-term timber supply modelling. We can assume that pest incidence and severity, and climatic damage will increase over the next decades. Therefore, we must learn from these studies and design our future forests with a clear end-goal in mind and aim for greater resilience in our young forests.

KEY MESSAGES

1. Different types of surveys and installations are needed across ecosystems to track pest response to climate change and tree response to pests.
2. Must do research on pest response to climate change.
3. Data from these types of studies must be incorporated into hazard rating (spatial) systems.
4. Clearly define the desired outcome of young stands-can we achieve these?
5. Pathways to resilience and minimizing pest impacts.

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Climate Change and Drought Risk

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Summary

Climate trends from weather station data in north and central British Columbia (B.C.) show declines in mean annual precipitation, mostly driven by declining winter precipitation. Areas such as Mackenzie and Prince George have also seen decreases of approximately 30% in summer months (Table 1). Data from long-term weather stations show temperatures are increasing across the north (Foord 2016). Projections of future climate change indicate minor increases in mean annual precipitation, declining precipitation as snow, and little to no increase in summer precipitation in the Skeena and Omineca Natural Resource Regions (Foord 2016). This alone is not necessarily cause for concern of future drought; however, when combined with projections of increases in mean annual temperatures on the order of 3 degrees, the evaporative demand on our land and water systems may increase (Foord 2016). In other words, without significant increases in precipitation, higher evaporation rates driven by higher temperatures may cause moisture loss from soil, vegetation, and increase the potential for ecological drought.

Table 1. Precipitation change for several long-term Environment and Climate Change Canada weather stations in north-central British Columbia. Bold values are statistically significant (p<0.05).

	Change in Precipitation (%)				
Weather Station	**Annual**	**Winter**	**Spring**	**Summer**	**Fall**
Fort St John A (1942-2019)	10.7	-18.7	20.6	4.4	**42.2**
Mackenzie (1971-2019)	**-24.8**	**-50.1**	-15.3	**-30.1**	-7.1
Prince George A (1942-2019)	**-16.0**	**-41.2**	10.2	**-27.7**	1.2
Vanderhoof (1980-2019)	8.1	-24.9	9.9	6.3	10.9
Wistaria (1926-2013)	-6.8	**-29.9**	-10.5	12.6	-7.1
Smithers A (1942-2019)	-5.0	**-36.5**	11.2	1.4	10.8
Terrace A (1953-2019)	-3.0	-10.1	23.5	-0.8	-6.1
Prince Rupert A (1963-2019)	**-10.6**	**-28.8**	-16.5	-15.8	-15.4

Changes to large-scale weather patterns in the last decade, driven by the Arctic amplification of climate change, can lead to prolonged periods of dry weather such as the summers of 2017 and 2018 in B.C. It can also lead to prolonged wet weather, but this is beyond the scope of this discussion. The Arctic is warming faster than anywhere on the globe from climate change, and this affects the mid-latitude jet stream in the Northern Hemisphere (Coumou et al. 2018). One of the functions of the jet stream is to dissipate heat from the equator to the poles, driven by the temperature differences between the two, (https://www.weather.gov/jetstream/jet). Due to Arctic amplification of climate change, that temperature difference is now less, and the mid-latitude jet stream doesn't have to work as hard. It has become lazier and wavier, which affects our weather systems (Coumou et al. 2018). During the summer months in B.C., it is common to have a weather pattern known as a Pacific High, where the jet stream is to the north and the southern part of the province receives dry, warm weather. Under a climate change influenced jet stream, that same weather pattern extends further north in the province and stays longer, leading to an unusually prolonged period of dry, warm weather. This can have several effects. In northern B.C., summer is the wettest season and its ecosystems are not adapted to long periods of warm, dry weather. In southern B.C., the heat builds and systems dry out leading to elevated risks of hydrological and ecological drought impacts, as well as elevated fire risk from low moisture content of fuels and decreased weather-related fire suppression (i.e. rain).

Field research in the Omineca region is exploring the impacts of climate change driven moisture stress on forest health. For example, a preliminary analysis of tree cores from hybrid white spruce has shown growth rings from both moisture rich and dry sites had less growth in 2006-2016, as compared to 1996-2005 (Figure 1). 2006 to 2016 was a warmer and drier growing season climate (May – September) than 1996-2005 (data from Environment and Climate Change Canada's Prince George weather station: 2006-2016 mean growing season precipitation was 240 mm and mean growing season temperature was 13.2°C; 1995-2005 mean growing season precipitation was 306 mm and mean growing season temperature was 12.9°C; average {1942-2020} is 283 mm and 12.6°C, respectively). Studies in the Omineca have also shown that warmer and drier growing seasons affect ecosystem productivity and net forest carbon balance, thus limiting forests' ability to act as growing season sinks of atmospheric carbon dioxide (Meyer et al. 2018). Kirchmeier-Young et al. (2019) found the record-breaking area burned from wildfires in 2017 was related to abnormally hot temperatures prior to initiation driven by climate change. The prolonged dry conditions from a persistent Pacific High weather pattern also inhibited natural fire suppression.

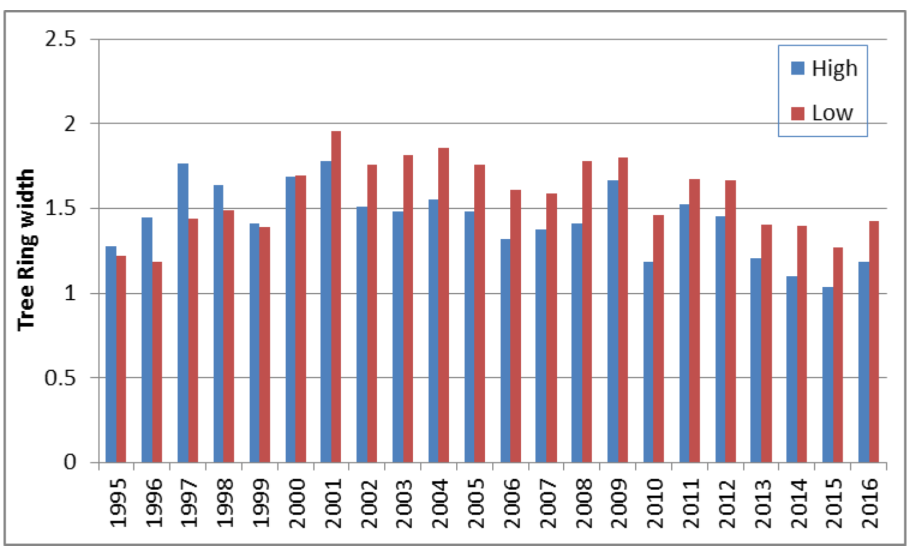

Figure 1. Mean tree ring width from over 40 tree cores in randomly selected field sites in the Omineca Natural Resource Region, representing both high (drier sites) and low (wetter sites) risk of drought.

In response to these growing concerns of increasing ecological drought and threats to forest heath and productivity from climate change, the Stand-Level Drought Risk Assessment Tool has been developed (DeLong et al. 2019). The tool projects the risk of tree mortality from drought in both current and future climates using information from the Biogeoclimatic Ecosystem Classification (BEC) system, weather station data, climate projections from ClimateBC (Wang et al. 2006) and site level soil characteristics (DeLong et al. 2019). Soil characteristics are obtained from field sampling or predictive ecosystem mapping and tree-climate relationships are obtained from a sub-model, the Tree and Climate Assessment model (Nitchske and Innes 2008). Weather station data are used to calculate actual evapotranspiration (AET) to potential evapotranspiration (PET) ratios for modal soil conditions representing a relative soil moisture regime (RSMR) and areas of relatively homogeneous climate represented by BEC units. Once AET/ PET rations have been calculated, a site is assigned to an actual soil moisture regime class, ranging from very wet to excessively dry (DeLong et al. 2019). An AET/PET threshold is assigned to a tree species by examining site series where the species is present in a RSMR but absent or rare in the next driest RSMR (DeLong et al. 2019). When the threshold for a tree species is exceeded, this represents a potential drought risk. This information can be projected into the future using climate modelled data to assess site-specific risks of drought-induced tree mortality (Figure 2).

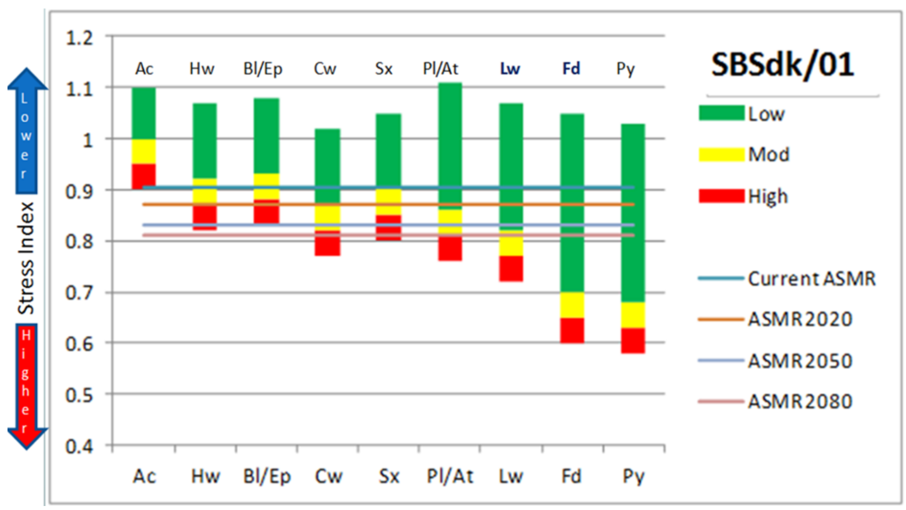

Figure 2. Example output from the Stand-Level Drought Risk Assessment Tool. Users can select a BEC variant and relative soil moisture regime to derive an assessment of drought-induced mortality of common tree species in B.C. under current and future climate conditions. In this example, tree species below the actual soil moisture regime (ASMR) lines on the graph are at low drought risk whereas above the lines are at high drought risk. Climate periods used are Current: 1961-1990, 2020: 2011-2040, 2050: 2041-2070, and 2080: 2071-2100. (Available at: https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/natural-resources-climate-change/natural-resources-climate-change-adaptation/tools).

This information can be used to inform timber supply, direct harvesting, create hazard maps, and direct retention areas for protecting watershed health, wildlife habitat, or future timber supply. The model has the potential to be integrated into other decision-making tools such as for watershed health, wildfire threat, tree species selection, and wildlife habitat modelling. Preliminary drought risk mapping has been done by tree species in the Omineca Natural Resource Region to help inform natural resource management decisions (Figure 3). This work is currently funded by the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development Research Program and the Omineca Natural Resource Region. Current efforts are focused on field validation of drought stress, model improvements, and expansion of the ecological units available.

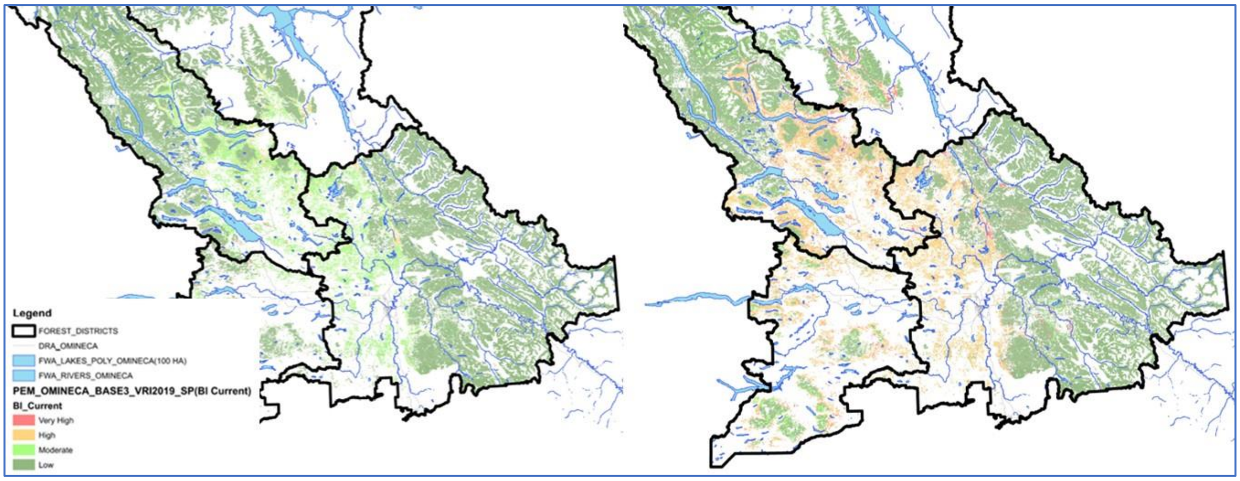

Figure 3. Example of drought risk mapping for subalpine fir in the south Omineca Natural Resource Region. Map on the left shows risk using baseline climate (1961-1990) and map on the right shows future risk in 2050 (2041-2070). Map credit Sean Barry.

KEY MESSAGES

1. Temperatures are increasing across the province and precipitation is declining in some areas and/or some seasons.
2. Future climate projections of increasing temperatures outweigh minor increases in precipitation, which will likely increase moisture stress and potential forest health issues.
3. The Stand-Level Drought Risk Assessment tool has been developed to project the risk of tree mortality from changes in soil moisture regime and future climate projections to aid in natural resource management decisions.

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Perfect Storm: Climate Change, Expanding Pest and Disease Impacts and Mitigation Strategies

Surprise is inevitable: Adaptive management for reforestation in times of uncertainty

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Abstract

Climate change is modifying many disturbance regimes in western North American forests, such as wildfires, droughts, and insect outbreaks, which are increasing in frequency, extent and severity. With these changes, there is increasing uncertainty about the resilience of forest communities, challenging our understanding how disturbances impact forests in the near- and long-term. Understanding the impacts of climate change and associated changes in disturbance regimes however is critical to effectively manage a multitude of ecosystem services, including timber, carbon sequestration, habitat and biodiversity. Exacerbating these uncertainties is the challenge of regenerating forests across large disturbed landscapes that will be resilient to future conditions. The uncertainties we face necessitate a critical assessment of whether standard reforestation practices that have historically emphasized establishing dense, low-diversity conifer crops in gridded plantings (i.e., pines in lines) followed by intensive management, will create resilient and robust forests of the future. C.S. (Buzz) Holling understood that our knowledge of natural systems is always incomplete, and that surprise is inevitable. However, once we accept this, "the essential point is that evolving systems require policies and actions that not only satisfy social objectives but at the same time provide flexibility for adaptation". Thus, providing the flexibility for adaptation and what this looks like in different areas of B.C. is our central challenge in creating resilient and productive forests of the future.

Summary

What do we mean when we talk about forest health, whether an old and established forest, a young stand or newly regenerating seedlings? While definitions of forest health have been criticized as value laden, considering what constitutes a healthy forest is foundational before specifically considering the health of young stands. Trumbore et al. (2015) define forest health as "…one that encompasses a mosaic of successional patches representing all stages in the natural range of disturbance and recovery – such forests promote a diversity of nutrient dynamics, cover types and stand structures, and they create a range of habitat niches…" As climate changes and extreme events increase in their frequency and intensity, the concept of managing within the natural range of disturbance variability becomes increasingly challenging. Decreasing tree health, and tree mortality, is often the result of complex interactions among multiple factors. This can be visualized as a tree death funnel (Fig. 1) that relates a tree's vulnerability to disturbance agents to its overall health - the farther a tree descends down the funnel, the more susceptible it becomes to a variety of mortality agents, some more potent than others (Axelson et al. 2019). While disturbances are a natural part of forest ecosystems and tree death is inevitable even in healthy forests, the above definition also points out natural ranges of recovery.

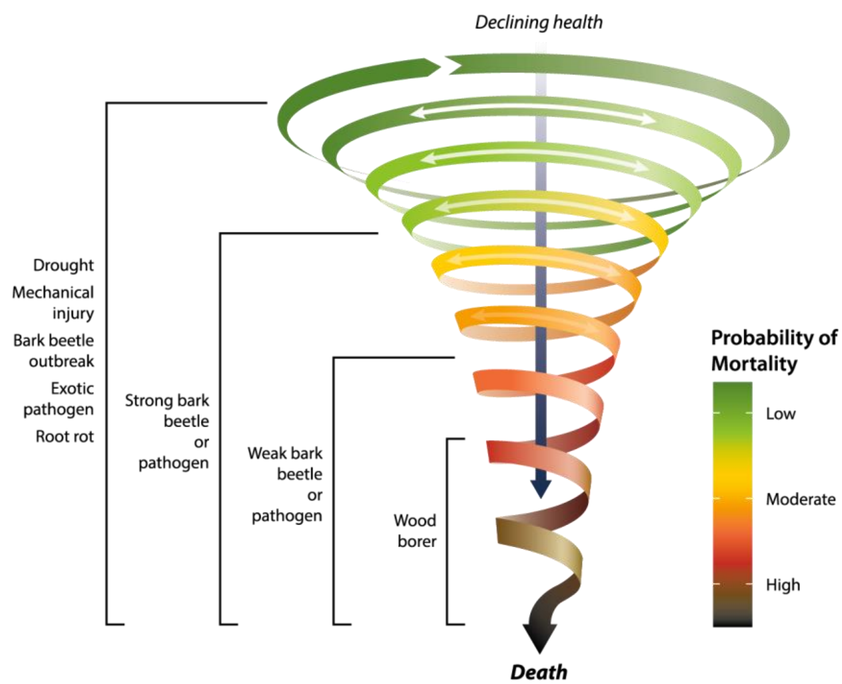

Figure 1. The conceptual tree death funnel shows that as the health of an individual declines, the risk of death increases, requiring less potent disturbances to lead to mortality. As conditions change, trees may recover and move back up the funnel (white arrows). However, the farther a tree declines down the funnel the less likely it is to recover (fading white arrows), until there is no escape and the tree dies (Axelson et al. 2019).

Not only are disturbance regimes changing (e.g., drought severity, annual extent of wildfire, insect outbreak severity, and disturbance return interval), but silvicultural systems that ostensibly are used to mimic natural disturbances have shifted in the past two to three decades to be dominated by clearcut logging with a preponderance of lodgepole pine used to satisfy requirements for reforestation (Fig. 2). All of these factors interact to increase vulnerabilities and result in a myriad of forest health problems for young stands, and particularly lodgepole pine, which suffers from a variety of disturbance agents (Heineman et al. 2010, Mather et al. 2010, Roach et al. 2015, Maclauchlan and Brooks 2020). Increasing uncertainty necessitates a critical assessment of whether standard reforestation practices that have historically emphasized establishing conifer crops in gridded plantings (i.e., pines in lines) and removal of unwanted species (e.g., broadleaf species) will create resilient and robust forests of the future. For the Interior Douglas-fir (IDF) BEC zone, reforestation is not creating resilient forests, as a special investigation (Forest Practices Board 2020) indicated that over 60% of young stands evaluated were in poor to marginal condition. This special investigation found that overall, there was an over reliance on clearcutting, reforestation was only meeting minimum targets, and perhaps most concerning of all, there was an apparent lack of critical thinking regarding long-term stand development.

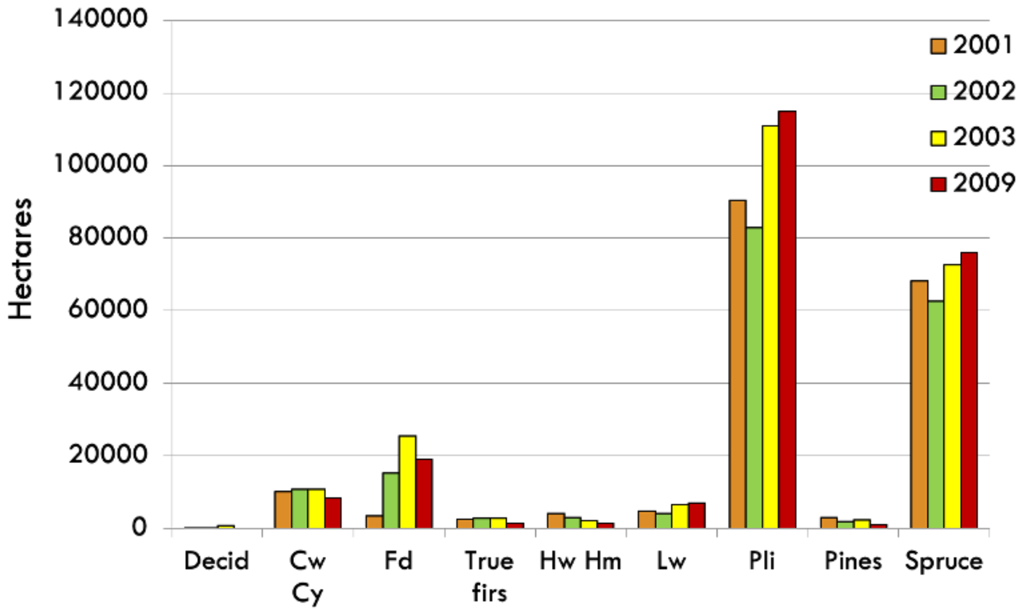

Figure 2. Area planted (hectares) in B.C. from 2001-09 by tree genera or species. During this period lodgepole pine (Pli) dominated, ranging from 80,000 to nearly 120,000 hectares being planted annually. Source: Compiled from B.C. Ministry of Forests, Lands and Natural Resource Operations Annual Reports, https://www.for.gov.bc.ca/mof/annualreports.htm

The time to embrace complexity in our reforestation practices, and arguably the initial silviculture system used, has never been greater. Partial cutting studies have shown that overstory retention facilitates successful natural regeneration as well as facilitating the survivorship of planted seedlings. For example, the Mother Tree Project, initiated by Suzanne Simard in 2015 examines explicitly the interactions of climate, harvesting practices and genotypes in a replicated experiment distributed across nine sites representing different climate regions (https://mothertreeproject.org/mother-tree-experiment/). Overwhelmingly this study has demonstrated the overstory retention is crucial on harsh sites, that it helps maintain biodiversity as well as conserve carbon, and leads to successful natural regeneration of a number of species (Fig. 3) (Simard et al. 2020 and 2021).

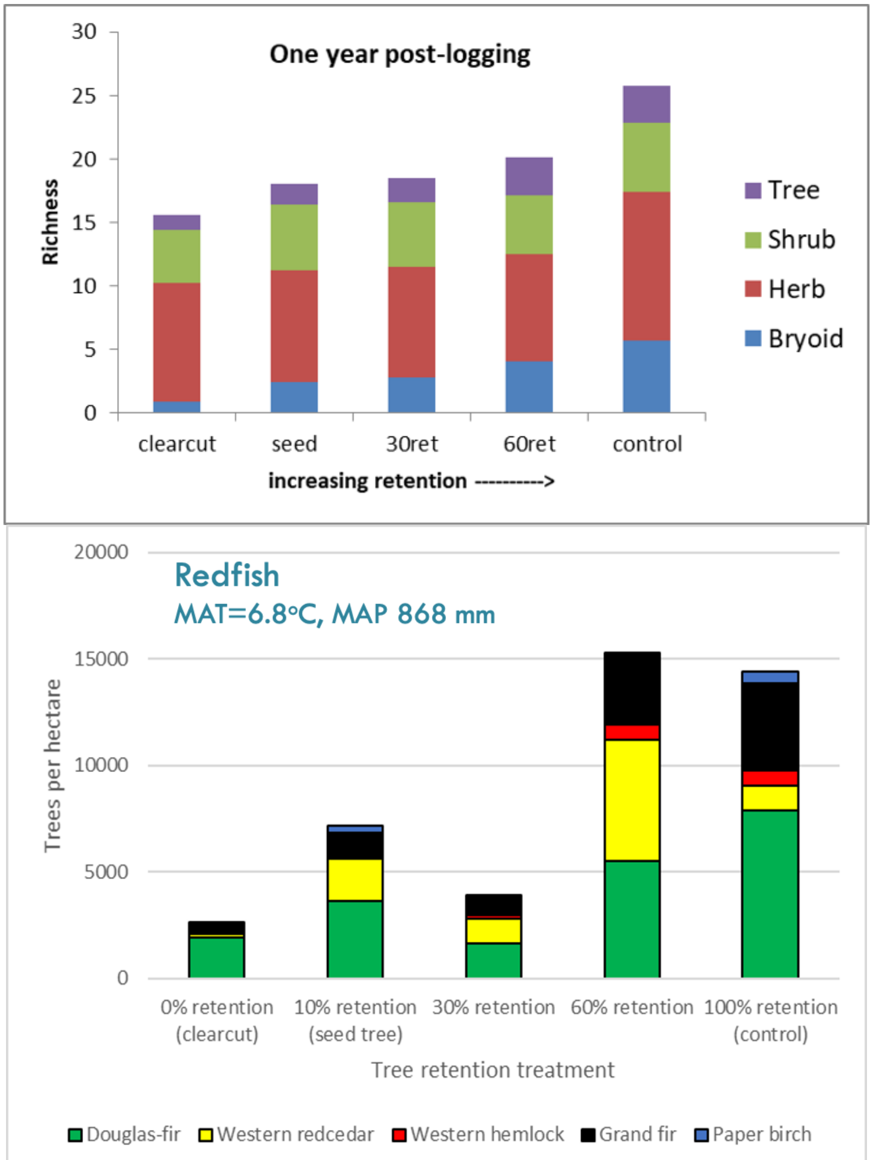

Figure 3. From the Mother Tree Project, the top graph shows that as retention increases overall, biodiversity also increases, especially for herbs and bryoids. The bottom graph demonstrates at the Redfish site (near Nelson) the natural regeneration in each harvesting type three years after logging, with the highest amounts of natural regeneration occurring in the 60% overstory retention blocks. This pattern expresses itself across the 900 km geographic range that the project spans and is even more pronounced in harsher sites (adapted from Simard et al. 2020 and 2021).

The Mother Tree project, and the many partial cutting studies developed by FLNRORD (Wiensczyk 2012) provide extremely valuable information on how retained overstory trees and regeneration interact over-time and in different ecosystems. These studies are crucial to inform us on sustainable practices and what is required if we want to see resilient future forests. The empirical research that these studies provide helps inform us on what needs to be done, educate and motivate practicing foresters on the different options available, and calibrate and validate models that project productivity into the future. A lot of science has been done on silviculture systems and regeneration, and it is more urgent than ever that the knowledge gained from this research be implemented in our forestry practices at scale in the province. No longer can the real or perceived barriers to implementation be touted as reasonable excuses to maintain the status quo. In the words of Buzz Holling, “the essential point is that evolving systems require policies and actions that not only satisfy social objectives but at the same time provide flexibility for adaptation”. Understanding the central tenants of adaptive management as well as implementation of policies that provide flexibility for adaptation is our critical challenge in creating resilient and productive forests of the future. While not too late, it has never been more important to change our perspective and actions, so we do not continue to miss the forest for the trees.

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Session 4: Policy and Tools: Improving the Health of Young Stands

Re-imagining the Role of Silviculture: Forest Protection

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In their new silviculture textbook, Ashton and Kelty (2018) provide over 700 pages of text; however, only 77 pages deal with plantation establishment to sapling stage. Current silvicultural practice in British Columbia is strongly weighted to efficient and effective regeneration in pursuit of a timber objective. We are focused on plantation establishment to achieve Free Growing, and pay very little attention to stands beyond that. We are applying only a small measure of the accumulated knowledge around the practice of silviculture, to our own detriment.

With climate change, we face both unforeseen and known forest health issues in increasingly novel ecological conditions. Biotic and abiotic disturbance is increasing at a rapid pace. I propose that it is time we look to another chapter in Ashton and Kelty's text, and begin to imagine silviculture as a means of "maintaining healthy forest ecosystems."

Currently we incorporate forest health into silvicultural methods, but only as directed by the forest health program. I suggest it is time that we undertake silviculture with a primary focus on maintaining healthy forest ecosystems, throughout the life of stands.

To take up this new paradigm for silviculture, we will need:

1. A solid understanding of stand dynamics and biotic and abiotic agents and risks;
2. Established objectives to determine desired stand structures and appropriate species mixtures; and
3. Modified harvest methods to establish desired stand structures.

The intersection of forest health and silviculture is stand dynamics: the study of how stands change through time and how disturbance affects those changes (Oliver and Larson 1996). Growing stands and landscapes in a condition of severe competition means increasing episodic mortality events caused by fire, snow press, bark beetles, and defoliators often in complex interactions with other agents (e.g., root disease, stem decay, dwarf-mistletoe). Silvicultural practices can and should be used as indirect control methods, seeking to make stands less susceptible to the range of damaging agents that confront us. The combined threats of climate change and invasive species make this more critical.

To make this shift we need to:

1. Take a system approach – Silviculture includes regeneration <u>and</u> intermediate treatments to achieve our objectives.
2. Think about growing space and competition for site resources. – Trees with insufficient growing space cannot maintain their crown and root volume, support their height, heal their

wounds, or protect themselves from herbivory. Stands suffer high levels of competition resulting in self-thinning, often in episodic mortality that creates good habitat for insects and diseases, and increases surface and ladder fuels.

3. Provide shelter – Dappled shade to reduce insolation, transpiration demands, and heating; and to reduce nighttime radiation and convective frost damage.
4. Carry out intermediate treatments – To reduce density, decrease losses, maintain vigour, manage species composition and improve stand quality.

To pay the bills for this more intensive silviculture, we need to manage our forests for value over volume. If we increase the value of the growing stock at each entry, we will realize real financial gains later. We need to adjust the expectation around revenues to the crown, to recognize the higher cost and lower value of the thinning harvest. Then, we can expect higher revenues at final harvest.

KEY MESSAGES

1. Resistance and resilience should be stated goals of land management.
2. Silvicultural controls can mitigate forest health risks.
3. Silvicultural systems set out plans to manage stands and forests to achieve our objectives and maintain our values; and to protect stands, values, and communities.
4. Stand dynamics are intimately linked to forest health risks.
5. Strategies that produce low-value commodities at high risk will not pay the bills.

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Health of Young Stands – A Coastal Perspective

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Background

Forest health of young stands on the Coast does not get the attention that it does in the Interior. However, the Coast does have many forest health issues. Some of them are independent of climate change, while others are potentially or certainly highly influenced by climate change. We need to think about how we can best move forward in planning and growing young stands that will be resilient. I believe opportunities exist to better focus foresters and to make changes to policies, including those dealing with site plans and stocking standards that will lead to greater success in dealing with present and future forest health issues.

Setting up foresters for success – how we think and how we learn

As forestry has become more complicated and technologically driven, we have unfortunately become linear thinkers. Consider the checklist. Every cutblock has a multi-page checklist. The site plan is a checklist. In a forestry world where success is defined as compliance, linear thinking is encouraged and often expected – the checklist rules. However, we also need some time to think outside the box, to think more globally, to try something new. If you do not think you are a linear thinker, then answer this question: have you done any trials lately? The forester that does not do trials or experiment with new techniques is doomed to remain a linear thinker. We must find time to try new things and not be afraid to make mistakes along the way. That is how we learn. This is as true for forest health as it is for many other aspects of forestry.

Foresters who are given the opportunity to manage an area, compared to those who are focused on specific activities, like site plans, will learn much faster. They will have the benefit of living with their mistakes for several years compared to perhaps never knowing they made a mistake. The quicker we learn, the better prepared we will be to recognize and deal with present and developing forest health issues. A focus on projects or activities may be more cost effective in the short-term, but it is not in the long-term. This principle holds for staff foresters and contract foresters. Give them an area to manage and they will be much more successful.

Rethinking the site plan through to Free Growing

Every cutblock has a site plan and every site plan identifies the ecology. In turn, the ecology is linked to stocking standards, which identify preferred/acceptable or ecologically suitable species. The problem potentially arises when we have too narrow a view of the objectives for doing this work. Often different site series in a cutblock are lumped together into one standards unit for the dominant site series. This facilitates surveys and compliance but potentially closes the door on being able to diagnose future forest health issues in these young stands that, for example, may be happening on the drier site series. Given GPS, there is very little extra work involved in mapping the different site series in a cutblock. Better planting prescriptions are also a likely benefit.

Similarly, we should consider how we do our Free Growing surveys. With climate change, it is important to understand which species on a given site will be the future crop trees. Bringing greater consistency to how these surveys are done, especially with respect to the silviculture label, is important.

Landscape stocking standards

Climate change is creating a future where certain species growing on certain sites will become winners, while others will become losers. We want our future forests to be resilient. How do we achieve this goal as we replant stands? Rumour has it tactical landscape planning is on the horizon. If this is true, we need to consider the use of landscape stocking standards. Landscape standards will provide the opportunity to define the elements of a resilient forest and to deploy the desired species where agreed, with all licensees participating to achieve the common standard. With climate change, species like western hemlock and western redcedar will likely become less suited to drier sites, while western white pine and red alder, for various reasons, may become a larger part of the future coastal forest.

Other policies

There are numerous other policies that impact forest health. In my presentation, I talked about a galactic evil. In the discussion groups, I revealed this to be the stumpage system. The stumpage system has a powerful impact on forest practices. What is needed is a policy that provides an incentive or fair reimbursement for licensees to undertake projects that are costly but that have an agreed benefit to the landowner. For example, on the south Coast, Armillaria and Phellinus root rots are an important forest health concern. Post-harvest stumping is costly, but is recognized as an effective treatment to allow the regeneration of ecologically suitable species. However, there is no allowance in the appraisal manual for stumping. No stumping treatments have been done and reported in cost surveys for several years.

KEY MESSAGES

1. Foresters will learn faster and recognize issues sooner if they think more globally, do trials and have an area based approach to management.
2. Better ecological mapping in site plans will lead to better understanding of future forest health risks.
3. Landscape stocking standards, which apply equally to all licensees, may be the best way to manage for forest resilience.

A Genetics Approach to Forest Health Issues

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Research Scientist Tree Breeder, Forests, Lands, Natural Resource Operations & Rural Development, Forest Improvement & Research Management Branch, Surrey, B.C.

Tree breeders managing the breeding programs associated with each commercial tree species in British Columbia have incorporated at least one forest health issue into their testing, selection and breeding objectives. In this talk, I will review some of the strategies used by tree breeders to find resistant trees which can be used in seed orchards for reforestation. I will also talk about the research and information needed to allow us to contribute to the resilience and productivity of young stands. Most breeding programs have now advanced through two cycles of testing that span several decades and accumulated a significant amount of data on the trees in the breeding program. Therefore, the most effective way to incorporate forest health objectives into existing breeding programs is to gather forest health information about the trees already in the breeding program. Surveying existing field trials is a very quick and efficient way to gather this information; however, in some situations controlled screening programs are more appropriate. Furthermore, genomic projects can develop tools that one day may become useful for breeding programs but must utilize trees from the breeding program to be most effective. Finally, directing deployment of orchard seed lots with high resistance to high priority locations is essential and requires collaboration with our forest health partners and silviculturalists.

Species Selection in the Time of Climate Change: Guided Tree Species Diversification as a Strategy for Minimizing Future Forest Health Risks

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Climate change will variably affect the environmental suitability of tree species in different climate + site conditions found in British Columbia. A Climate Change Informed Species Selection (CCISS) analysis (MacKenzie and Mahony 2021) is an ecological approach to forecasting site series-specific changes to species feasibility at the local level. The analysis first projects the redistribution of biogeoclimatic (BGC) units in 30 plausible climate futures using random forest machine learning and climate data from ClimateBC (Wang et al. 2016). The analysis then aligns equivalent site series concepts and associated tree species feasibility ratings between current BGC and all modelled future BGCs. The outcome of this analysis is a weighted probability of future feasibility rating for each tree species in each site series through three 30-year future normal periods.

The variation in predicted future species suitability between global climate model/carbon scenarios reflects uncertainty in future environmental condition and should be accounted for in operational reforestation decisions. Additionally, it is anticipated that the dynamics of species-specific forest health agents are likely to shift under climate change and become an increasingly important ecological factor adding to our uncertainty of future risks (Linnakoski et al. 2019).

Ecological theory highlights species diversity as a critical component of ecosystem resilience. Similarly, in contemporary economic theory, investment diversity using Modern Portfolio Theory (MPT) (Harry Markowitz 1952) is a Nobel prize winning mathematic approach to managing for market uncertainty. Application of an MPT approach to tree species selection using the CCISS analysis to forecast trends in species feasibility and probabilistic risks of losses from episodic environmental and forest health factors can provide guidance on selecting optimal risk-minimizing tree species mixes for long-term reforestation investment under a changing climate.

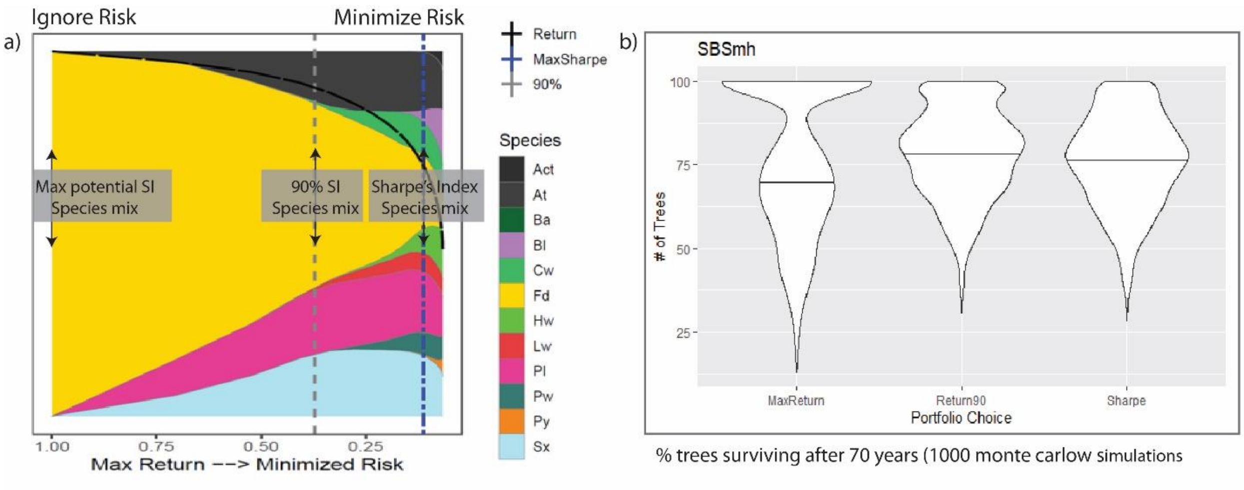

Figure 1. Modern portfolio theory tree species mixes for climate change informed reforestation. a) Portfolio graph showing three possible efficient species mixes choices representing different levels of risk avoidance. b) Violin chart of fractional tree survivorship from 1000 simulations for 3 different portfolio choices.

Climate-changed informed tools such as Climate Based Seed Transfer and CCISS support best management practices that account for climate change in reforestation decisions. However, the unavoidable uncertainty in future climate state and implications to reforestation success should also be managed. A strategy of guided diversification to minimize risk and increase forest resilience to climate change is supported by both an ecological and economic theory.

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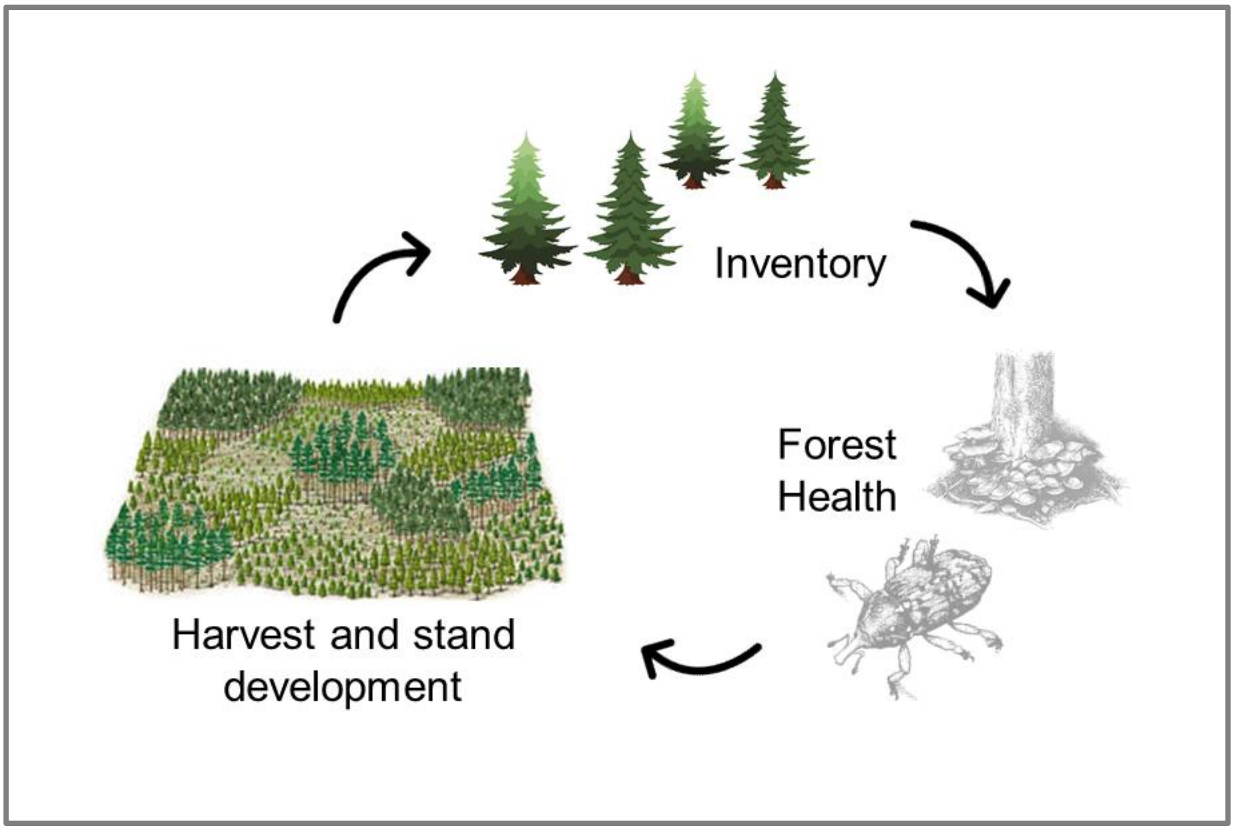
Session 5: Modelling the Uncertainty



Modelling For Decisions

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How models are used in a decision is often misconstrued and may lead to discrediting valid models and decisions. At the root of this misunderstanding is a failure to understand what is a model and what is a decision but it also may simply be the failure to recognize that the meaning of the word "for" implies "for the purpose of". In this presentation, I discuss briefly, what are models, modelling and decisions. I then look at the decision process for determining British Columbia's allowable annual cut, and how information on forest health of young stands may be incorporated into the decision.

Models are simplifications, often a representation of a system or a process that are useful for understanding. In the context of natural resource management, models are found in many forms, some of which we may have forgotten are models. Most people would envision a model as a computer-based model like the BC Tree and Stand Simulator (TASS) that is useful for understanding stand development and the implications of silviculture treatments. However, they may not envision a map of forest inventory that provides a simplified visual understanding of the forest composition across a landscape, as a model.

Modelling is commonly defined as the act of making a model. Based on this definition, modelling seems to apply simply to the work of those who created a model like TASS. However, this narrow view of modelling fails to recognize that models like TASS are also a tool that enables a user to create outputs that are themselves models (e.g., output of stand volume over time) based on inputs (e.g., regeneration information) to the model. Modelling, therefore, can also be viewed as using a model (i.e., as a tool) to create specific modelled outputs and to gain understanding about these models.

Models in natural resource management are used for understanding for various purposes and can have a key role in decisions. A decision by definition is a determination by making a judgement. However, as a judgement, a decision is made by the decision-maker, not by a model. Models are useful for understanding which can inform a decision-maker in making their judgement. Further to be useful, modelling should be tailored to address both the needs of the decision and the decision-maker.

The Allowable Annual Cut Determination

In British Columbia, an example of a natural resource management decision that utilizes models is the *Forest Act* Section 8[2] allowable annual cut determination (AAC) by the Chief Forester for major forest management units. To inform these decisions, a process called the Timber Supply Review[3] (TSR) was developed to address both legislative and statutory decision requirements. The TSR is a formal process leading to the AAC determination that usually consists of gathering relevant data, models, and information; developing a model of the timber supply over time; and ensuring input from engagement with parties with interest, particularly First Nations.

Modelling in the TSR is focused on the decision and the decision-maker's information needs. Legislatively, this focus is the rate of harvest (i.e., the timber supply) and factors that influence the rate of harvest. As such, much of the modelling to assist the Chief Forester reflects the need to understand the timber supply dynamics of a management unit. In the TSR, the most visible modelling is the use of a forest estate model (FEM) whose primary result is a harvest flow over time (i.e., timber supply) given inputs on the land base composition, forest growth, legislative objectives, and forest management. This modelling does not provide "the AAC" but provides necessary information and tools to the Chief Forester. The modelling not only includes finding the timber supply expectations given current forest composition and management but also aids the decision-maker by exploring information uncertainty and assumptions in order to provide a detailed understanding of the timber supply dynamics.

In an AAC determination, the Chief Forester needs information that is able to assist with a decision that outwardly looks to be simple (i.e., rate of harvest for a 10 year period) but in application can be difficult given the spatial and temporal complexity of timber supply in a forest management unit. Because of the complexity, tools such as forest estate models are necessary for understanding how stand level issues impact the timber supply at a management unit level.

Forest Health in Young Stands Information in the AAC Determination

Forest health information and data are diverse given forest health needs vary from base research to operational decisions. For the AAC determination, while various information is contextually useful, information for understanding the timber supply implications can be summarized as (1) where is the forest health issue found and (2) what will be the stand-level impact. "Where a forest issue is found" may be spatially identified directly or indirectly tied to another attribute (e.g., stand composition or biogeoclimatic subzone) that can be spatially identified. "Where" is also complicated given the temporal nature of forest health issues. "What is the stand level impact" is often the more difficult question as the impact is on the merchantable volume at the time of harvest and the time of future harvest is not known.

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[2] See bclaws.ca for legislative requirements of the AAC determination.

[3] For background on the Timber Supply Review see https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/forest-analysis-inventory/tsr-annual-allowable-cut/tsr_backgrounder2.pdf

In Figure 1, the schematic shows that forest health information can be brought into the AAC determination process at many steps. It may be brought early into the TSR forest estate modelling (←1) or presented directly to the Chief Forester (←9) for the determination. In the paragraphs below the symbols (←1) refer to the number arrows in Figure 1.

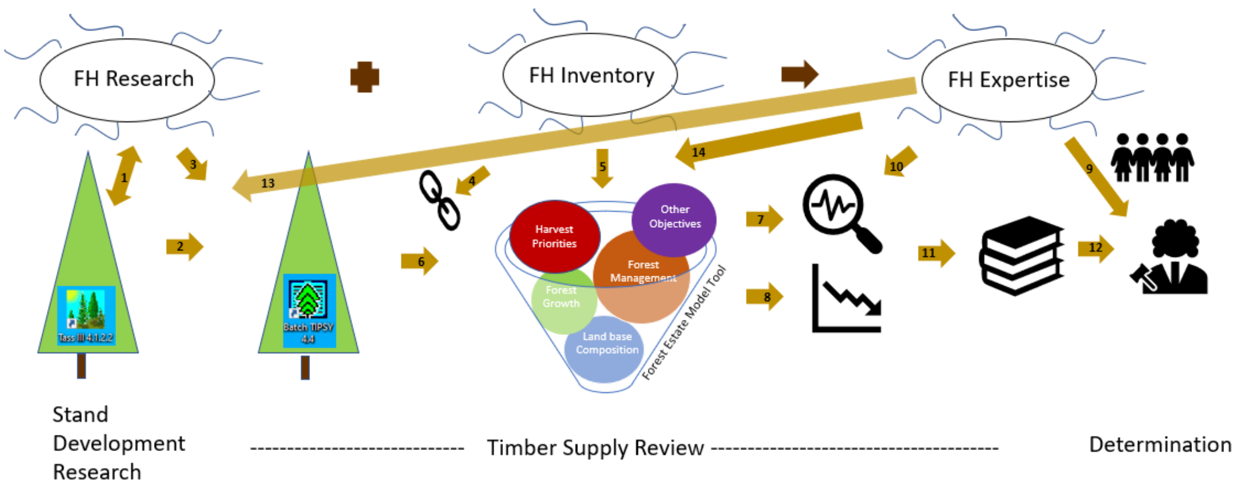

Figure 1. Schematic incorporating forest health information for young stands into the AAC Determination

For FEM tools used in the TSR, a stand-level identifier for a forest health issue (presence and other information such as incidence) is incorporated (←5) into the FEM data that describes the forest land base and consequently these stands need to be linked (←4) to tables of merchantable volume over time that have incorporated the impacts of the forest issue. This is a critical linkage of the spatial and temporal components of the FEM model.

In British Columbia, long-term data on young stands and particularly with tracked forest health issues are necessary but currently insufficient. Stand development models such as TASS that assist with our stand development understanding in young stands can also be utilized to gain an understanding of the impacts of the forest health agents. The structure of TASS (spatially explicit individual tree) model provides a flexible framework to explore a wide range of possible tree level damage (e.g., mortality, damage to leaders, reduce foliage) due to forest health issues and their stand-level impact. Modelling of forest health issues with TASS requires physically modifying the programming code of TASS to incorporate forest health research understandings (←1)[4] and forest health experts working with forest stand development modellers to create appropriate modules (←13).

In the TSR, currently most volume tables for post-harvest young stands are generated with the Table Interpolation Program for Stand Yield (TIPSY) based on regeneration information derived from silviculture information in the RESULTS database (←6). TIPSY, as the name suggests, interpolates

[4] See symposium summary by Derek Sattler titled "Impacts of Stem Rusts: GRIM & CRIME TASS II Modules"

from a database of volume tables that are generated from TASS to obtain volume tables for specific regeneration inputs. As the database, and hence interpolation, does not include modelled forest health issues, the model requires the application of operational adjustments factors (OAF) to adjust, if desired, the volume tables to consider forest health and other operational issues such as stand gaps. OAFs may be derived in a variety of ways such as the translation of results from TASS modelling of a forest health issue[3] (⟵12) or derived from specific field studies[5] (⟵3).

With appropriate impact, location information, and forest health expertise (⟵14), a forest health issue and its timber supply implications can be incorporated into base FEM scenarios (⟵8) and explored with sensitivity or critical issues analyses based on different assumptions (⟵7). This information then becomes part of the technical summary of information provided to the Chief Forester for the AAC determination (⟵11, ⟵12). A less desirable route for information is that forest health information is not directly incorporated into the FEM but is simply presented to the Chief Forester (⟵9) or makes use of generalized FEM sensitivities to hypothesize timber supply impacts (⟵10).

Forest health expertise can add greatly to the AAC determination but to be most effective, forest health information needs to address the information needs of the decision and decision-maker. To do this requires purposeful research, analysis, and modelling for the AAC determination and most importantly the collaboration of forest health experts, forest estate modellers and stand development modellers.

KEY MESSAGES

1. Models are simplifications that are useful for understanding.
2. Modelling should be tailored to a purpose.
3. Decisions are judgements not the results of a model.
4. For AAC determinations, forest health information is best incorporated by forest health experts, forest estate modellers, and stand development modellers working together from or before the start of the timber supply review.

[5] See symposium summary by Stefan Zeglen titled "Creating operational adjustment factors: root disease on the B.C. south Coast".

Estimating Rust Incidence for Post-Harvest Openings that have not been Surveyed

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Abstract

The modules for western gall rust (DSG) and comandra blister rust (DSC) that have been developed for the tree and stand simulator (TASS) are initialized by a user-supplied value for rust incidence at a stand age of 15 years. Use of the modules, particularly in the context of a timber supply review (TSR), may be hindered by an inability to obtain this value since some stands will not have been surveyed for rusts post-harvest. To overcome this potential limitation, a two equation hurdle model for the estimation of rust incidence at a stand-age of 15 years was developed for application in stands with no prior information on rust incidence. The first equation in the hurdle model is used to predict the probability of rust presence, while the second equation predicts rust incidence (percent of trees infected) at a stand age of 15 years, conditional on the presence of rust. The product of the two equations yields the marginal prediction of rust incidence, which would be the value used to initialize the rust modules in TASS. The empirical models that are presented are for use in the District of Mackenzie Timber Supply Area (DMK TSA). They were developed using data obtained from a provincial inventory of stands established post-harvest that had been surveyed for rusts and other diseases and pathogens.

Introduction

To simulate the potential impacts on lumber yields caused by western gall rust (DSG) and comandra blister rust (DSC), two modules were developed using repeated measurement data collected from experimental plots located in the central-interior region of British Columbia (BC). The modules, termed, GRIM (western gall rust) and CRIME (comandra blister rust), have been programmed to work with the tree and stand simulator (TASS) and the add-on lumber manufacturing simulator, SAWSIM (see Sattler et al. 2019 for a description of the modules). The two most common applications for the rust modules are in the development of silvicultural strategies and in timber supply review (TSR). Regardless of the context in which they are used, initialization of either module requires an estimate of rust incidence at a stand age of 15 years.

For a stand that has already been surveyed for rusts, a regression-based approach has been developed to standardize the observed rust incidence to the common age of 15 years. This approach is described in a separate paper (Sattler et al. 2019), and is only briefly described here for DSG. The approach uses a power function where the predictor variable is rust incidence recorded during the survey. The two parameters of the power function are age-specific parameters; they take on a different value for each age (i.e., years since establishment; from 1 to 14), depending on when the stand was surveyed. The output from the equation is the rust incidence adjusted to the common age of 15 years. Once calculated, the simulation in TASS can proceed. For surveys conducted in stands older than 15 years, no adjustments are made as incidence levels are relatively stable beyond this point in time.

An obvious limitation for the rust modules is their application to stands that have not been surveyed for rusts. Such instances are frequently encountered within the Province's inventory of stands established following harvest. During a TSR, a timber supply analyst will form aggregate units from this inventory of stands which are then projected using TASS, or its derivative, TIPSY (Table Interpolation Program for Stand Yield). Thus, for the rust modules to be used in TSR, a method of estimating rust incidence for stands that have not been surveyed for rusts was needed.

To obtain an estimate for rust incidence for stands that have not been surveyed for rusts, one possible solution would be to take the rust incidence (standardized to the common age of 15 years) from stands that have been surveyed, and calculate an average value of rust incidence by BEC subzone. The average value for each subzone would then be applied to any stand within the subzone of interest that has not been surveyed. The downside to this approach is that it does not make use of other potentially useful predictor variables that are available at the stand or aggregate opening unit level. For example, climate variables such as relative humidity and temperature in spring have been shown to be correlated with the production of rust spores (Hiratsuka et al. 1987). Likewise, Peterson (1960) has suggested that variables such as topographic position and site productivity may be useful in explaining the variability in rust incidence. Such variables are available for each stand that resides within the inventory of stands established post-harvest. Therefore, a preferred solution would be to develop a model (or set of models) capable of predicting rust incidence at age 15, using climate and biophysical variables that are available for all managed stands.

In order to construct such a model, one must first consider the nature of the data that is available for model development. Within the Province's inventory of stands established following harvest, rusts are noted to be absent in many of the stands that have been surveyed. For TSAs where many of the surveyed stands show 0% incidence, the data are zero-inflated and, therefore, require special consideration during model development. A useful strategy in dealing with zero-inflated data is to use a hurdle model that consists of two equations. The first equation is used to predict the probability of observing either DSG or DSC within a stand (dependent variable is 0 when rust is absent, and 1 when present). A second equation is then used to predict the incidence of rust, conditional on the rust of interest being present. The product of the two equations yields the marginal prediction for either DSG or DSC. It is this latter value that would then be used to initialize a TASS/TIPSY simulation for a stand that has not been surveyed for rusts. It should also be noted that, for a given TSA, where all surveyed stands have some level of rust, one can simply apply (or develop) the second equation in the hurdle model to obtain an estimate of rust incidence at age 15.

This pragmatic approach to estimating rust incidence in stands that have not been surveyed would be best performed on TSA-by-TSA basis, since the individual equations of the hurdle model would be largely empirical. With this in mind, the main objective of this paper is to provide a description of methods that could be used when developing hurdle models for the purpose of initializing the GRIM and CRIME modules for stands that have not been surveyed. To help illustrate the model development process, the Mackenzie Timber Supply Area (DMK TSA) is used as an example. A secondary objective of this paper is to gain further insight into the climatic and biophysical variables that affect the presence and incidence of DSG and DSC. While the models that are presented are empirical in nature, the identification of variables that affect DSG and DSC in the DMK should contribute to our understanding of these rusts in neighboring TSAs.

Materials and Methods

The data used in the analysis were obtained from the Province's inventory of stands that are established post-harvest. In order to maintain consistent terminology, each unique record within the dataset is herein referred to as an opening. The area of focus for this study was the DMK, therefore, only openings within the DMK that had been surveyed for rusts were included. The dataset of surveyed openings for the DMK contained 5334 records covering thirteen different BEC subzones. Openings in the database were established through planting, natural regeneration, or a combination of these two. Values for both DSG and DSC rust incidence had been reported for all openings in the dataset. However, some openings within the dataset contained no pine (planted or naturals) and rust incidence in these openings was reported as 0% (applies for both DSG and DSC). These openings were removed prior to further analysis. Openings where pine made up less than 10% of the proportion, by sph (for either planted or naturals), were also removed, since the impact of rusts on the total volume of these stands would be minor. Finally, all openings that were less than 1 ha (5 openings) or greater than 4000 ha (4 openings) were removed. In the end, 3806 openings were available for further analysis.

In the resulting dataset, DSG incidence ranged from a low of 1% to a high of 56%, while that of DSC ranged from a low 1% to a high of 99%. Given that this dataset was not zero-inflated for either rust, development of the first equation in the two-stage hurdle model (i.e., presence/absence) was not necessary. Nevertheless, it is likely that the datasets obtained for other TSAs will be zero-inflated. For this reason, the steps involved in the development of both equations of the hurdle model are presented, while, results will only be provided for the second equation.

The vast number of openings were located in one of the four following BEC subzones: BWBSdk (14%), ESSFmv (20%), SBSmk (44%) and SBSwk (18%). The total area occupied by all openings in the dataset was 362,391 ha, with the same four BEC subzones occupying 20%, 22%, 38% and 14% of the area, respectively. To simplify the analysis, all other BEC subzones were merged into one of these four main BEC subzones based on similarities in biophysical characteristics.

Potential predictor variables contained within the dataset fell into three broad categories: i) biophysical attributes (e.g., slope, aspect, elevation), ii) productivity and species composition (i.e., site index, proportion of total sph that is pine), and iii) climate variables. The climate variables were specific to each opening and were obtained using ClimateBC software (Wang et al. 2016). Values for the climate variables represent the three-decade average for the climate normal period 1961-1990. Both annual and seasonal climate variables (i.e., winter, spring, summer, and fall) were included in the analysis.

The first step in the development of the hurdle models for DSG and DSC was to adjust all values for rust incidence to the common age of 15 years. After standardizing incidence to 15 years post-establishment, various summary statistics were calculated. These included the mean and area-weighted mean values for DSG and DSC by BEC subzone, as well as the number of openings and total area affected by different levels of rust incidence. Once these calculations were completed, the development of the hurdle models for DSG and DSC could begin.

Equations of the hurdle model

For a dataset in which the dependent variable is zero-inflated, the first equation in the hurdle model is formulated to predict the probability of the rust being present (i.e., incidence at age 15 > 0%). The equation should be formulated such that the binary dependent variable has a value of 1 when the rust (DSG or DSC) is present and 0 if the rust is absent. A generalized linear model (GLM) with a logit link function is then used to relate the dependent variable to a set of potential explanatory variables. This relationship is expressed through the following general equation:

eq.1 $P_{occurrence} = \exp(X\beta)/(1+\exp(X\beta))$

where X is a row vector of explanatory variables, β is vector of unknown parameters, and $P_{occurrence}$ is the probability of observing rust within an opening.

If the dependent variable is unbalanced (i.e., there is a large disparity between the number of zeros and ones), steps to balance the model-fitting dataset should be taken. The process of balancing a dataset with a binary dependent variable is described in Salas et al. (2018), and is reported to increase the precision of the parameter estimates, thus affecting statistical inference. The process involves placing observations, selected at random from the unbalanced dataset, into a model fitting dataset such that a fifty-fifty split of zeros and ones is achieved. For example, if the available dataset consists of 1000 zeros and 4000 ones, a balanced dataset may be created in which 900 observations are zeros and 900 observations are ones. Parameters for the first equation can then be obtained by fitting the model to the balanced dataset using maximum likelihood estimation.

The process of selecting the predictor variables to include in the model should begin by fitting an intercept-only model (i.e., no predictor variable). All available predictor variables should then be tested individually by adding them to the model one at time, with each variable evaluated using a Chi-square statistic. The predictor variable that produces the lowest AIC can then added to the model, and the process of testing the remaining individual terms is repeated using the new model. The process can be stopped when there is no further improvement to AIC. Care should be taken to avoid including predictor variables that are highly correlated.

The second equation in the hurdle model is formulated to predict rust proportion, conditional on rust being present in the opening. Consequently, one should ensure that the model fitting the dataset used to estimate parameters of the second equation include only openings where rust incidence is > 0%.

When the dependent variable falls within range [0, 1], but does not include 0 or 1, an appropriate model to use is a GLM in which the errors are assumed to follow a Gamma distribution. The Gamma distribution is appropriate for data that is right-skewed (i.e., most of the data is on the left side of the distribution) and where the variance of the positive dependent variable is near constant on the log scale. The relationship between rust proportion and the available explanatory variables can be expressed through the following general equation:

eq.2 $(\text{Incidence15} \mid P_{\text{occurrence}}=1) = \exp(X\alpha)/(1+\exp(X\alpha))$

in which X is a matrix containing the explanatory variables and αα is a vector of parameters which includes the intercept. For the current analysis, Eq. 2 was fit to the data using the 'glm' function within the 'stats' package in R (R core team 2020), in which a Gamma distribution with an inverse link function was specified. The selection of predictor variables for Eq.2 should follow the same process as that described for Eq.1.

The final step in the hurdle model is to generate predictions of rust incidence for openings that have not been surveyed for rusts. These are known as the marginal predictions, and are obtained through the product of Eqs 1 and 2. This step is expressed as follows:

eq.3 $E(\text{Incidence15}) = P_{\text{occurrence}} \times E(\text{Incidence15} \mid P_{\text{occurrence}}=1)$

where E(Incidence15) is the expected marginal rust incidence at age 15, and all other terms are as previously described. Since separate hurdle models were developed for DSG and DSC, the preceding equations will be referred to as Eq.DSG 1, Eq.DSG 2, Eq.DSG 3, Eq.DSC 1, Eq.DSC 2 and Eq.DSC 3 for the remainder of the text.

Examination of distance to local maxima

There is evidence which suggests that stands in close proximity to a high concentration of rust-infected trees (either DSG or DSC) are at greater risk of infection than those farther afield (for an example, see Jacobi et al. (1993). It is presumed that a stand with a relatively high level of incidence is where the rust first took hold. Such stands then become a source of inoculum, and nearby stands are likely to display similar levels of rust incidence. For DSG, there is no intermediate host, thus a causal relationship between inoculum source and distance to the next infected stand seems quite plausible. For DSC, a similar linkage is plausible, but made more complex, as the rust must first pass through an alternate host (i.e., bastard toadflax).

With these points in mind, a final potential predictor variable was calculated and then tested in the hurdle models for DSG and DSC. The potential predictor variable was the distance between an opening and the opening considered to be the local maxima. Calculation of this variable followed multiple steps. First, the study area (i.e., the DMK) was divided into 6 x 6 km square grids. Then, from each grid, the opening with the highest value for rust incidence was selected (note that the process was completed separately for DSG and DSC). This subset of data is referred to as the local maxima dataset. For DSG, the local maxima dataset contained 333 openings in which rust incidence ranged from 10% to 56%. For DSC, the equivalent dataset contained of 446 openings. The Euclidean distance (in km) between each opening identified in the local maxima dataset and all other openings in the analysis dataset was then calculated. This potential predictor variable was then added to the list of other predictors and tested in the hurdle models.

Evaluation of the distance to local maxima is included here as a final step in the analysis, since it is recognized that this variable may not be available to a timber supply analyst. The calculation of spatially explicit predictor variables in a timber supply analysis is complicated by several factors and will depend on the software and approach used by the analyst. Nevertheless, exploration of the predictive abilities of this variable seemed warranted.

Results

Incidence of DSG by BEC subzone

Frequency plots indicated that 27% of the total number of openings had no DSG, while 56% of openings had between 1 and 10% DSG incidence, and 12% had greater than 20% incidence (Figure 1). Among the openings where incidence exceeded 20%, the majority (60%) were within the SBSmk, followed by the SBSwk (30%).

In terms of area, approximately 21% of the total area occupied by all openings were reported to have no DSG, while 10% of the area had DSG incidence levels that exceeded 20% (Figure 2). Nearly 40% of the area where DSG incidence was greater than zero fell within the SBSmk, while 23% of the area affected by DSG fell within the BWBSdk. The area-weighted mean DSG incidence in the DMK, calculated from openings where DSG incidence was greater than zero, was 10%. A summary of the mean and area-weighted means for DSG incidence is provided in Table 1.

Table 1. Mean (and standard deviation) and area-weighted mean values for DSG incidence by BEC subzone within the DMK. An asterisk (*) indicates that openings with zero incidence were excluded.

BEC subzone	Total No. openings	Total area (ha)	Area (ha)*	No. Openings*	Mean DSG*	Area-Weighted Mean DSG*
BWBSdk	815	77721	67737	665	9 { 7 }	7
ESSFmv	1135	88955	65202	700	8 { 7 }	8
SBSmk	2394	141290	117776	1907	11 { 8 }	11
SBSwk	981	54427	37798	652	12 { 7 }	12

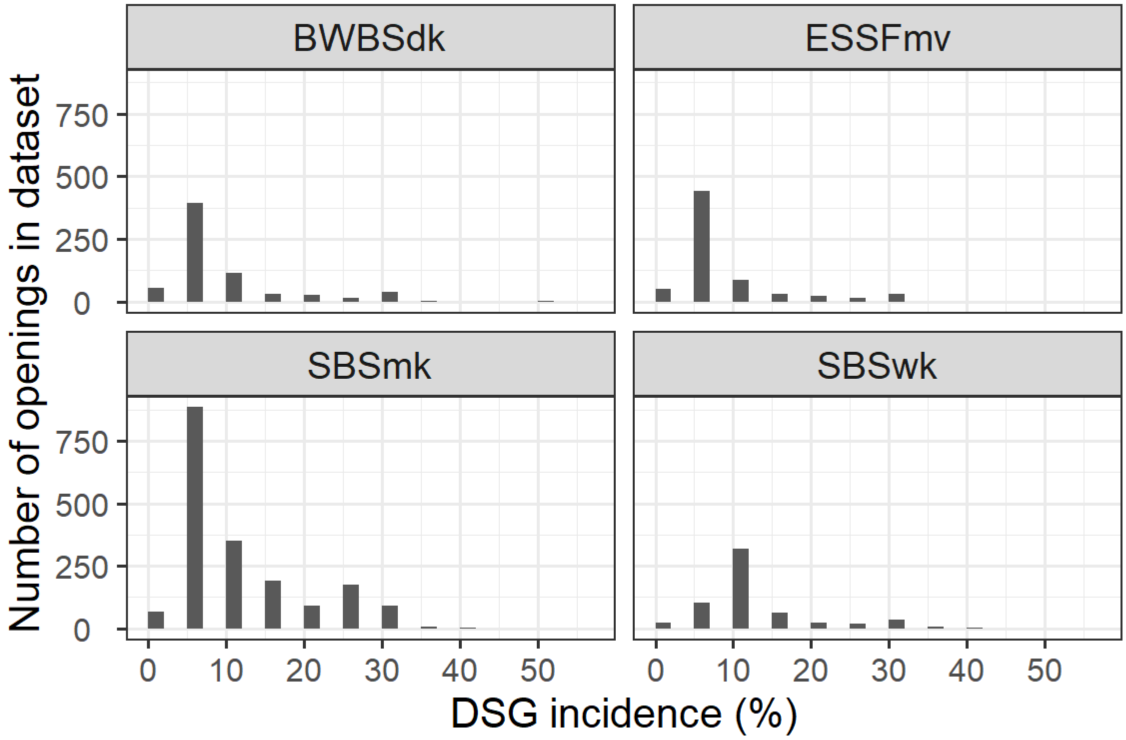

Figure 1. Number of openings by DSG incidence for the four main BEC zones in the DMK. Data for all other BEC zones present in the dataset were merged into one of the four BEC zones shown here.

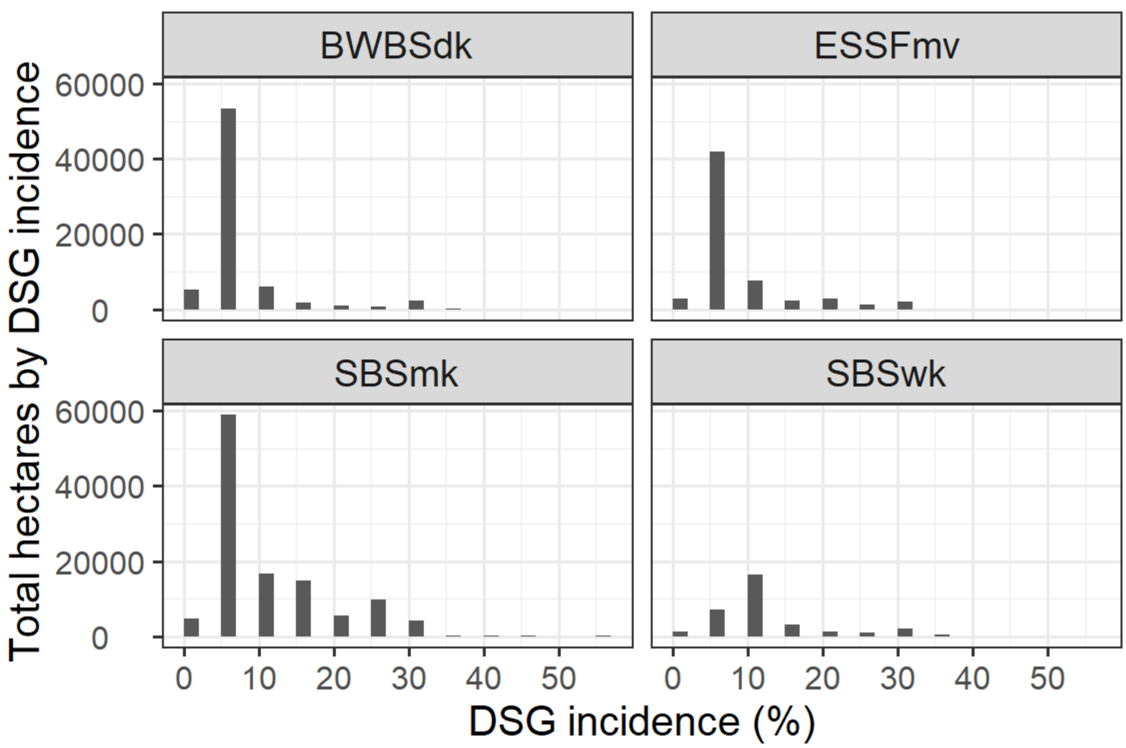

Figure 2. Total opening hectares by DSG incidence. Only the four main BEC zones in the DMK are shown, with data from all other BEC zones merged into one of the BEC zones shown here.

Model for DSG presence (Eq.DSG 1)
As previously mentioned, all openings with a pine component of 10% or more within the DMK contained some level of DSG. Therefore, a model for rust presence/absence was not developed. However, for future reference, a description of the diagnostics that should be evaluated is provided.

Diagnostics to evaluate the overall performance of a GLM in which the dependent variable is binary include a Receiver Operator Characteristic (ROC) and a pseudo R-square. The ROC test produces an area under the ROC curve (AUC), which indicates the specificity and sensitivity of the model. Generally, an AUC of 0.7 or greater is acceptable (an AUC of 0.5 is equivalent to flipping an unbiased coin). The pseudo R-square is used to characterize the strength of the relationship between the dependent variable and the set of independent variables. The value is obtained from the ratio of the model deviance to the null deviance, which is provided in the output of most statistical packages for GLMs.

Model for conditional DSG incidence (Eq.DSG 2)
The best model for the prediction of conditional DSG incidence included the following set of predictor variables:

- Mean coldest monthly temperature (MCMT)
- Relative humidity in spring (RH_sp)
- Hargreaves reference evaporation in summer (mm) (Eref_sm)
- Proportion of planted pine (Pl_prop)
- Distance to local maxima (km)

MCMT explained the most amount of variation in DSG incidence, and DSG incidence was found to increase with increasing MCMT (i.e., warmer conditions during the coldest periods in winter were positively correlated with DSG incidence). The relative humidity in the spring was also significant predictor and showed a positive correlation with DSG incidence. Likewise, there was a positive correlation between DSG incidence and Eref_sm. Among the non-climate based variables, the proportion of planted pine was the best predictor, and showed a positive correlation with DSG incidence. Parameters for the model without distance to local maxima are listed in Table 2. Plots of the residuals from the model were generally free of bias (Figure 3). Furthermore, there was no noticeable difference in model performance across the four main BEC subzones.

If the variable for distance to the local maxima is taken out of model, a pseudo R-square of 7% and an AIC of -11106 is obtained. However, the performance of the model improves significantly following the addition of the distance to a local maxima. With this latter variable included, model AIC was -11542 and the pseudo R-square increased to 17%. Among all the variables considered, the distance to local maxima was by far the best single predictor. DSG incidence decreased with increasing distance to local maxima, with the relationship clearly being non-linear.

Table 2. Parameter estimates (and associated statistics) for Eq.DSG.2 which predicts the conditional incidence of DSG (i.e., DSG incidence, when DSG is present).

Term	Estimate	Std. error	Statistic	p. value
Intercept	54.072	9.664	5.595	<0.001
Mean Cold Month Temp.	-0.585	0.170	-3.430	<0.001
Proportion of Pine	-2.067	0.311	-6.653	<0.001
Relative Humidity Spring	-0.605	0.109	-5.533	<0.001
Harg. ref. Evaporation Summer	-0.055	0.009	-6.236	<0.001

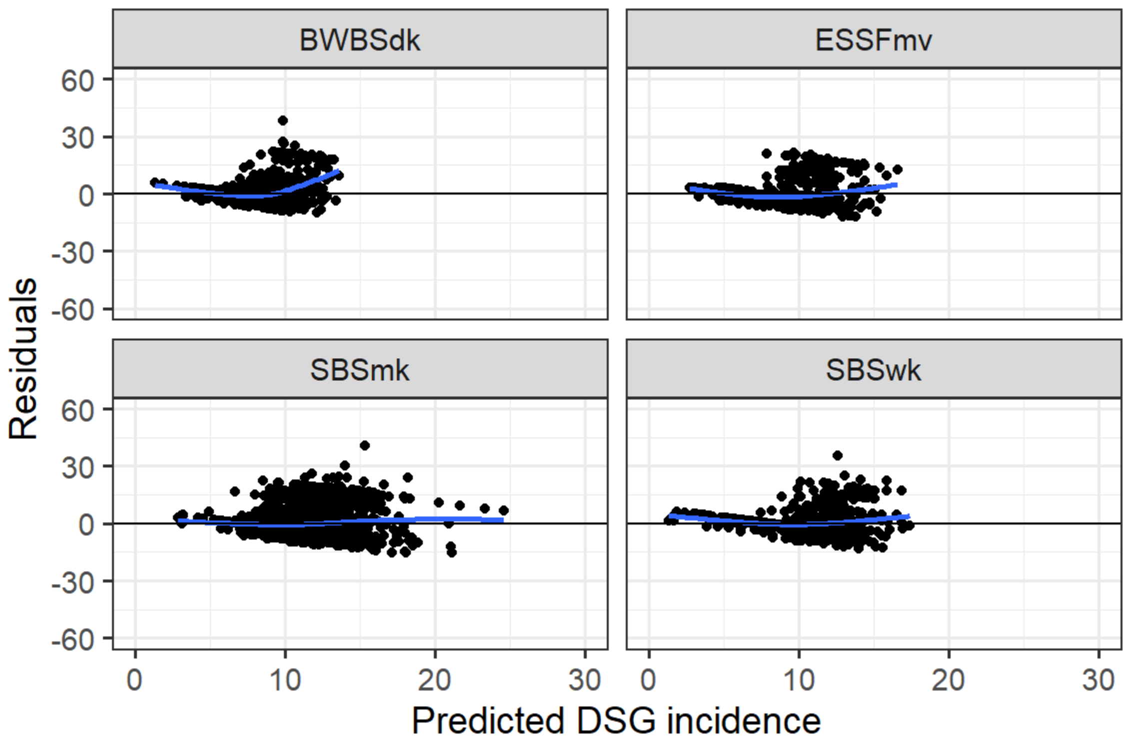

Figure 3. Plots of residuals versus the predicted incidence of DSG, by BEC subzone.

DSG marginal predictions and comparison to the mean

The marginal prediction of DSG incidence for an opening can be obtained through the product of Eq.DSG 1 and Eq.DSG 2. For the example of the DMK, we can set Eq.DSG 1 to equal 1, since DSG was present in all openings with at least 10% pine. The result of this product is depicted in Figure 4.

If distance to local maxima is withheld from the model, the RMSE (root mean square error) for the marginal prediction ranged from a low of 6.5% in the ESSFmv to a high of 7.8% in the SBSmk.

With distance to local maxima included, the RMSE for the marginal prediction of DSG improved slightly, with a low of 6.0% in the ESSFmv to a high of 7.4% in the SBSmk.

The alternative to using the marginal predictions from the hurdle model would be to simply apply the mean DSG incidence for each BEC subzone. In this regard, the RMSE obtained through use of the mean DSG incidence were about 1% greater than the marginal predictions within each of the BEC subzones. While this difference is small, the improved predictive abilities of the hurdle model become more evident as the DSG incidence increases. For example, within the ESSFmv, use of the hurdle model resulted in a RMSE of 14% for areas where the observed DSG incidence was greater than 15%. For the same area, using the average DSG incidence resulted in a RMSE of 17%.

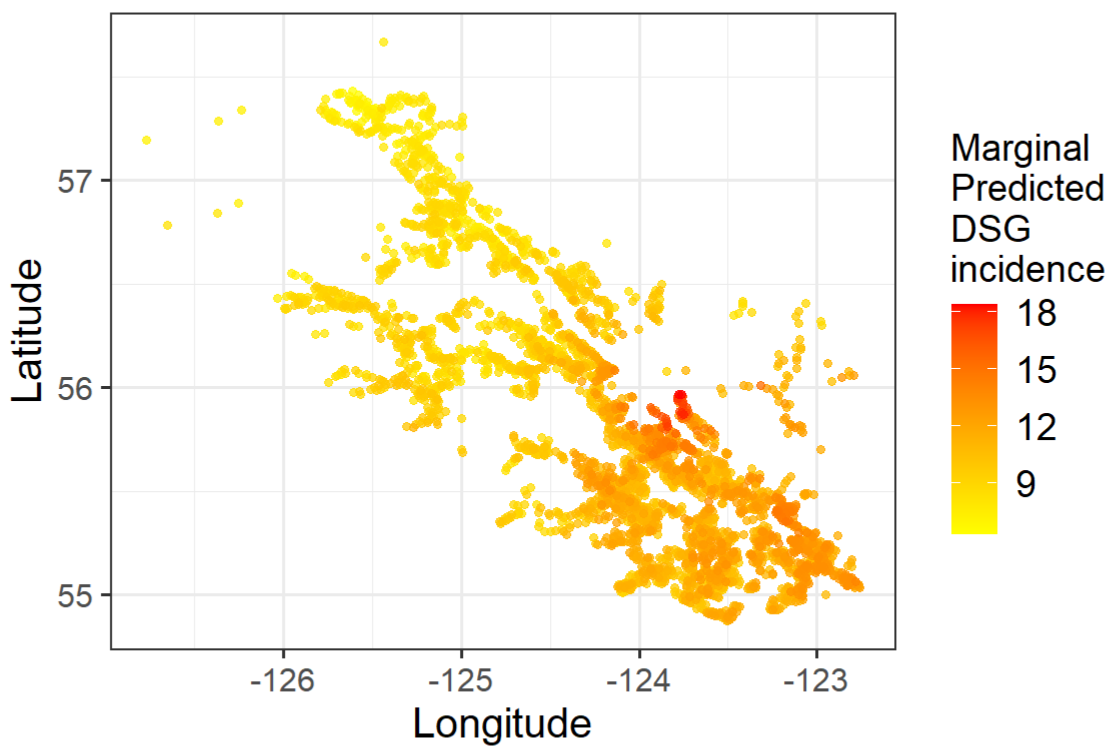

Figure 4. Marginal predicted DSG incidence (product of eq. DSG.1 and eq. DSG.2) for all openings in the original DMK dataset.

Incidence of DSC by BEC subzone

Roughly 42% of openings had between 1 and 10% DSC rust incidence, while about 27% of openings had DSC incidence levels equal to or greater than 20%. Mean incidence of DSC (Figure 5), which included openings with no DSC, was greatest in the SBSmk (mean = 16%), followed by the SBSwk (11%), BWBSdk (10%) and ESSFmv (5%).

About 40% of the area affected fell within the SBSmk, 24% within the BWBSdk, 11% within the SBSwk, and 21% in the ESSFmv (Figure 6). The SBSmk had the greatest amount of area where DSC incidence was above 20%. The remaining three BEC subzones each showed DSC incidence above 20% on roughly 2% of the total area. The area-weighted mean DSC incidence, calculated from all openings where DSC was present, is 15%.

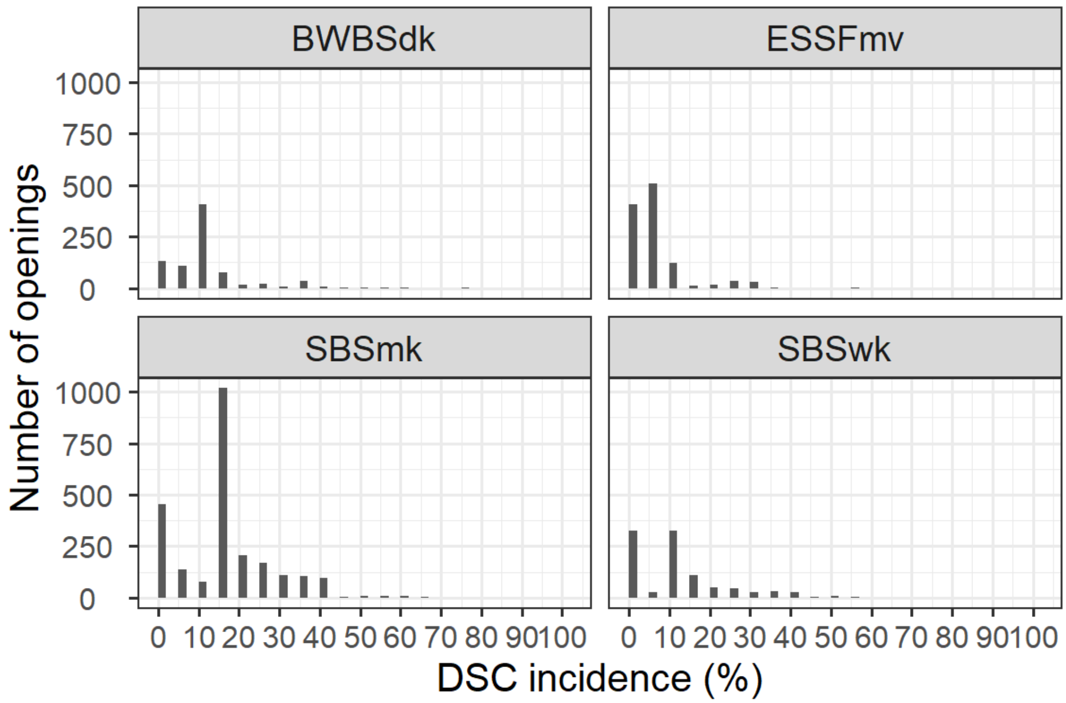

Figure 5. Number of openings by DSC incidence for dataset containing surveyed openings in the DMK.

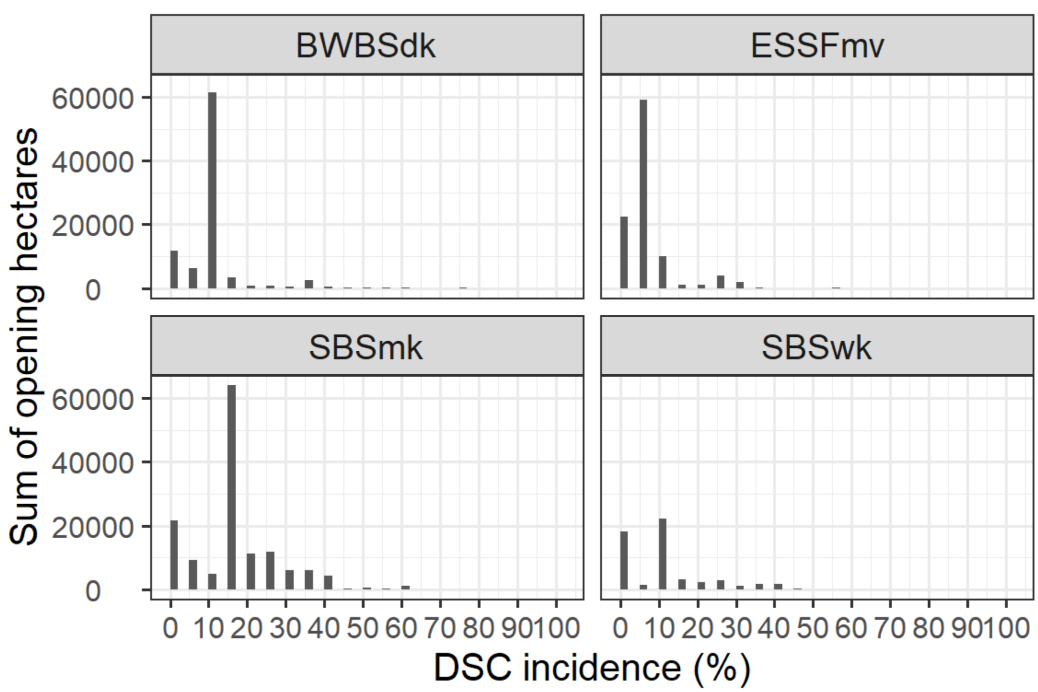

Figure 6. Sum of opening hectares by DSG incidence for dataset containing surveyed openings in the DMK.

Model for DSC presence (Eq.DSC 1)

All openings with a pine component of 10% or more within the DMK contained some level of DSC. Therefore, a model for DSC rust presence/absence was not developed.

Model for conditional DSC incidence (Eq.DSC 2)

The best model for the prediction of DSC incidence included the following set of predictor variables:

- Average temperature in spring (Tave_sp)
- First day of the frost free period (bFFP)
- Proportion of planted pine (Pl_prop)
- Relative humidity in the spring (RH_sp)
- Distance to local maxima (km)

The mean temperature in spring was the variable that provided the greatest improvement relative to the null model (i.e., intercept only), explaining roughly 13% of the variability in the dependent variable on its own. The relationship indicated that DSC incidence increased with increasing mean temperature in spring. The next best climate variable was the first day of the frost-free period (bFFP), which explained just over 5% of the variability. DSC incidence was shown to decrease with increasing bFFP. The last climate variable to be included was that for relative humidity in spring (RH_sp), which displayed a positive relationship with DSC incidence. Excluding climate and spatially dependent variables, the proportion of planted pine was the only variable to be included in the model. As was the case with DSG, the incidence of DSC showed a small, yet, significant increase with increasing proportion of planted pine.

After withholding the variable for distance to local maxima from the model, the pseudo R-square was 18% with an AIC of -8761.1. With distance to local maxima added back into the model, the pseudo R-square was 25%, with an AIC of -9073.7, indicating that the variable was clearly important in predicting DSC incidence. The relationship with distance to local maxima was non-linear, with DSC incidence decreasing exponentially over increasing distance to local maxima. Parameters for the model without the variable for distance to local maxima are listed in Table 3.

Plots of the residuals from the model were free from any noticeable bias (Figure 7). Importantly, there was no indication of bias in the residuals due to unaccounted differences across BEC subzone.

Table 3. Parameter estimates (and associated statistics) for Eq. DSC.2 which predicts the conditional incidence of DSC (i.e., DSC incidence when its presence is known).

Term	Estimate	Std. error	Statistic	p. value
Intercept	94.393	5.938	15.897	<0.001
First day of frost free period	-0.315	0.029	-10.882	<0.001
Proportion of pine	-1.213	0.171	-7.107	<0.001
Relative Humidity Spring	-0.542	0.045	-11.967	<0.001
Average Spring Temperature	-3.324	0.171	-19.417	<0.001

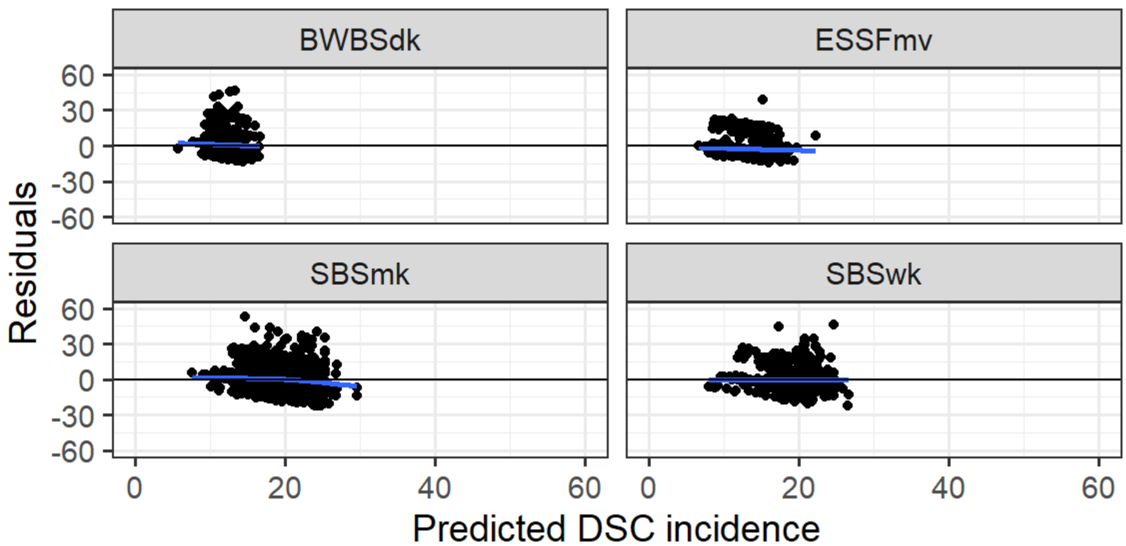

Figure 7. Plots of residuals versus the predicted incidence of DSC, by BEC subzone.

Marginal predictions of DSC incidence

The product of Eq.DSC 1 and Eq.DSC 2 yields the marginal predictions for DSC incidence. Since all openings that had been surveyed for rusts within the DMK had some DSC, we can set Eq.DSC 1 to equal 1. Figure 8 depicts the marginal predictions for DSC incidence for the openings that were in the analysis. The RMSE for the marginal predictions ranged from a low of 6.5% in the ESSFmv to a high of 10% in the SBSwk. Comparatively, if one were to replace predictions from the hurdle model with the average DSC incidence from each BEC subzone, the RMSE would increase by roughly 1% in each BEC subzone.

The improved predictive abilities of the hurdle model relative to an average value for DSC incidence become more evident as DSC incidence increases. For example, in the ESSFmv, the calculation of RMSE for areas where DSC incidence was greater than 20%, was 13% when using the hurdle model, and 18% when using the average.

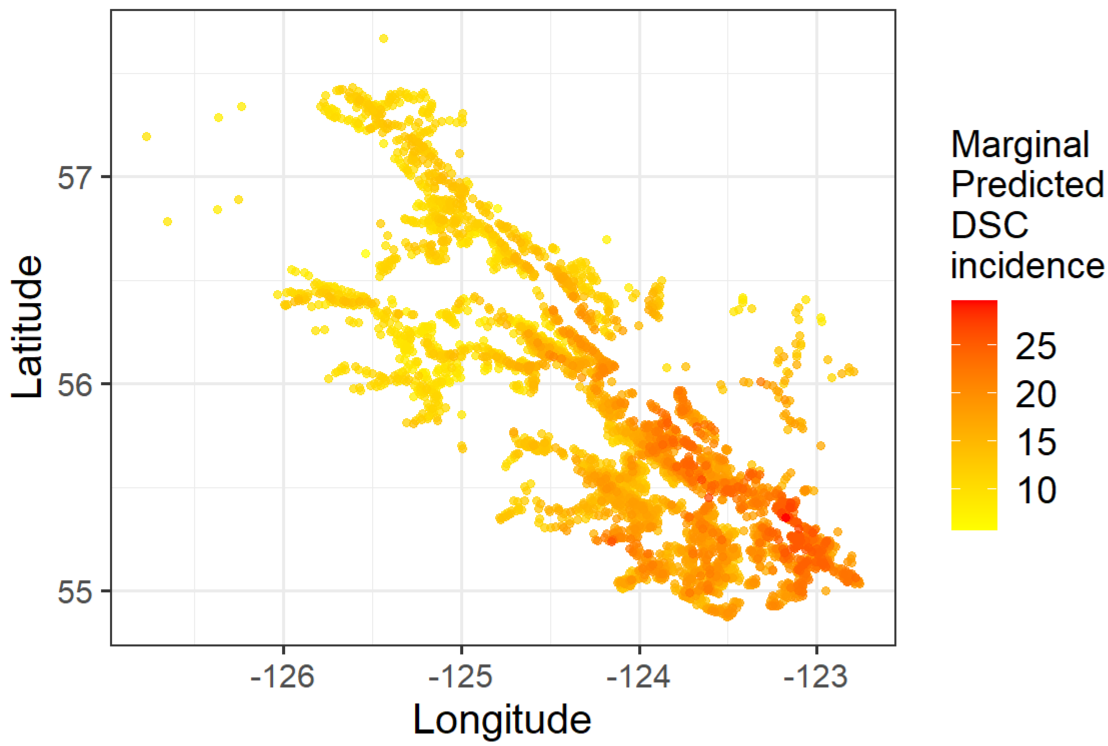

Figure 8. Marginal (product of eq. DSC.1 and eq. DSC.2) predicted DSC incidence for all openings in the original dataset.

Conclusions

The preceding text lays out a methodology for estimating the incidence of DSG and DSC for openings that have not been surveyed for these rusts. Using the DMK as an example, the methodology employs a class of model known as a hurdle model. For the rust of interest, the hurdle model estimates i) the probability of rust presence, ii) the conditional incidence of the rust, and iii) the marginal predicted rust incidence, the latter of which is then used to initialize the rust modules in TASS. The approach used to develop the individual equations is one that is largely driven by empirical modeling techniques. The approach is pragmatic in that it makes use of the Provincial inventory of stands established post-harvest, and the relationships with the array of predictor variables therein. A better, more complete, mechanistic-based model may be possible in the future. Development of such a model would require a dataset generated using a more rigorous sampling design that included a more comprehensive set of climate and biophysical variables, and would be spatially explicit. Currently, such a dataset does not exist.

The results for the DMK demonstrate the advantages of using a hurdle model to obtain an estimate of rust incidence. Namely, the hurdle model deals with data that is zero-inflated, while at the same time it provides insight into the factors affecting rust presence and rust incidence. In terms of model performance, the hurdle models demonstrated an improvement over a BEC-subzone average value of rust incidence. Despite the improvement, some bias remained. Those who wish to use the current set of hurdle models should, therefore, make note of this bias when formulating rust management strategies. While the DMK is used as an example, the intent is that the process of selecting predictor variables for the equations in the hurdle model is repeated for each TSA where DSG and DSC are of concern. The predictor variables that were selected in the current set of equations should, nevertheless, serve as a starting point for other TSAs.

The greatest strength of the dataset used to develop the models is that it covered a wide range of climatic and biophysical characteristics within an area where DSG and DSC are of concern. The dataset that was used also carries with it several weaknesses when it comes to modeling rusts. Inconsistencies in the time of year when the surveys were conducted, and doubts about the rigor applied in identifying rust species, are but two examples. Choosing not to use models for rust incidence developed from this or a similar dataset would leave one with three options: 1) use a BEC-subzone average for rust incidence; 2) assume there is no rust; or 3) develop a better, mechanistic-based model. Option 3 is certainly the most attractive, but a dataset capable of supporting this approach is not yet available. Options 1 and 2 are not recommended, as they would lead to an under-estimate of rust incidence in many of the non-surveyed openings. Thus, until a more mechanistic model is available, using the methodology that has been presented here appears to be a reasonable, interim, solution.

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Impacts of Stem Rusts: Application in TSR

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This is a summary of a potential methodology for deriving and incorporating stem rust impacts from RESULTS forest health data into TSR. Derek Sattler (Canadian Forest Service) developed the technical details. Please see his presentation for more information.

The inclusion of forest health data into TSR is part of a larger system that integrates RESULTS data into TSR to derive managed stand yield tables (MSYT). This system takes planting data and uses data from the RESULTS forest cover inventory survey to adjust species composition to account for mortality, and to some extent ingress.

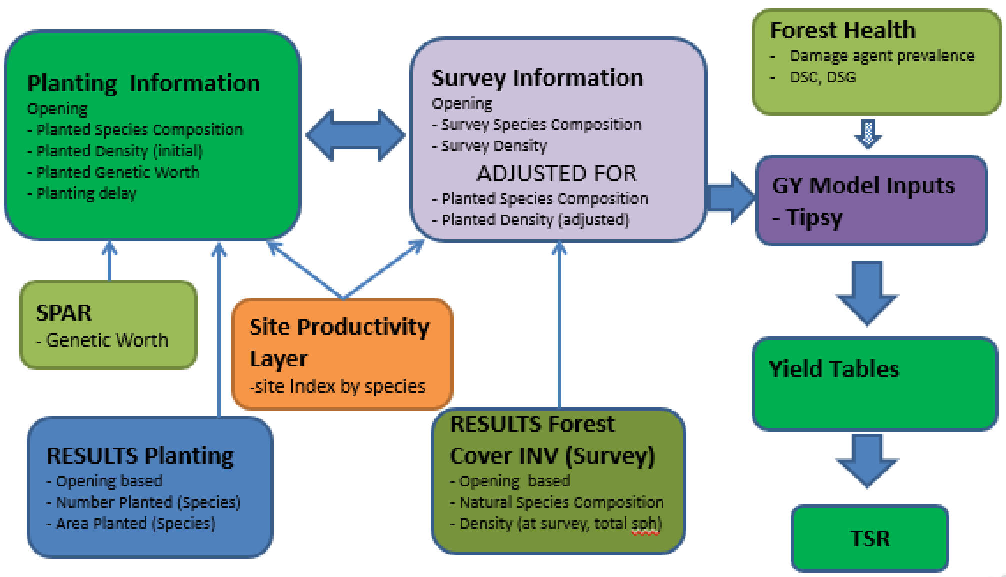

Figure 1. MSYT process diagram

In addition to species composition, information about damage agent incidence is obtainable from RESULTS. In this study, information about the incidence of two stem rusts, comandra blister rust and western gall rust is used. An age correction factor is applied to the incidence numbers, to a common base of 15 years. The adjusted incidence numbers can then be summarized for stands with a non-zero-incidence.

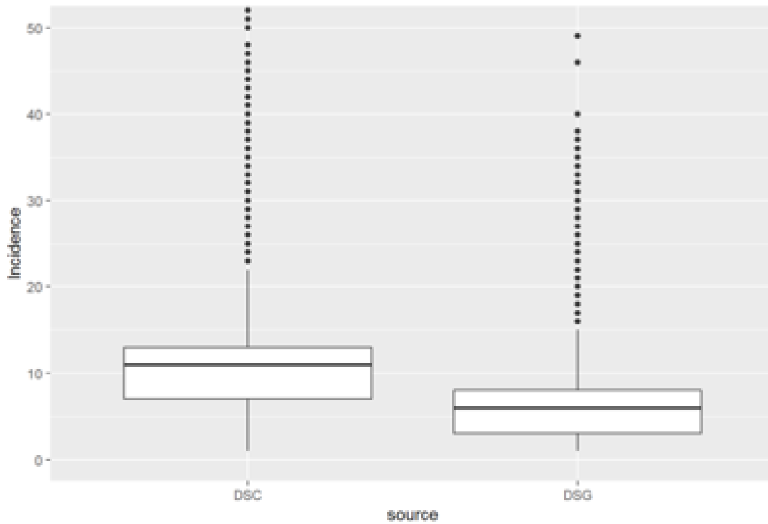

Figure 2. Rust non-zero percent incidence, MacKenzie TSA.

It is important to note that the RESULTS data exhibit a concentration of stands with zero-incidence, as shown in Figure 3.

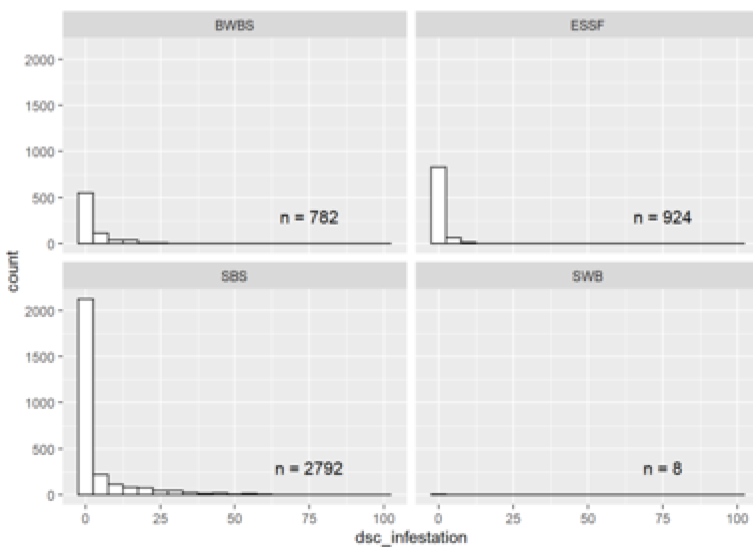

Figure 3. All rust percent incidence by BEC zone.

The abundance of zero-incidence data must be accounted for if incidence is going to be used to predict impact. The abundance of zero-incidence data raises the question about why there are so many zeros. Is the survey occurring at the wrong time of year or is the detection of the damage agent difficult?

Derek Sattler (CFS) has proposed using a hurdle model approach, where the incidence data from the non-zero data can be used to predict the incidence in the zero-incidence data. The model can be parameterized using other data elements such as BEC zone, latitude, longitude, slope, and elevation, as well as ClimateBC data. This approach is being tested in the MacKenzie TSA. Incidence for the zero-incidence data is predicted using a parameterized hurdle model and these data are then used to generate TASS merchantable volume tables. These tables can then be compared to non-rust MSYTs and an adjustment factor can be derived. Once these factors are applied in a timber supply model, impacts to timber supply can be assessed.

The purpose of this presentation was to show the application of a hurdle model to derive incidence and impacts. Using a hurdle model approach, the gaps created by the zero-incidence data can be filled.

KEY MESSAGES

1. This presentation shows the application of models to derive incidence and impacts.
2. It also demonstrates that RESULTS forest health data has gaps, which can be filled.
3. It shows the need for better data collected at various points in time.
4. It implies that there is the potential to use this methodology for other damage agents, but again this requires data.

Creating Operational Adjustment Factors: An Example Using Root Disease on the B.C. South Coast

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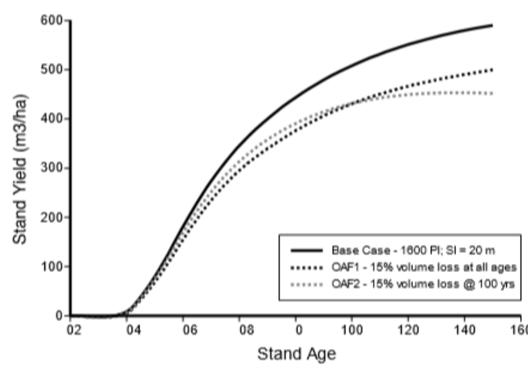
Given that growth and yield models are often designed and tested using assumptions and data from a perfect world, there must be some factor provided to model users that injects some reality into the model process or output. This talk outlines how one such operational adjustment factor (OAF) was created for use when modelling the growth of Douglas-fir (*Pseudotsuga menziesii*) in root disease-infested stands on the south Coast of British Columbia (B.C.) for timber supply purposes.

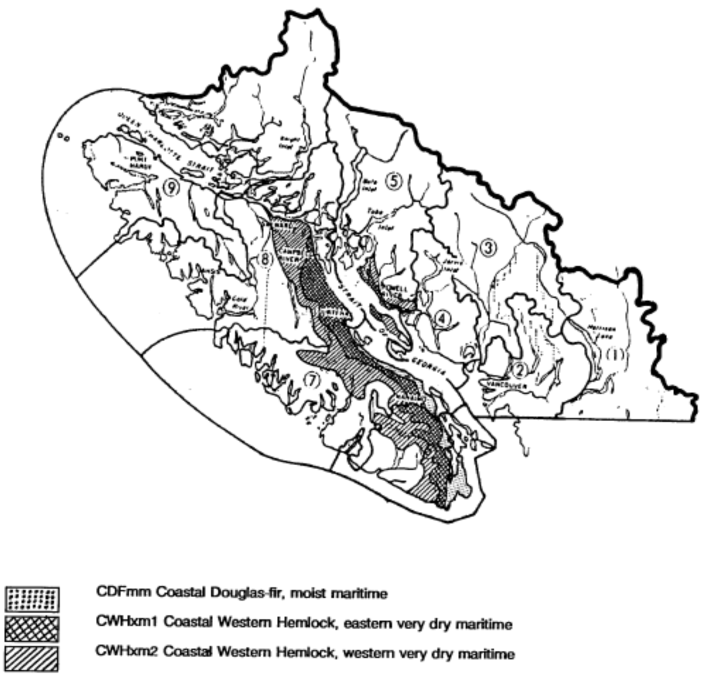
In B.C., the primary growth and yield model used for timber supply analysis is the Tree and Stand Simulator (TASS). TASS is, as you might suspect, not built for everyday use by mere mortals. So, modellers have developed a derivative model called TIPSY (Table Interpolation Program for Stand Yields) that takes a range of tabular output from TASS and, depending on a range of inputs, creates potential yields for user scenarios. An OAF can be applied to these yield estimates to reflect constraints in the operational environment, like pests. There are two primary OAFs available for use: OAF 1 and OAF 2.

The OAF 1 represents abiotic factors, primarily gaps in stand stocking for whatever reason (i.e., wet or rocky terrain, unplantable area, etc.) The default value for the OAF 1 is 15% (0.85) and it is applied across all ages of the yield curve at a constant rate. There is provision to adjust the factor up or down depending on if the user believes gaps may be more or less common in the area being modelled. The OAF 2 represents biotic factors, primarily decay, waste and breakage from harvesting operations. The default value for this OAF is 5% (0.95) but it is applied differently than the OAF 1. The OAF 2 begins at zero in year 1 and increases to the full value at year 100 and continues to increase past that point. The difference over time is illustrated in the graph to the right. The OAF 2 does not account for losses caused by specific pests unless a factor is created specifically for that purpose as we have done for root disease on the south Coast.



The primary purpose of the OAF is to inject some reality into the model output. Ideally, we would have a submodel or routine(s) that would mimic the action of a pest on tree growth subject to user inputs describing actual stand conditions. Attributes like incidence, severity, rate of spread, mortality, etc. would all be useful and would allow the model to alter tree growth incrementally as the stand ages. For many pests, however, we lack this type of data, so we use an adjustment on the model output to reflect that there is some impact by pests on the forest; however, we just can't model it well and instead account for it by using a blunt adjustment like an OAF. An adjustment is necessary though. Otherwise, unadjusted model outputs would be created for the various scenarios of a timber supply review, resulting in inflated volumes being used in timber supply determinations by the Chief Forester.

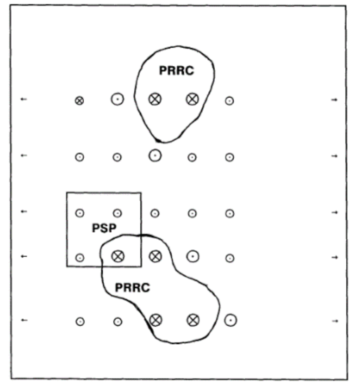
Our example is to talk about how we constructed an OAF 2 to account for losses to root disease in Douglas-fir stands on the south Coast of B.C. First, some background. The primary root diseases of Douglas-fir on the B.C. Coast are *Coniferiporia sulphurascens* (= *Phellinus weirii* Douglas-fir form for those of you of a certain vintage) and, to a lesser extent, *Armillaria ostoyae* (= *A. solidipes*) and, to an even lesser extent, *Heterobasidion occidentale* (= *H. annosum* spruce-type). The first two are by far the most prevalent and damaging, with *Armillaria* being more obvious in younger stands and *Phellinus* (the name I'll use from now on) in older stands and the two can often be found together.



I'll give you the punch line first: the OAF 2 for root disease on the Coast is 7.5%. This is added to the default 5% (which does not account for specific pest issues like root disease) for a total OAF 2 of 12.5%. This value is applied to all managed forest Douglas-fir-leading analysis units occurring in the Coastal Douglas-fir moist maritime (CDFmm) and Coastal Western Hemlock very dry maritime (CWHxm1 & 2) ecological subzones (see map). Or it should be. The unmanaged forest analysis units are handled by a different model – VDYP – and are assumed accounted for by that model. But that's another story.

The root disease OAF 2 was determined two different ways. The first was via an extensive study started by Jeff Beale, former Regional Forest Pathologist, in the 1980's, that culminated in his 1992 MSc thesis from UBC. He examined 215 permanent sample plots established in 30-40-year-old stands between 1955 and 1965 by MacMillan-Bloedel and Canadian Pacific Forest Products (two companies that no longer exist). These plots were established for growth and yield purposes and were placed without regard for root disease occurrence since these diseases were not well recognized at the time by most field staff. As such, the plots should not be biased regarding any root diseases present and should reflect the variety of stand types and productivity levels found in these ecological subzones.

The permanent sample plot areas were usually about 0.04 ha in area, which is generally too small to assess root disease dynamics very well (i.e., area affected, spread in and out, etc.). Beale got around this by overlaying 139 grids covering 1 ha over each sample plot(s) (see figure at right). These grids consisted of an array of twenty-five 50 m^2 (3.99 m radius) plots that included the permanent plots plus the area around them. Beale collected tree, ecological, soils and disease data from the permanent plots and the grid plots, and he ran transects between the grid plots to map root disease centers. He used the tree data from the sample plots for growth and yield purposes and for modelling impact on stand volume at varying levels of root disease incidence.



From Beale's work came a couple of key findings. One was that 87% of the grids had an identifiable root disease present on the trees within them. Another was that when stand volumes were calculated and categorized, a volume reduction at stand age 80 was determined of 8.25 to 8.86%, depending on subzone and stand type. For simplicity, the OAF 2 was calculated as 8.86% x 0.87 = 7.7% reduction for the applicable CDF and CWH subzones.

The second approach to determining the OAF 2 for root disease happened in 1999. That year we examined 39 B.C. Ministry of Forests growth & yield plots on the Sunshine Coast that had just reached their 30th anniversary. All plots were Douglas-fir leading (on initiation in 1969) and located in the CWHxm1 subzone. We examined the live and dead trees in the plots for signs of root disease and then used the inventory volumes to determine what proportion of plot volume belonged in each category. The table below gives our results for all trees.

Forest Health Factor	Douglas-fir	Western Hemlock
Phellinus	7.68%	2.57%
Armillaria	0.59%	0.83%
Sum	8.27%	3.4%

For Douglas-fir, the total infected tree volume was 8.27% when both *Phellinus* and *Armillaria* were considered. Other root diseases were noted, but their presence was minor, and they do not occur widely or consistently. The infected western hemlock was discounted because *Phellinus* is usually only found on western hemlock on the Coast when it is growing in association with Douglas-fir. Given this, it would be difficult to apply the OAF 2 to western hemlock since we did not achieve a good understanding of how consistently infected hemlock were found in Douglas-fir-leading stands.

Applying the 'Beale factor' of 0.87 to our findings, we calculated a 7.2% reduction to volume for these stands. Considering this, alongside Beale's findings, we split the difference between the two estimates and created the current 7.5% OAF 2. This value should be applied in a timber supply review to any Douglas-fir-leading analysis unit in the CDFmm and CWHxm1 & 2 subzones. The

OAF 2 value likely applies to more than just those subzones (e.g., CWHdm) but we do not yet have enough data to confirm this.

So, is an OAF the best way to account for pest losses? Creating an OAF is not a trivial exercise so one should not launch into it unless the result will be worth the effort. In our case, given the use of TIPSY for timber supply modelling, we have little choice but to create a blunt tool to adjust another blunt tool. This is somewhat unsatisfactory and leaves many unanswered questions. It would be better to create or adjust submodels like the Western Root Disease model used with the Forest Vegetation Simulator in the United States or follow the path of creating new submodels like GRIM or CRIME (simulating the impact of western gall rust and comandra blister rust, respectively) for use directly with TASS. These approaches, however, are often even more complicated and require a multi-disciplinary collaborative approach but will likely result in a more satisfying and useful product.

An Operational Adjustment Factor with Armillaria Root Disease: Estimating Harvestable Volume in the Arrow Lakes Region

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Tree root disease caused by the pathogen, *Armillaria ostoyae* has significant influence on the ecology and timber economy of southern B.C. The economic importance of *A. ostoyae* is closely tied to timber production. This disease impacts sustainable forest management due to its ability to increase following logging, to reduce tree growth rates, and cause mortality, especially in young regeneration (Morrison 2000; Cruickshank et al. 2011). The earliest stages of plantation development are especially vulnerable due to the tendency for *A. ostoyae* to cause heavy mortality during the first 5-20 years of a rotation (Morrison et al. 1988; Morrison and Pellow 1994). By the time of plantation maturity, up to 100% of mature trees can be infected with *A. ostoyae* (Morrison et al. 2001).

Unlike most other pathogens and insects, *Armillaria* infects all conifer species used in commercial timber production. It is therefore a major determinant for volume available for harvest. Each of 37 Timber Supply Areas (TSA), and 34 Tree Farms – receive a periodic review – about every 10 years. An output of every Timber Supply Review (TSR) is the allowable annual cut of timber volume for each TSA. Multiple factors are considered in the analysis of timber supply; including up-to-date volume estimates, harvest constraints, and predicted future volume. To accomplish the analysis, an inter-disciplinary team of specialists is employed to incorporate their expert input.

To achieve a timber volume forecast, standard adjustment factors are applied for B.C. It is common to apply two separate operational adjustment factors (OAF). The first factor, OAF1, is a constant percentage reduction (-15%) to account for small, unproductive areas within stands, uneven stem distribution, and endemic losses that do not increase with age. The second factor, OAF2, accounts for losses that increase with stand age due to disease, insects, decay, waste and breakage. This value telescopes from 0 to 5% as the stand matures to harvest age.

In the southern interior, *Armillaria* is so widespread and impactful, that a third adjustment factor specifically focusing on this disease's impact can enhance our analysis and forecast of timber supply. The Arrow TSA, located between the U.S.A. Border and Revelstoke, is heavily impacted by *Armillaria* root disease. The previous timber supply review, completed in 2005, included an OAF dedicated solely to *Armillaria*. It applied specifically to Douglas-fir in the Interior Cedar-Hemlock (ICH) biogeoclimatic zone. Biological data (growth and yield impacts) were incorporated into the Table Interpolation Program for Stand Yields (TIPSY) to generate this OAF (Stearns-Smith et al. 2004). Upon completion of this TSR in 2005, the Chief Forester recommended that the following TSR further refine volume losses due to *Armillaria*.

For the most recent Arrow timber supply review (FLNRORD 2016a), a team of specialists created a more comprehensive OAF. The previous OAF addressed Douglas-fir in the ICH zone. The new OAF incorporated all plantation conifer species across all biogeoclimatic zones. Initially, detailed adjustment factors were provided from the neighboring Kootenay Lake District (Norris 2000). They were listed for each species according to decade post-harvest (tree plantation age). Furthermore, these reduction values varied by site-specific infection severity: low, medium or high. The values were assigned based on previous estimates in southeast B.C. (Norris 2000; Skimikin research trial, and empirical knowledge). These 'working estimates' should be refined periodically as more data become available as trees in the research trials age. Detailed growth and yield reduction values form the foundation of our overall OAF approach.

The next step combined the growth and yield reduction values from all species to predict overall volume estimates by decade in post-harvest regeneration. This was accomplished using the Tree and Stand Simulator model (TASS). Next, the TASS results needed to be translated to individual tree stands. These stands consist of mapped polygons and are referred to as Forest Analysis Units (AU). An AU is composed of stands with similar tree species composition, timber growing potential, treatment regimes, and other management considerations. They are based on biogeoclimatic units with two appended values: Site Index (high, medium, low) and moisture (dry, moist, wet) except for the ESSF (l=lower, d=dry) (FLNRORD 2016b).

An infection severity (low, medium, high) was assigned to each conifer species within each AU. We relied on local *Armillaria* incidence data in the Stand Development Monitoring (SDM) and Young Stand Monitoring (YSM) programs administered by FLNRORD, as well as Norris et al. (1998). Because each AU differed in growth and yield reductions, we translated the reductions based on the proportional representation of each AU across the TSA, using GIS (Figure 1).

au	Sp1	Pct1	SP1 Infection severity	Sp2	Pct2	SP2 Infection severity
d_essfblhig	Sw	70	M	Pl	20	M
d_essfblmed	Sw	70	M	Pl	20	M
d_essfplhig	Pl	50	M	Sw	40	M
d_essfplmed	Pl	50	M	Sw	40	M
d_essfSwhig	Sw	60	M	Pl	30	M
d_essfSwmed	Sw	50	M	Pl	30	M
d_ichcwall	Lw	40	M	Fd	30	H
d_ichfihig	Fd	30	H	Lw	30	M
d_ichfilow	Fd	30	H	Pl	30	M
d_ichfimed	Fd	30	H	Lw	30	M
d_ichfpall	Fd	50	H	Lw	30	M
d_ichhwall	Lw	40	M	Fd	30	H
d_ichplhig	Fd	30	H	Lw	30	M
d_ichplmed	Fd	30	H	Lw	30	M
deciduousall	PL	30	L	Fd	30	M
l_essfblhig	Sw	30	M	Pl	30	M
l_essfblmed	Sw	30	M	Pl	30	M

Figure 1. Forest analysis units (AU) included infection severity estimates for each species. A resulting OAF was derived based on the summed extent of each AU in the Arrow Timber Supply Area.

By incorporating the reduction estimates across the entire TSA, volume projections were calculated. It was estimated that growing stock would be 17% lower than that in the 'base case' (OAFS 1 & 2) alone (FLNRORD 2017). Similarly, the long-term harvest level would be 12% lower. Thus, by age 100, we expected losses to approximate minus 17% among all conifers due to *Armillaria* root disease.

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Discussion Groups Summary

Two discussion groups were held online on November 24, 2020. Session 1 addressed two critical issues: 1) was there adequate information to determine the health of young stands in B.C. and 2) identify any knowledge or information gaps that could be filled to ensure young stand health and productivity. Session 2 focused on whether changes in legislation, policy or practice, if any, were needed to mitigate forest health risks in young regenerating forests. Given the numerous decision tools and models described in the presentations, how could these be incorporated into the current forest management cycle without overwhelming the user?

After a lively online discussion in Session 1, expertly led by Tim Ebata, Ann Lockley and Francesco Cortini, with valuable and insightful input from many participants, the consensus seemed to be that all forest health data collected in young stands today would be much more useful if stored as a multi-layered database in one easily accessible location.

Many surveys collect forest health data. Free Growing surveys, YSM plots, SDM surveys, G&Y plots, POYS, SPI, PSP, and TSP collect young stand forest health information. However, forest health data are collected at different times during stand development, and for different reasons. Some surveys and plots collect pest incidence, while others collect pest impact and severity. Some surveys, such as free growing surveys only collect pest information if it exceeds the threshold for declaring a tree to be free growing. Some surveys target specific tree species (e.g. lodgepole pine) or pests, such as stem rusts, Swiss needle cast, terminal weevils and balsam woolly adelgid. All surveys need to be supported with good training to ensure damaging agents are accurately identified.

One of the key recommendations from these discussions was to create and maintain an amalgamated, standardized spatial database for forest health data that extracts forest health information from numerous sources and converts it into a useable format. Forest health data should be extracted from the numerous data collection systems and amalgamated into one dataset that would enable users to extract and use data according to location, BEC or other search parameters. The data should be sorted by the depth of how it was collected: incidence or impact; long- or short- term; surveys or plots. The goal would be to have a database that could be sorted by BEC, tree species, stand age, insect or disease or other parameters. Accessing forest health data spatially would be a tremendous asset for a wide spectrum of users who could access it via mobile or desktop web map applications. For instance, FAIB data are designated open data and there is a spatial web app that allows all ground data to be accessed. Currently, mensurational data are obtainable, and it is not beyond the scope to include forest health by pest into the summaries, including YSM, because forest health data are being collected during sampling. At this time, there are upwards of 20,000 ground samples from across the province.

Climate data should be incorporated into the database, to aid in assessing the risk of climate change. Similarly, remote sensing technologies will likely be useful for assessing pest incidence at a landscape level.

It is important to look at forest management through the whole cycle from pre-harvest and beyond free growing. To facilitate this perspective, access to the information collected by licensees at pre-harvest and any subsequent treatments or prescriptions implemented need to be recorded and made available to the licensees and the ministry when the obligation returns to the Crown. Forest health information recorded in RESULTS is passed on to the forest inventory label. The need for a reliable and easily accessible spatial/digital forest health database was identified as the highest priority. This type of database would streamline the retrieval, analysis and interpretation of forest health data in young stands. To accomplish this task there needs to be dedicated resources assigned to develop and deliver this product. This task cannot be addressed in a piece-meal fashion and there needs to be a plan to adequately accomplish and maintain this critically needed database. To fully answer the question "do we have adequate information to determine the health of young stands in B.C." we need seamless coverage containing a comprehensive database that covers the diverse ecosystems in B.C. To move forward in our goal to grow healthy, productive forests we must first have the critical tools to inform managers and reforestation specialists.

Stefan Zeglen moderated Session 2, with technical assistance from Ann Lockley and Francesco Cortini. Many topics were deliberated, ranging from the possibility of adding forest health objectives to FRPA, to managing from a landscape perspective rather than a cut block basis, to the need for a large, easily accessible forest health database for model development and TSR.

It was clear from the discussion that there was a desire to encourage resiliency in provincial forested lands and that forest health should be approached from a landscape perspective. To do so, stocking standards and species selection criteria will require reform and increased flexibility given observed and predicted climate change impacts being seen. Managing for more ecologically appropriate species, including hardwoods, rather than the species which reach free growing most quickly may better meet provincial goals for the range of forest values that have been established. Reforestation should not simply be a replication of what was harvested, but we should learn from what occupied the site and the surrounding landscape. Specifically, what was the species harvested, what was the species makeup at the regeneration phase (if already reforested) and how has it changed? Silviculture should be considered and practised throughout a rotation, to manage density, improve health, mitigate damage and grow value. Modelling exercises have shown that intermediate silviculture treatments can have a positive impact on timber volume, value and even resilience if applied appropriately. Tenure and legislation/policy reform was mentioned since licensees are only required to fulfill legal obligation and further surveys, silviculture treatments or planting hard-to-grow species can only happen if there is a financial incentive or if the regulations are changed. Another impediment is the appraisal system, which is sometimes out of sync with promoting desired forest practices on Crown lands.

Modelling tools such as CBST, CCIS, MPT, CRIME, GRIM, VDYP, TASS, TIPSY, and OAFs were discussed, and the development of pest-specific modules was proposed. Some participants expressed concern over the ease of use of these models and the lack of maintenance on the information comprising the models. As well, the end use of the models should be considered, with some models aimed at high-level strategic decision-making (TSA level), and therefore not useful at a stand level, and others such as VDYP and TASS being appropriate at the stand level. The greatest struggle for those involved in creating the models was access to large, representative forest health datasets. A suggestion was made that more information be entered into RESULTS, when site plans were being prepared. A standardized forest pest database could aid modelling efforts in determining the relationship between forest health agents in young stands and their impact at rotation.

Appendix 1 - List of Acronyms

AAC	Allowable Annual Cut
AET	Actual Evapotranspiration
AIC	Akaike Information Criterion
AU	Forest Analysis Units
AUC	Area Under the Curve
BCGW	British Columbia Geographic Warehouse
BEC	Biogeoclimatic Ecosystem Classification
BWBSdk	Boreal White and Black Spruce dry cool
CDFmm	Coastal Douglas-fir moist maritime
CWHdm	Coastal Western Hemlock dry maritime
CWHxm	Coastal Western Hemlock very dry maritime
ESSFmv	Engelmann Spruce- Subalpine Fir moist very cold
ICH	Interior Cedar Hemlock
IDFdm	Interior Douglas-fir dry mild
MS	Montane Spruce
SBSmk	Sub-boreal Spruce moist cool
SBSwk	Sub-boreal Spruce wet cool
BGC	Biogeoclimatic
CBST	Climate Based Seed Transfer
CCISS	Climate Change Informed Species Selection
CFS	Canadian Forestry Service
DD5	Degree-Days above 5°C
FAIB	Forest Inventory and Analysis Branch
FEM	Forest Estate Model
FG	Free Growing
FIDS	Forest Insect and Disease Surveys
FIRM	Forest Improvement and Research Management Branch
FPG	Forest Practices Guidebooks
FRDA	Forest Resource Development Agreement
FREP	Forest and Range Evaluation Program
FRPA	Forest and Range Practices Act
FTE	Full Time Equivalent
GLM	General Linear Model
G&Y	Growth and Yield
MAP	Mean Annual Precipitation

Appendix 1 - continued

MAT	Mean Annual Temperature
MCMT	Mean Coldest Month Temperature
MPT	Modern Portfolio Theory
MSP	Mean Summer Precipitation
MSYT	Managed Stand Yield Tables
NFI	National Forest Inventory
OAF	Operational Adjustment Factor
PAS	Precipitation As Snow
PET	Potential Evapotranspiration
POYS	Pests of Young Stands
PSP	Permanent Sample Plot
RESULTS	Reporting Silviculture Updates and Land Status Tracking System
RMSE	Root Mean Square Error
ROC	Receiver Operator Characteristic
RSMR	Relative Soil Moisture Regime
SDM	Stand Development Monitoring
SEDA	Stand Establishment Decision Aids
SI	Site Index
SSTD	Safe Seed Transfer Distance
TASS	Tree and Stand Simulator
TD	Temperature Difference between mean warmest month temperature and mean coldest month temperature
TF	Tree Farm
TFL	Tree Farm Licence
THLB	Timber Harvesting Land Base
TIPSY	Table Interpolation Program for Stand Yields
TSA	Timber Supply Area
TSP	Temporary Sample Plot
TSR	Timber Supply Review
VDYP	Variable Density Yield Projection
VRI	Vegetation Resources Inventory
YSM	Young Stand Monitoring

Appendix 2 – Questions and Feedback from the Discussion Groups

The following is a distillation of the thoughts and ideas retrieved from the 3½-hour audio file from the discussion groups on the Health of Young Stands Symposium, held online November 24, 2020. Whereas the summary in the text is a synopsis of the whole, this part of the summary simply lists the questions and the feedback that ensued from the discussion.

Session 1-(The Challenge and the Science, A Scattergram of Data, The Science and Future: Uncertainty and Climate Change)
Moderator: Tim Ebata

Theme A: With the information currently available, can we adequately determine the health of young stands?

Can we extract information from existing data sets? If we had the resources, what would we do?

Tim: What changes are required for existing surveys (i.e. silvicultural, free growing, SDM, YSM, G&Y, genetic plots, etc.) or to the development of new forest health specific surveys to:

- *Improve record keeping systems*

Consensus from the group that provincial forest health data should be easier to access, that reporting methods should be standardized and if possible, that the distribution of forest health agents be accessible spatially. An integrated set of maps, colour coded with monitoring trials would be great.

Forest health agent impact data should be collected together with incidence data.

Summarizing all existing forest health data would be great, but there is a lack of resources available to collate the provincial forest health data or dedicate an FTE for the job.

Comment: RESULTS may not be the best place to store forest health data.

Long-term studies are important. Forest health data will change as the stands age and it would be nice to have pest information from regeneration through rotation. In long-term plots, you could do destructive sampling and see what the overall impact is of forest health agents in the plot.

Possibility of using forest health records for doing hazard and risk ratings for planning cutblocks and reforestation.

Comments from a few participants to the effect that they were frustrated trying to access forest health data from RESULTS, that there were inconsistencies in the quality of the data when comparing stands that were in close proximity to each other; or that there was no centralized database from which to glean forest health information.

Examples given of databases that have a forest health component and could produce summaries: RESULTS, YSM, FAIB plots. GRIM/CRIME modules can also produce spatial data.

Can we tweak existing procedures to improve efficacy of forest health data? FG, YSM, PSP. Confirm whether they are set up to collect forest health data appropriately. Is there a need for new forest health surveys and how would they be used?

- *Ensure adequate training in forest health survey data collection*

Lots of discussion around the difficulties in recognizing forest health damage agents and the need to ensure adequate training for silviculture surveys / FG surveys and the forest health information being collected. Recognized as a huge opportunity to collect forest health data because every hectare of reforestation is surveyed. However, records are only tallied if they affect FG. Timing and age of when surveys are conducted may also be an issue. Therefore, incomplete forest health data collection.

There is a high standard of training, but due to economic pressures, things can deteriorate. There may be inconsistency in the data due to inexperience on the part of workers. Lots of discussion around poor wages, low bids, economic pressures of production and piecework.

There seems to be a need for extension services relating to forest health training, with an emphasis on focusing on regional pests. Possibility of building in training into a survey contract to encourage high quality forest health data. Semi-annual field trips between Forest Health and FAIB to try to ensure that surveyors are interpreting pest severity in the same way. Survey within rust window.

Possible to tie in root rot training with mountain pine beetle and Douglas-fir beetle surveys; found it cost effective and doable.

The Free Growing Working Group is trying to address some of these issues to improve data collection.

- *Fill data gaps including climate change risks*

Discussion around climate change and the forest health data collected to predict impacts.

Micro-scale: In stand monitoring using weather stations helpful to understand microclimates, climate change and the impact on stem rusts. Possibility of being useful with climate assisted migration and can be related to climate models.

Micro-scale: possibility of a portable DNA id tool for pathogens e.g. rusts. If there are questions or doubts about the identification of the pest, samples are collected and identified post survey.

Macro-scale: Use of technologies, e.g. remote sensing, when looking at large landscape level disturbances such as wildfire, to prioritize landscapes for reforestation that might be successful, given climatic challenges.

- *How can we incorporate forest health risk into current seed (CBST) and species selection tools?*

The possibility exists of developing transfer functions for forest pests, similar to what has been done for tree performance: height and growth. However, it is a costly prospect, given that test sites must have sufficient problems, but no extremes, e.g. 10% pest affected or 90% pest affected. Provenance tests are costly and time consuming. It is expected that genetic clines would be observed for forest health traits, e.g. Lophodermella needle cast, Swiss needle cast, Rhabdocline, western gall rust, and needle retention.

- *Better inform reforestation and young stand management decisions*

Tim: The dream is to have a forest health data layer that has all information readily available. We have great mobile tools; so much has changed but we must ensure good quality data. Although we have access to lots of data, must make sure it is useable and meaningful. We need a product that is understandable and clear. Then it will be possible build hazard and risk ratings for pests with the data.

The possibility exists of connecting RESULTS data with SP and seeing how they relate to forest health outcomes. It would be a challenge, but it is a possibility. RESULTS does ask for pre-harvest inventory info, which means it could be a good place for pre-harvest forest health information to be captured for future reference.

YSM program is excellent opportunity to collect long-term (1-15 year) age stand data.

FAIB data are designated open data and there is a spatial web app that allows all ground data to be accessed. Mensurational data, but not beyond the scope to include forest health by pest into the summaries, including YSM, because forest health data are being collected. Upwards of 20,000 ground samples from across the province.

Example: A map exists, published by the Canadian Phytopathic Society of 35% of the Invermere TSA, which has 23 years of Armillaria data and coverage (from 1979-2002). These data cover young and mature stands tied to old forest cover maps, now spatially linked. Also tied to eco-associations and in BEC tied to BEC and forest cover maps and survey method used. Possible great source of historical information.

iMap BC has forest health layers linked to the BC Government Data Warehouse. Can we possibly link all the forest health data from RESULTS so that it also shows up in the BCGW data layers?

- *Better inform forest health decisions*

YSM: PSP based method that works very well for collecting forest health information. So far, the majority of the interior TSAs have been done and now is expanding to the coast and north. Up to 5 forest health agents per tree are collected along with pest severity and a 5 year re-measurement cycle. One of the purposes of YSM is to estimate future impacts through modelling, e.g. CRIME and GRIM, for the pine stem rusts. With more detailed and standardized forest health info, we could project YSM data forwards and quantify potential impacts. Require more forest health models/modules. Data review and committee meetings to help improve procedures. Aerial Overview Survey data provided to contractors to help with local knowledge and 10% quality check.

Example: YSM used to look at impacts of lodgepole pine dwarf mistletoe in the Cariboo. Better than RESULTS data, which only collects incidence. Includes both incidence and severity of pests, and PSP data; put the data into Prognosis BC to see if it was possible to predict impacts of lodgepole pine dwarf mistletoe.

FG survey methodology data collection protocol may be changing from a compliance model (Yes FG, no FG) to one that focuses on capturing data needed to support decisions for other programs. Which data are needed to support models that show impacts from young to mid to rotation? In discussion with subject matter experts including climate change, wildfire and forest health professionals to allow the process to better serve us. This is a great opportunity to amend a survey that is a legal requirement and 100% survey.

Comment: How can we worry about forest health when the object is free growing?

Forest health decisions could be better informed if there was a broader perspective in how we follow the stand from pre-harvest prescriptions to the next harvest and we understood implied values of the stand and make sure all the information (silviculture prescription/ site plan) is carried forward. It is important to have educated staff and foresters on the ground. How forest health is integrated in the process will be a challenge.

Is it possible for **forest inventory** (RESULTS) to deliver information on the state of the forests? It could then be used for prescriptions and subsequent treatments. If data are collected, they should be entered.

Example: If there is an Armillaria centre, it might be not be harvested, but there will be no mention anywhere, so it would still be considered part of the productive landbase. Conversely, it might be harvested, but there would be no mention of it having Armillaria, because there is no legal obligation to do so. Then, post FG, FLNRORD inherits a stand with Armillaria issues. Stands may or may not have been treated, but FLNRORD doesn't have access to the information. Root disease could be included in the inventory, but there must be some incentive. Forest health info is added to the inventory info through RESULTS, but if it isn't a surveyed opening with an obligation, the info won't be there. Once in RESULTS, it is linked to VRI polygons that come out of it, so it is linkable in the future for openings with obligations where these damage agents are identified.

Forest health surveys should be tweaked to gather appropriate information and put it in RESULTS. Take a more global approach, where foresters are involved in site planning from beginning to end.

Theme B: What are the key information gaps (data/research) we need to fill to ensure young stands remain healthy and productive?

What are the critical data/research needs?

- *How to link young stand pest incidence and severity to impact at rotation?*
- *How will forest health factors respond to a changing climate?*

Should we be focusing on optimization or resilience? Given climate change, forests are likely to experience more accelerated or extreme events, with the possibility of conversion to where they may no longer be supported. This is an information gap.

Suggestion of doing both broad based and targeted research and following how pests change over time. Look at resilience. Focus on many factors, not just pests that impact trees: natural regeneration and interaction with migrated genotypes, biodiversity, water, carbon storage, development of transfer functions for forest health and other factors.

Who answers these questions? Very expensive; sustaining long-term trials is a challenge.

- *Can we use technology to improve our HOYS surveys?*

Macro-scale: Use of technologies, e.g. remote sensing, when looking at large landscape level disturbances such as wildfire, to prioritize landscapes for reforestation that might be successful given climatic challenges.

Micro-scale: In stand monitoring using weather stations helpful to understand microclimates, climate change and the impact on stem rusts. Possibility to be useful with climate assisted migration and can be related to climate models.]

Micro-scale: possibility of a portable DNA id tool for challenging pathogens e.g. rusts. If there are doubts about the identification of the pest, samples are collected and identified post survey.

A possibility exists of using spatial tools that incorporate forest inventory, forest health, natural disturbances and climate information to inform decision-making.

- *Can we accurately predict future pest hazards and risks?*

Emphasis of tree breeding programs is shifting toward selecting for forest health. Unlikely to find cures to pests, but rather resistance to insects and disease.

Suggestion that due to climate, long-term studies are being lost to wildfire and the focus should be on survival rather than health. Identify climate factors and put research efforts into them. Is it possible to do a climate/forest health risk assessment?

How do we forecast future impacts of climate change and how do we monitor these changes and impacts on forests?

Incorporate climate change in wildfire risk modelling, increase our understanding of wildfire research on reducing risks through treatments and how that translates to changing risks on the landscape for wildfire or other disturbances (pests, diseases, drought-impact of multiple disturbances).

Are there problems in young stands? Yes, in some places, maybe in others. Overriding theme is accessibility and centralization of data, spatial and otherwise. Resurvey old plots before they are lost to wildfire or harvesting. Targeted research on how insects respond to climate change (survival and reproduction). What is different today and how should we manage differently?

Session 2-(Policy and Tools: Improving the Health of Young Stands, Modelling the Uncertainty)

Moderator: Stefan Zeglen

Theme A: What change(s) to legislation, policy or practice would best result in mitigating risk in regenerating new stands?

- *How does the current legislative structure under FRPA hinder our ability to deal with risk when regenerating new stands?*

Suggestion that the policy around site plans and FG should be tightened up to ensure more information is entered into the RESULTS database. Rather than a single dominant site series being identified, with one stocking standard and one site unit, multiple ecosystems within an area should be identified and sampled accordingly. With GPS, it is a much easier exercise than previously. Focus on ecology to enhance forest health and timber supply.

Stefan: One of the biggest complaints is that species selection is heavily driven towards selecting trees that will reach FG as quickly as possible and may not be the most ecologically suitable or desirable from a timber point of view. How can we prevent or mitigate those choices being made for economic reasons rather than for ecological or silvicultural reasons?

Must understand how stands were originally achieved and not reforest in a simplistic way, e.g. by simply replanting the same species mix that was there pre-harvest. What was the makeup of the stand at regeneration and how did it change over time?

Important to consider the ecology of the area and how to grow resilient stands. Current legislation only looks at cut block level, not landscape level. It would be better to have a broader approach. In addition, stocking standards not required to be met by all licensees. This should be standardized if there is a desire/need for more expensive and challenging species to be planted.

There has been a focus on planting mixed species rather than ensuring appropriate densities for specific species (e.g., Pl planted at too low a density and you get bushy trees). In addition, there are pest issues for multiple species. Density is a very important factor at the outset to create a well-stocked stand, but it cannot be maintained through the life of the stand or there will be stagnation. Intermediate treatments are possibly the answer. Otherwise, too openly planted Pl stands have branches to the ground and no sawlog potential.

Policies from Chief Forester's Office to plant two or more species per hectare may not be appropriate in some situations. Stocking standards should be adjusted. Forest health, climate change pushing us toward multiple species planting at low density. What are the resource objectives? Some deciduous species have been accepted in the FG stocking standards. Should we have enhanced stocking standards? Is tenure reform required? Forest values other than timber? Why not add forest health objectives to FRPA?

Stefan: From the different ingredients for success in your presentations, which ones can we act upon most quickly and with the greatest chance of results?

- *Are the current tools available sufficient to allow foresters to make informed decisions?*

Suggestion that silviculture be practiced throughout the rotation to improve health, mitigate damage and maintain value, and that it does not simply equate to regeneration. It may be possible to improve outcomes over time.

Suggestion that foresters be more intimately involved with regenerating stands over the long-term; that if you are in a block multiple times, then you learn from your mistakes.

Enhanced stocking standards are objective driven, whether it is promoting higher density planting or species selection or meeting certain wildlife management objectives. Lessen the risk of utilizing higher risk species.

- *What tools do we still need to develop?*
- *Are we too focussed on the site and not enough on the landscape?*

Forest health should inherently involve a landscape perspective, because tree diseases spread according to the varied spatial patterns of host occurrence, topography, climate, which affect disease movement and flow.

Discussion around modelling, using TASS to explore resilience, species diversity and timber. Some degree of success. Through modelling, found that to have improved timber volume, stands growing on a smaller area of the landbase that are managed for shorter rotations, with silviculture treatments, worked well.

Stefan: We have been discussing species selection and stocking standards and other topics, which have been hindering silviculture accomplishments and management for the past /future. As far as ecology goes, where does CCISS fit in for correcting some of the problems that we have?

CCIS and MPT are tools that should help foresters with decision making for the future. Based on the idea of diversification at the landscape level, rather than the stand level.

Some discussion around red alder being planted as an alternate species and its economic value. All agree that a minimum number of hectares must be planted in order to support a sawmill. Red alder has a shorter rotation than conifers and hardwoods might mitigate wildfire threats. How can this species fit into a policy framework and be made acceptable? Should be considered at a landscape level and if so, then discussions with First Nations, other stakeholders, non-timber issues should take place. How important is it to have alder on the site ecologically? Possibility of incorporating deciduous species into planning.

Theme B: How do we incorporate the numerous decision tools mentioned in the presentations (e.g. CCISS, CBST, etc.) into the current forest management cycle (planning-harvesting-reforestation-stand tending) without overwhelming the user?

Stefan: How user friendly are modelling tools? As simplifications of the real world, how are they incorporated, and do they suit your needs? How easy is it to maintain oversight and ongoing development of models?

- *Are the models we have adequate for the tasks involved?*
- *How do we reduce the uncertainty in model predictions?*

Not all models have the same end use. Therefore, it is important to use them appropriately. Some models are intended to be used for high-level strategic decision-making (TSA) and are not accurate at the stand level (e.g. VRI), whereas models such as VDYP and TASS, are used in stand development. They can be brought up to help support decisions for the AAC, by using OAFs, but they may not be the best tool. It might be a good idea to have more pest modules so there would be better linkage between forest health and stand development.

There is documentation available as to how models are created, and how to use them, but if they aren't commercial, then there is no funding and it is a workload to maintain and update the information that goes into a model.

- *Is the example of the development of GRIM/CRIME a blueprint for modelling other pests?*

Stefan: CRIME and GRIM were developed to deal with mortality of young stands in the interior. What was missing from the forest health side and silviculture side? What would have made it easier to build the model and verify it?

Models require individual tree data from an early age, such as stand density, forest health data, tree data and plots should be surveyed regularly; at least once every 5 years. The RESULTS database may not be perfect, but it does have the widest coverage to initialize models. The biggest struggle was acquiring large forest health data sets. A repository of standardized, easily accessed and useable forest health data with incidence and impact at a management unit level would be ideal. New data from trials to validate CRIME and GRIM would be very beneficial. Suggest mandating it. Look to developing further pest modules in consultation with the forest health professionals.

- *Are OAFs the best way to "correct" model output?*

Armillaria is a huge factor in B.C. An OAF for Armillaria was derived and applied across the Arrow TSA. Justified because Armillaria affects all species in our plantations. There were many good Armillaria trials in the Thompson Okanagan and Kootenays; therefore, we had reasonable data. We also had good modellers, and so we arrived at a reasonable estimate of volume impact. This was done independently from a similar effort on the coast, and the results were compatible.

Stefan: Did we meet objectives? Everyone is concerned about free growing as they have been for decades. Is it doing the job? Call for reform of stocking standards and more acceptability of hardwoods. No incentive to grow value, because the system is not structured in that way. As far as modelling goes, perfect data is the solution.