Decision Support Tool for Managing Biodiversity and Ecosystem Resilience in Mountain Pine Beetle-Susceptible Landscapes

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Abstract

We designed a GIS-based toolbox, called *MPB-Biodiversity* (MPBio), to facilitate the assessment of alternative mountain pine beetle- (MPB-) infestation management strategies on wildlife habitat and other sustainable management indicators. The toolbox simulates MPB infestation and salvage logging, projects changes in wildlife habitat supply and landscape structure, and regenerates and ages harvested stands. The main function of the toolbox is to support forest management decisions by assessing the impacts of different salvage logging scenarios on ecological indicators. MPBio is a Beta-release version that is currently limited by its processing speed, lack of graphical user interface or a harvest simulator, and the simplistic treatment of succession in unsalvaged post-MPB forest stands. A case study illustrating the use of the tool in a managed forest landscape in northeastern British Columbia revealed that the succession of post-MPB stands is a critical factor and should be refined as the assumptions used in projecting stand establishment were more influential than salvage logging criteria for dictating avian response. Avian species responded differently depending on salvage logging intensity and criteria used to determine whether a stand was eligible for salvage logging, but not with the range of retention levels examined in this study. These results suggest that increasing retention level in very large cutblocks as was done in the case study to counter the negative impacts of salvage logging will not be effective. Our results also underscore that the best management strategy for sustaining wildlife habitat will be specific to the target species and the time horizon in question.

Keywords: Mountain pine beetle, decision support system, songbirds, habitat supply models, landscape dynamics, forest succession, infestation, salvage logging.

Résumé

Nous avons élaboré un outil basé sur le SIG appelé MPB-Biodiversity (MPBio), conçu pour faciliter l'évaluation de nouvelles stratégies de gestion de l'infestation du dendroctone du pin ponderosa sur l'habitat faunique et autres indicateurs de gestion durable. L'outil simule une infestation du DPP et une coupe de sauvetage pour ensuite extrapoler les changements dans la disponibilité de l'habitat faunique et la structure du paysage et régénérer et déterminer l'âge des peuplements récoltés. La principale fonction de l'outil consiste à valider les décisions de gestion des ressources forestières en évaluant les incidences des différents scénarios de coupes de sauvetage sur les indicateurs écologiques Le MPBio est une version bêta de logiciel; il est actuellement limité par certains facteurs tels qu'une vitesse de traitement lente, un manque d'interface graphique ou d'un simulateur de récolte et un traitement simpliste de la succession des peuplements forestiers détruits après une infestation par le DPP. Une étude de cas illustrant l'utilisation de l'outil dans un territoire forestier sous aménagement dans le nord-est de la Colombie-Britannique a révélé que la succession des peuplements après une infestation par le DPP constitue un facteur critique qui devrait être affiné, étant donné que les hypothèses utilisées dans les prévisions de l'implantation ont souvent comme résultat des différences encore plus considérables dans la réaction aviaire que les critères utilisés pour déterminer si un peuplement est admissible à une coupe de sauvetage. Les espèces aviaires ont aussi réagi différemment selon l'intensité de la coupe de sauvetage et des critères utilisés pour déterminer si un peuplement remplissait les conditions requises pour une coupe de sauvetage, mais sans la gamme des niveaux de conservation étudiés dans le présent travail. Ces résultats semblent indiquer qu'une augmentation du niveau de conservation pour contrer les incidences négatives de la coupe de sauvetage ne sera pas efficace pour la région faisant l'objet de l'étude de cas.

Mots clés: dendroctone du pin ponderosa, système d'aide à la prise de décision, oiseaux chanteurs, modèles de disponibilité de l'habitat, succession de la forêt, infestation par le DPP, coupe de sauvetage.

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1 Introduction

The current mountain pine beetle (MPB) outbreak has dramatically transformed the British Columbian landscape, with model projections indicating that 80% of the pine in the province will be killed by 2013. Because the projected volume of beetle-kill far exceeds the current annual allowable cut (AAC) for both the northern and southern interior of British Columbia, substantial amounts of dead pine will be left unharvested. Forest managers are faced with the complex challenge of implementing large-scale salvage logging in a manner that will simultaneously consider future timber supply, the sustainability of non-timber resources such as wildlife and habitat, and ecosystem resilience against future beetle epidemics. This task is particularly challenging because the consequences of management scenarios must be weighed across spatial and temporal scales. Silvicultural prescriptions at the stand level that may help contain the beetle at an endemic level must be integrated with management of habitat attributes important to wildlife. At the same time, landscape-level decisions for salvage logging must be compatible with objectives for habitat supply and connectivity, and ecosystem resilience.

Tools that project consequences of alternative management scenarios at multiple temporal and spatial scales are needed to aid complex decision making. Forest managers continue to have limited ability to assess the effects of alternative mountain pine beetle management strategies, especially as they pertain to multi-resource values across space and time. Consequently, we developed a prototype decision support tool. The prototype is based on the conceptual framework developed by Chan-McLeod et al. (2006) that linked six major factors influencing mountain pine beetle impacts: socio-economic-political constraints, anthropogenic disturbances and practices, natural disturbances and stand ecological practices, site features, landscape attributes, and ecological processes. The prototype tool extends this work by applying key criteria for forest practitioners to assess management outcomes for real landscapes.

This project developed a decision-support tool that will facilitate assessment of alternative management strategies in beetle-affected or beetle-susceptible ecosystems. Specifically, the tool lets the resource manager explore strategies for improving ecosystem resilience against future beetle epidemics while maintaining wildlife habitat in current and future ecosystems. We use the occurrence and diversity of forest songbirds as indicators of the effectiveness of achieving biodiversity goals. Our objectives are to:

1) Adapt the mountain pine beetle framework of Chan-McLeod et al. (2006) into a decision support tool for exploring strategies to improve ecosystem resilience while enhancing non-timber values.

2) Incorporate a spatial, GIS-based capability in the support tool so managers can assess management outcomes for real landscapes; and

3) Apply the decision support tool in a case study in the Peace Forest District to explore how alternative future scenarios will affect forest stand susceptibility to the mountain pine beetle and wildlife habitat supply.

2 Methods

2.1 Forest Inventory Data and Habitat Characteristics

Prior to developing habitat-based models for forest songbirds, we used digital vegetation resources inventory (VRI) data to measure habitat characteristics in and adjacent to georeferenced bird detections. We updated the inventory data with the location of recent cutblocks and wildfires. VRI data comprise several stand attributes that are potentially useful for modeling wildlife habitat relationships including leading tree species composition, stand height, crown closure, and estimated stand origin (age). This layer also includes information on non-forest cover types such as permanent clearings, lakes, and wetlands. We developed a habitat classification system based on stand age, management history, and non-forest cover types and used it to create a generalized map of forest and non-forest habitat classes in the study area. We gridded all required map layers to a 100 m resolution prior to measuring habitat characteristics. We also used a digital elevation model to measure elevation, slope, and aspect at each bird location.

We measured habitat characteristics at the stand scale and the neighbourhood scale. At the stand scale, habitat variables measured characteristics of a 1-ha area (1 pixel) at the location of each bird detection (Table 2; Stand). VariablesCovariates characterized the broad habitat class of the stand that contained the detection as well as the elevation, slope, and aspect. Stand age was also used as a covariate. Neighbourhood variables measured habitat patterns within a 100-500m annulus around the 1-ha "stand" area (Tables 2; Neighbourhood). Variables included the proportional area of young and mature deciduous, coniferous, and mixed forest. Additionally, n_pine quantified the lodgepole pine component of the neighbourhood while n_variety measured the number of different habitat types within the neighbourhood.

Table 1. **Habitat covariates measured at the stand and neighbourhood scales.**

Scale	Variable	Description
Stand	elev	Elevation at station centre
	slope	Slope at station centre
	aspect	Aspect at station centre
	age	Stand age (time since disturbance) in years
	nonveg	Roads, gas wells, urban areas
	nonfor	Wetlands, pasture, alpine meadows, seismic cutlines
	recent	Burns and clearcuts (<30 years)
	ydecid	> 75% of total tree cover is deciduous (31-90 years)
	odecid	> 75% of total tree cover is deciduous (91+ years)
	yconif	> 75% of total tree cover is coniferous (31-140 years)
	oconif	> 75% of total tree cover is coniferous (141+ years)
	ymixed	< 75% of total tree cover is deciduous or coniferous (31-90 yrs)
	omixed	< 75% of total tree cover is deciduous or coniferous (91+ years)
Neighbourhood	n_nonfor	Percent nonforested habitat within 100-500m annulus
	n_recent	Percent recently harvested area within 100-500m annulus
	n_ydecid	Percent young deciduous forest within 100-500m annulus
	n_odecid	Percent old deciduous forest within 100-500m annulus
	n_yconif	Percent young coniferous forest within 100-500m annulus
	n_oconif	Percent old coniferous forest within 100-500m annulus
	n_ymixed	Percent young mixedwood forest within 100-500m annulus
	n_omixed	Percent old mixedwood forest within 100-500m annulus
	n_pine	Mean proportion of pine trees within 100-500m annulus
	n_variety	Number of different habitat types within 100-500m annulus

2.2 Forest Songbird Data

We developed avian habitat models using 2006-08 data collected as part of Canfor's biodiversity monitoring program. The study area consisted of harvested and unharvested forest landscapes that lie within the boreal white and black spruce (BWBS), sub-boreal spruce (SBS), and Engelmann spruce-subalpine fir (ESSF) biogeoclimatic zones. Alpine tundra (AT) occurs at higher elevations in the western half of the study area. The leading merchantable tree species in the study area include lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*), white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), and spruce hybrid (*Picea cross*).

The bird surveys were conducted along 26 breeding bird survey (BBS) routes on logging roads in TFL 48 and the Fort St John TSA (Figure 1). Data consisted of species occurrences obtained using BBS-type roadside surveys and forest interior stations (Preston et al. 2006). Each roadside survey had 25-50 point count stations which were located 800 m apart. Point counts were conducted once during late spring-early summer. Forest interior surveys were conducted at stations greater than 200m from roads and other hard edges in mature conifer, deciduous, and mixed forests near existing routes. Preston et al. (2006) provide additional details on the survey protocol.

We selected eight forest songbird species to be highlighted in the case study using the criteria of:. 1) known species sensitivities to stand and landscape habitat types and disturbances, 2) a minimum detection frequency in at least 5% of the surveyed stations, 3) availability of data to permit assessment of response in beetle-attacked forests; and 4) predictive ability of the models.

Table 2. Selected avian indicators.

Code	Common name	Scientific name
ALFL	Alder Flycatcher	*Empidonax alnorum*
BTNW	Black-throated Green Warbler	*Dendroica virens*
GCKI	Golden-crowned Kinglet	*Regulus satrapa*
LEFL	Least Flycatcher	*Empidonax minimus*
REVI	Red-eyed Vireo	*Vireo alivaceus*
TOWA	Townsend's Warbler	*Dendroica townsendi*
VATH	Varied Thrush	*Ixoreus naevius*
WETA	Western Tanager	*Piranga ludoviciana*

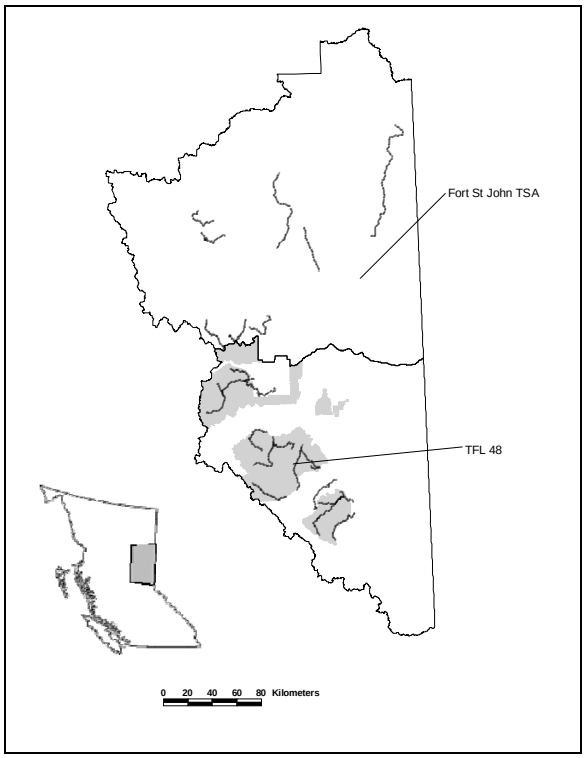

Figure 1. Survey locations in TFL 48 and Fort St John

2.2.1 Avian Habitat Models

We related species occurrences to habitat variables measured from VRI data (Vernier and Bunnell 2008). Specifically, we used multiple logistic regression to estimate the probability of occurrence of each bird species as a function of stand and neighbourhood habitat covariates:

$p_i = e^{\eta}_i / 1 + e^{\eta}_i$

where p_i is the detection probability (probability of occurrence at pixel i), and $\eta_i = \beta_0 + \sum\beta_i x_i$ is the linear predictor, the x_i are the stand- and neighbourhood-level covariates and the βi are the parameters to be estimated. For each species, we started with a model that included all covariates and used Akaike's information criterion (AIC) to remove extraneous variables. We considered only the species that were detected at least 5% of the time to avoid unstable parameter estimates.

2.2.2 Avian Response to Post-Beetle Pine Stands

Avian species occurrence in post-beetle stands was not conducted using the above avian habitat models because we could not acquire post-beetle stand structures from existing inventory databases. Furthermore, we could not reasonably assume that the relationship between bird occurrence and neighbourhood covariates would still apply in beetle-killed landscapes.

To simulate avian response to post-beetle pine stands, we had to first identify the post-beetle stand structure and then calculate its effects on avian occurrence. We based the structure on published data from Bull 1983, Mitchell 1998, Lewis and Hartley 2005, Dykstra and Braumandl 2006, and Dordel et al. 2008. Relationships between the post-beetle structure and the abundance of alder flycatcher, golden-crowned kinglet, least flycatcher, red-eyed vireo, and western tanager were based on Chan-McLeod 2009. Relationships between the post-beetle basal area and the abundance of black-throated green warbler, Townsend's warbler, and varied thrush were based on

Chan-McLeod's unpublished data from non-mountain pine beetle attack areas, because relevant data for beetle-attacked areas were lacking.

2.2.3 MPB Susceptibility Index

Following Shore and Safranyik's (1992) mountain pine beetle susceptibility index, we calculated the susceptibility of differently managed landscapes to future beetle attack as

$S = P * A * D * L$

where P = the percentage of susceptible pine basal area

A = age factor

D = density factor

L = location factor

In our GIS-based decision support tool, the MPB index is generated for each simulation and provided in the output.

2.2.4 GIS-based Decision Support Tool

We used ArcGIS 9.2 and the Python scripting language to make the decision support tool more user-friendly. ArcGIS is commonly used by the British Columbia forest industry, and the Python scripting language is freely available for all computing platforms and will make the product more efficient, defensible, and repeatable. We wrote the scripts for the decision support framework developed in MPBI Project #8.55 (Chan-McLeod et al. 2008). The scripts included the following components: 1) Landscape Dynamics, to simulate infestation, salvage harvesting, and succession of forested stands; 2) Biodiversity Assessment, for quantifying landscape structure and projecting the distribution and abundance of habitat supply for forest songbirds and guilds (e.g., mature forest-dwelling species); and 3) Decision Analysis, for facilitating the design and implementation of scenario and trade-off analyses. The prototype can be applied to MPB-affected managed forest landscapes for which current forest inventory data (preferably VRI data) and habitat supply models are available.

2.2.5 Case Study Scenarios

We evaluated 5 management scenarios with varying salvage logging criteria and retention levels (Baseline, Low Pine, High Pine, Low Retention, High Retention) (see Table 2 in manual for scenario parameters). Each management scenario simulated 3 assumed rates of forest re-establishment in unsalvaged, beetle-killed stands (Rapid, Moderate, and Delayed). The rate of forest re-establishment in unsalvaged stands is hugely complex and depends on many factors including stand type, site, understorey, disintegration rate of the beetle-killed trees, and the effect of the post-beetle stand structure on understorey growth and establishment. Given the lack of data and the extreme complexity of these relationships, we adopted the parsimonious approach of bracketing uncertain and assumed stand re-establishment rates.

In the scenario for Rapid Stand Establishment, we assume that the average age for the understorey regeneration is 15 years (e.g., Dykstra and Braumandl 2006). Thus, in the first year after the overstorey has been killed by the mountain pine beetle, the new stand is set at 15 years old. This scenario assumes that the advanced regeneration will be released by the death of the overstorey, as resources normally used by the overstorey are now available to the understorey.

In the scenario for Moderate Rate of Stand Establishment, we assume that the new stand is not established until 10 years following the death of the pine stand because a regeneration layer is lacking and the slow breakup of the overstorey canopy hinders the establishment of seedlings.

In the scenario for Delayed Stand Establishment, we assume the lack of seed source and the persistence of a dead overstorey prolong stand re-establishment to 30 years after the death of the original pine overstorey.

3 Results and Discussion

3.1 Avian Habitat Models

Table 3 provides the final logistic regression function for each species.

Table 3. Logistic regression functions for avian indicators. Coefficients are significant at p = 0.05.

Species	Logistic Regression Function
Alder Flycatcher	ALFL = 2.502 - 0.008 age - 0.001 elev - 0.049 slope - 0.001 aspect + 0.885 nonveg + 0.728 nonfor + 0.866 recent + 0.649 odecid + 0.503 ymixed - 0.008 n_ydecid - 0.017 n_odecid - 0.208 n_variety - 0.006 n_pine
Black-throated Green Warbler	BTNW = -3.813 + 0.003 elev + 1.120 recent + 0.842 odecid + 2.059 yconif + 1.985 oconif + 2.724 ymixed + 1.120 omixed + n_ydecid + 0.024 n_odecid - 0.024 n_yconif - 0.034 n_ymixed + 0.043 n_omixed
Golden-crowned Kinglet	GCKI = -4.131 + 0.006 age + 0.002 elev + 0.035 slope + 0.374 recent - 1.040 ydecid + 0.501 yconif + 0.978 ymixed + 0.009 n_yconif + 0.017 n_oconif - 0.032 n_ymixed + 0.016 n_omixed + 0.112 n_variety
Least Flycatcher	LEFL = 2.202 - 0.005 age - 0.002 elev + 0.027 slope - 0.441 nonfor - 0.894 recent + 0.702 odecid - 0.485 yconif - 0.740 oconif + 0.008 n_ydecid + n_odecid - 0.026 n_yconif - 0.036 n_oconif - 0.018 n_ymixed - 0.016 n_omixed + 0.112 n_variety
Red-eyed Vireo	REVI = 4.932 - 0.004 elev - 0.042 slope - 0.658 yconif - 1.305 oconif + 0.554 ymixed - 0.024 n_yconif - 0.023 n_oconif - 0.032 n_omixed - 0.141 n_variety
Townsend's Warbler	TOWA = -19.912 + 0.004 age + 0.004 elev + 0.083 slope + 13.852 nonveg + 14.202 nonfor + 14.836 recent + 15.088 ydecid + 14.980 odecid + 15.239 yconif + 15.186 oconif + 15.054 omixed - 0.128 n_ydecid - 0.080 n_odecid + 0.014 n_oconif - 0.072 n_ymixed + 0.184 n_variety - 0.017 n_pine
Varied Thrush	VATH = -2.121 + 0.003 age + 0.002 elev + 0.032 slope - 2.673 nonveg - 2.016 nonfor - 2.031 recent - 3.067 ydecid - 1.634 odecid - 1.963 yconif - 2.256 oconif - 1.960 ymixed - 1.692 omixed + 0.021 n_yconif + 0.024 n_oconif - 0.040 n_ymixed + 0.149 n_variety
Western Tanager	WETA = 0.031 + 0.005 age - 0.003 elev + 0.038 slope + 0.400 odecid + 0.584 oconif + 0.016 n_odecid + 0.016 n_ymixed + 0.023 n_omixed + 0.139 n_variety - 0.014 n_pine

3.2 MPBIO – A GIS-Based Decision Support Tool

Scripts written to date (available for viewing in http://biod.forestry.ubc.ca/mpb/) include:

- MPB infestation. Infests pine stands in a landscape based on minimum size or age requirement and proportion of landscape affected.
- Salvage harvesting. Simulates salvage harvesting after an MPB infestation. Parameters including opening size and retention level can be modified.
- Forest succession. Ages all forested stands in a landscape. It will not allow species transitions, e.g., deciduous to conifer.
- Habitat classification and pattern. Classifies landscapes based on tree species and seral stages and summarizes landscape-level habitat composition. Landscape configuration metrics such as connectivity will be added.
- Avian habitat supply. Maps and summarizes habitat supply for selected forest songbirds and guilds (e.g., mature forest-dwelling species). Currently based on habitat covariates measured from VRI data. Several bird species models have been developed.
- Scenario analysis. Helps implement scenarios to simulate MPB infestation and salvage harvesting strategies.

The structure, installation, and execution of MPBio, including information on input and output, are detailed in the manual. Sample output, including the maps of habitat types and species distributions, can be viewed from the scenario viewer in http://biod.forestry.ubc.ca/mpb/.

3.3 Case Study of Peace Forest District

Avian species responded differently depending on whether there was salvage logging, the criteria used to determine whether a stand was eligible for salvage logging, and the assumptions used in projecting stand re-establishment following beetle attack (Appendix: Figures). However, the probability of avian occurrence varied little with retention level: case study results were virtually identical for the Low Retention Scenario, High Retention Scenario, and the Baseline Scenario. Consequently, we present only the results for the Baseline Scenario and not for the High or Low Retention Scenarios.

In general, the assumptions used in projecting stand establishment resulted in more dramatic differences in avian response than the criteria used to determine whether a stand was eligible for salvage logging. Whereas salvage logging criteria affected the magnitude of the species response, the stand establishment scenario sometimes affected both the magnitude and direction of response. Three major patterns of avian response emerged: one characterized the response of birds that typically inhabit mature coniferous forests, the second characterized the flycatchers, which live in deciduous thickets near wetlands, and the last was that of the Red-eyed Vireo.

3.3.1 Mature forest-dwelling birds

The mature conifer forest-dwelling group included five of eight species modeled in the case study: Black-throated Green Warbler, Golden-crowned Kinglet, Townsend's Warbler, Varied Thrush, and Western Tanager (Appendix: Figures). In the delayed stand establishment scenario, this group declined under all salvage logging scenarios until 30 years after the-beetle attack, then increased to almost pre-beetle levels by year 45. In contrast, this same group increased under the no-salvage logging scenario for 15 years after the beetle attack before declining and persisting at low levels until the end of the simulated time horizon. Consequently, the absence of salvage logging benefitted this group in the short and medium timeframe (< 30 years) after beetle attack, but resulted in the least available suitable habitat for this group in the longer term (> 30 years).

In the scenario for moderate rate of stand establishment, the mature conifer forest-dwelling group was insensitive to all management scenarios, with the probability of occurrence being largely unaffected by the criteria for salvage logging, the retention level, or even whether any salvage logging occurred. For all scenarios and assumptions, the probability of occurrence for this group of species declined until year 15, stayed relatively level until year 30, and then increased. The magnitude of decline in the first 15 years varied depending on species: for example, the Black-throated Green Warbler declined by only 15% whereas Townsend's Warbler declined by >60%.

In the scenario for rapid stand establishment, all management scenarios resulted in declining bird occurrence in the first 15 years post-beetle, followed by increases that exceeded pre-beetle levels by the end of the simulated time horizon. The recovery rate was much faster for the no-salvage logging scenario than for the Low Pine, High Pine, or Baseline scenarios, regardless of bird species.

3.3.2 Flycatchers

A second pattern of avian response was exhibited by the flycatchers (Alder Flycatcher, Least Flycatcher), which are typically associated with deciduous thickets near wetlands. Because both species occur in open habitats (though the Alder Flycatcher is relatively more common in new, regenerating cutblocks than the Least Flycatcher, which tends to frequent semi-open, mid- to late-successional forests), their response to the management scenarios was opposite to that exhibited by the mature-forest-dwelling avian group. In the Delayed Stand Establishment scenario, the

flycatchers increased under all salvage logging scenarios until 30 years post-beetle, before decreasing to approximately pre-beetle levels by year 45. Under the scenario of no salvage logging, the flycatchers declined slightly in the 15 years post-beetle then increased rapidly. Similar to the mature-forest-dwelling avian group, the flycatchers were not sensitive to either salvage logging criteria or to retention level when post-beetle stand establishment proceeded at a moderate rate. In contrast to the mature-forest-dwelling group, however, the flycatchers responded positively to all management scenarios in the first 15 years post-MPB, then declined until the end of the simulation period.

3.3.3 Red-eyed Vireo

The Red-eyed vireo response pattern differed considerably from the other two groups (Appendix: Figures). For this species, the highest intensity of salvage logging (i.e. Low Pine Scenario) produced the highest probability of occurrence, while the no salvage logging scenario produced the lowest probability of occurrence, independent of the rate of stand re-establishment.

4 Conclusions

We developed a GIS-based toolbox to facilitate the assessment of alternative mountain pine beetle management strategies on wildlife habitat and other sustainable management indicators. Specifically, the toolbox simulates beetle infestation and salvage logging, projects changes in wildlife habitat supply and landscape structure, and regenerates and ages harvested stands. The main function of the toolbox is to support forest management decisions by assessing the impacts of different salvage logging scenarios on ecological indicators. MPBio is a beta release that is currently limited by such factors as slow processing speed, lack of a graphical user interface or a harvest simulator, and the simplistic treatment of succession in unsalvaged post-MPB forest stands. A case study illustrating the use of the tool in a managed forest landscape in northeast BC revealed that the succession of post-MPB stands is a critical factor and should be refined, as the assumptions used in projecting stand establishment often resulted in more dramatic differences in avian response than the criteria used to determine whether a stand was eligible for salvage logging. Avian species also responded differentially depending on salvage logging intensity and criteria used to determine whether a stand was eligible for salvage logging, but not with the range of retention levels examined in this study. These results suggest that increasing retention level in very large cutblocks as was done in the case study to counter the negative impacts of extensive salvage logging will not be effective. The results also underscore that the best management strategy for sustaining wildlife habitat will inexorably depend on the target species and the time horizon in question.

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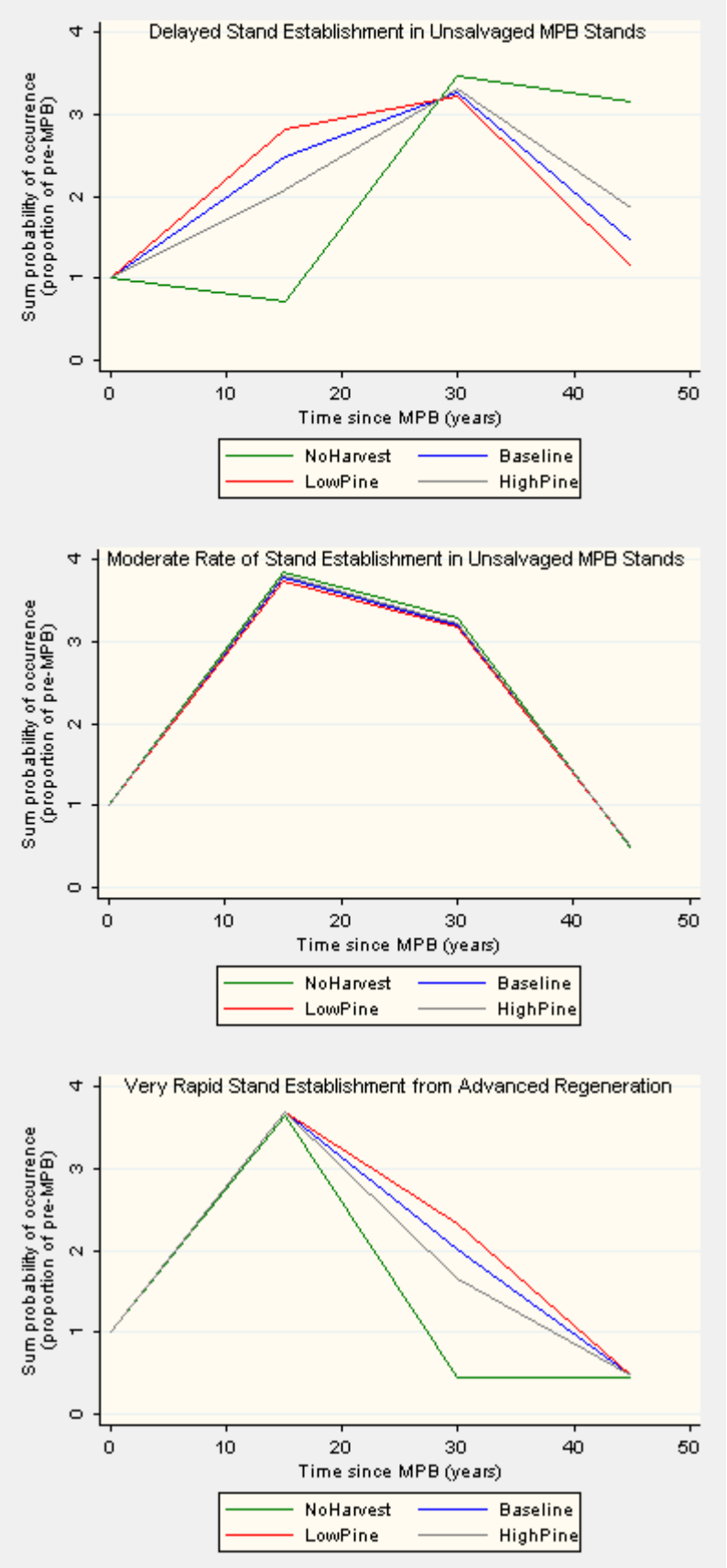
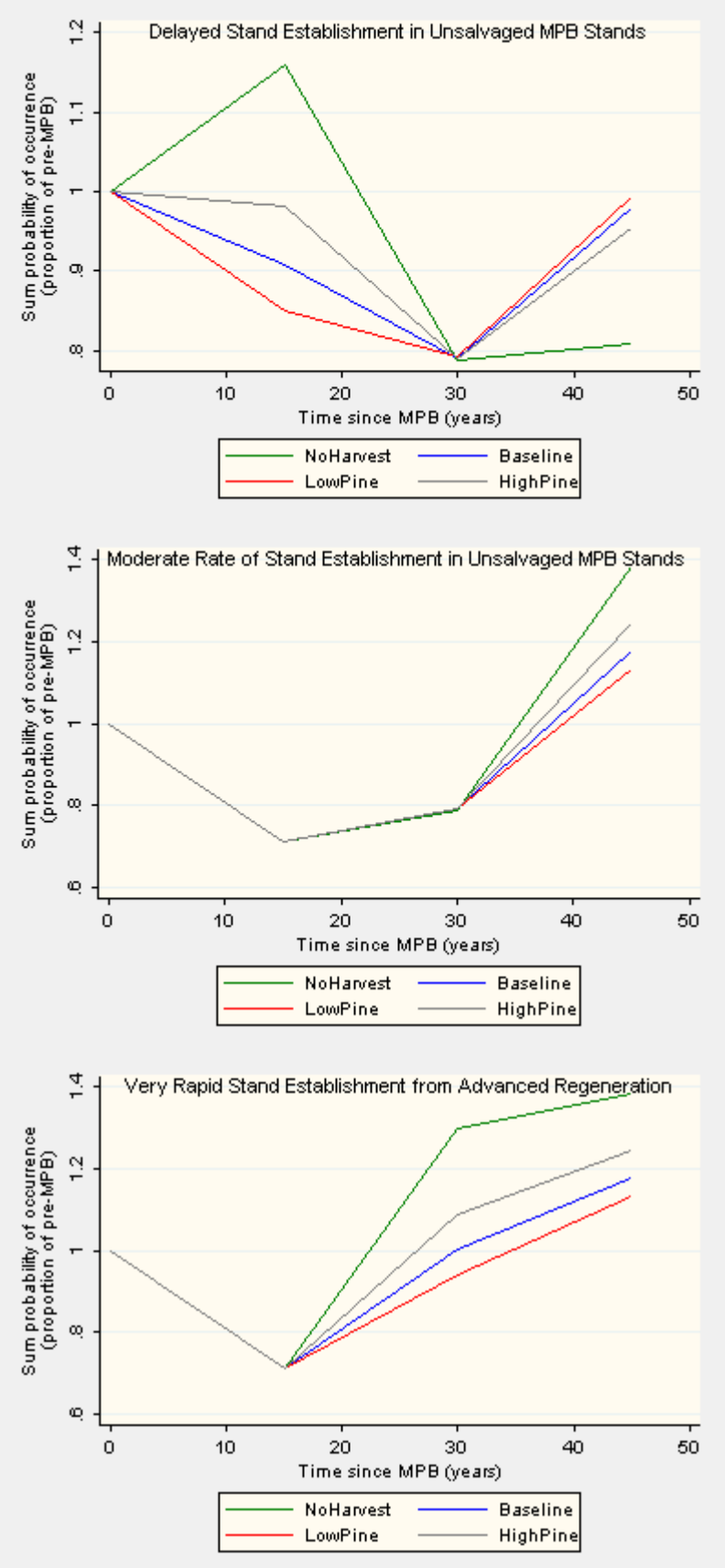
8 Appendix:

Figures of Avian Response to Post-beetle Pine Stands

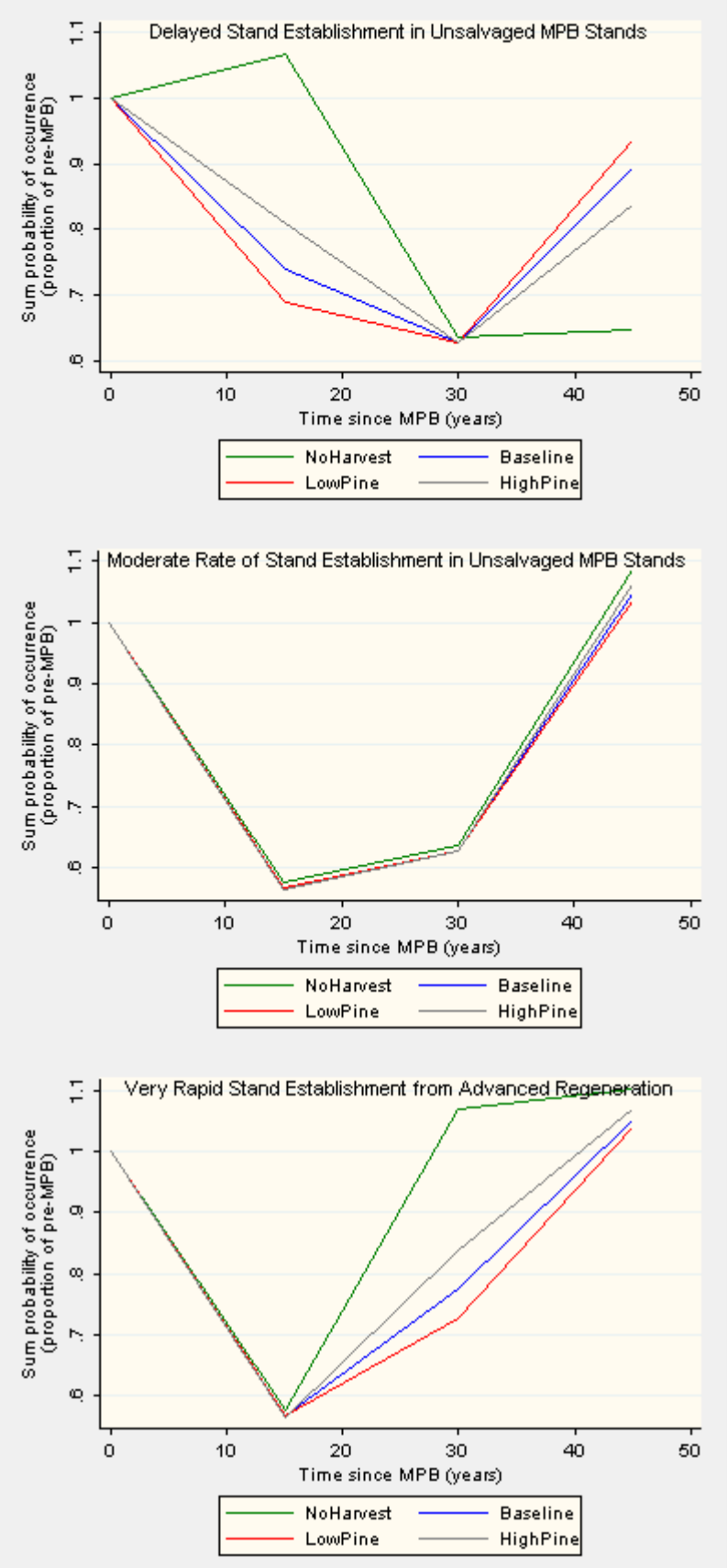
Alder Flycatcher



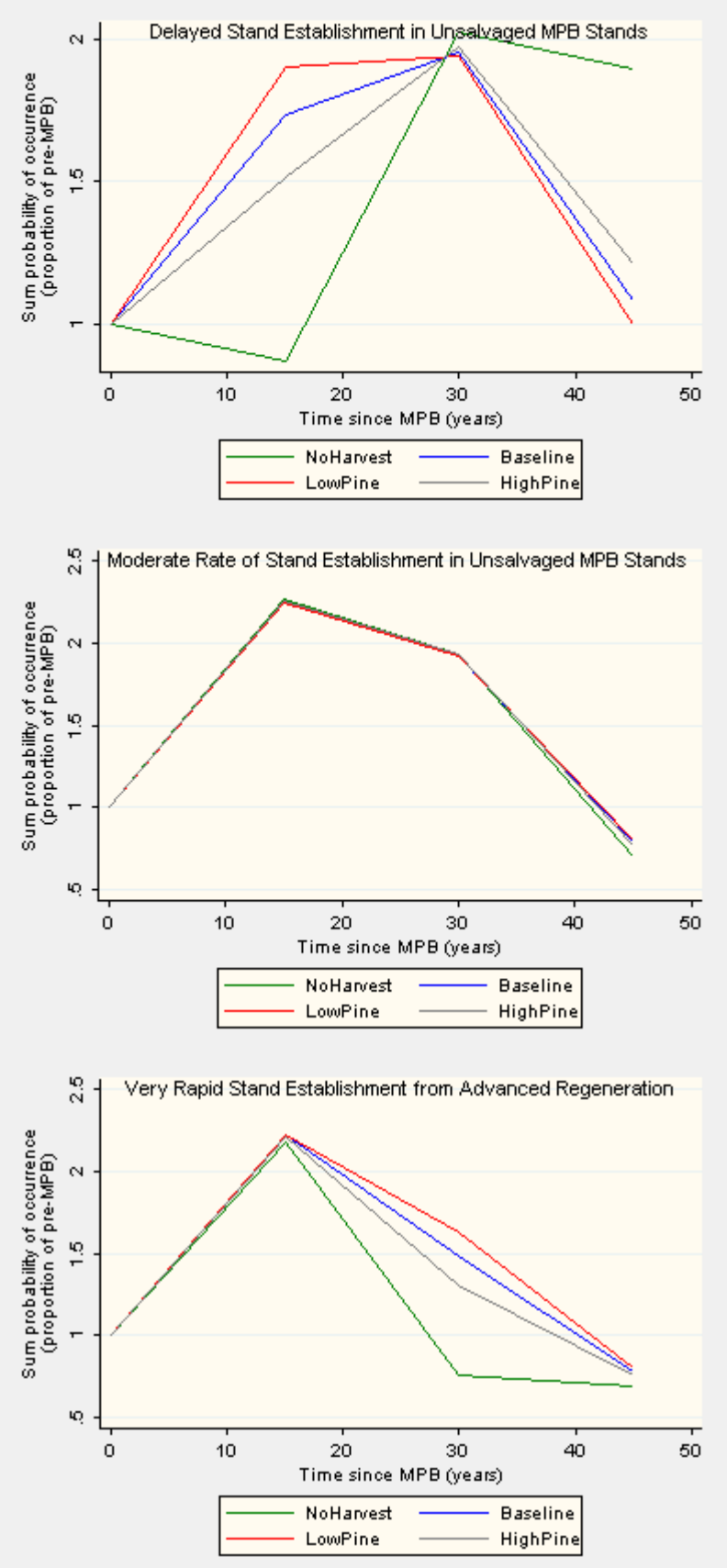
Black-throated Green Warbler



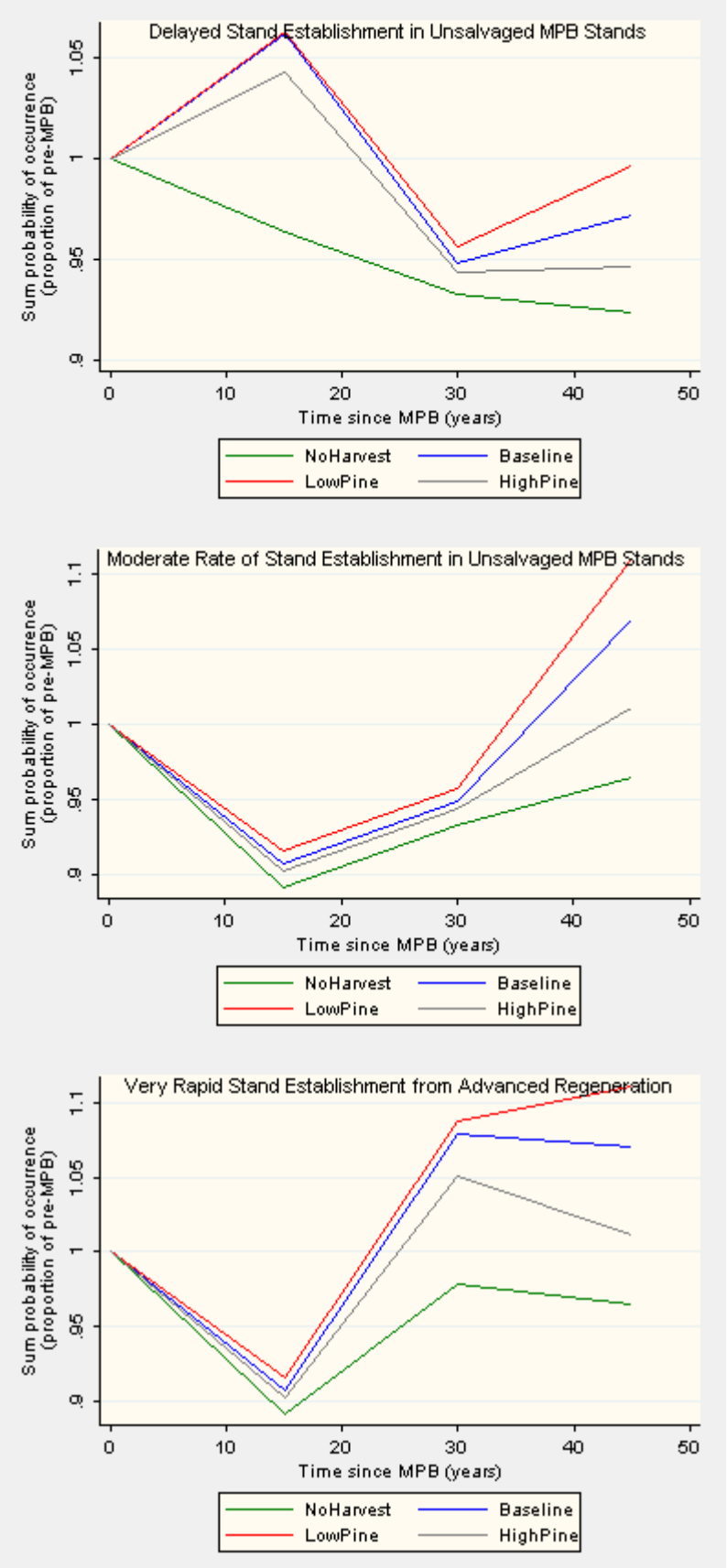
Golden-crowned Kinglet



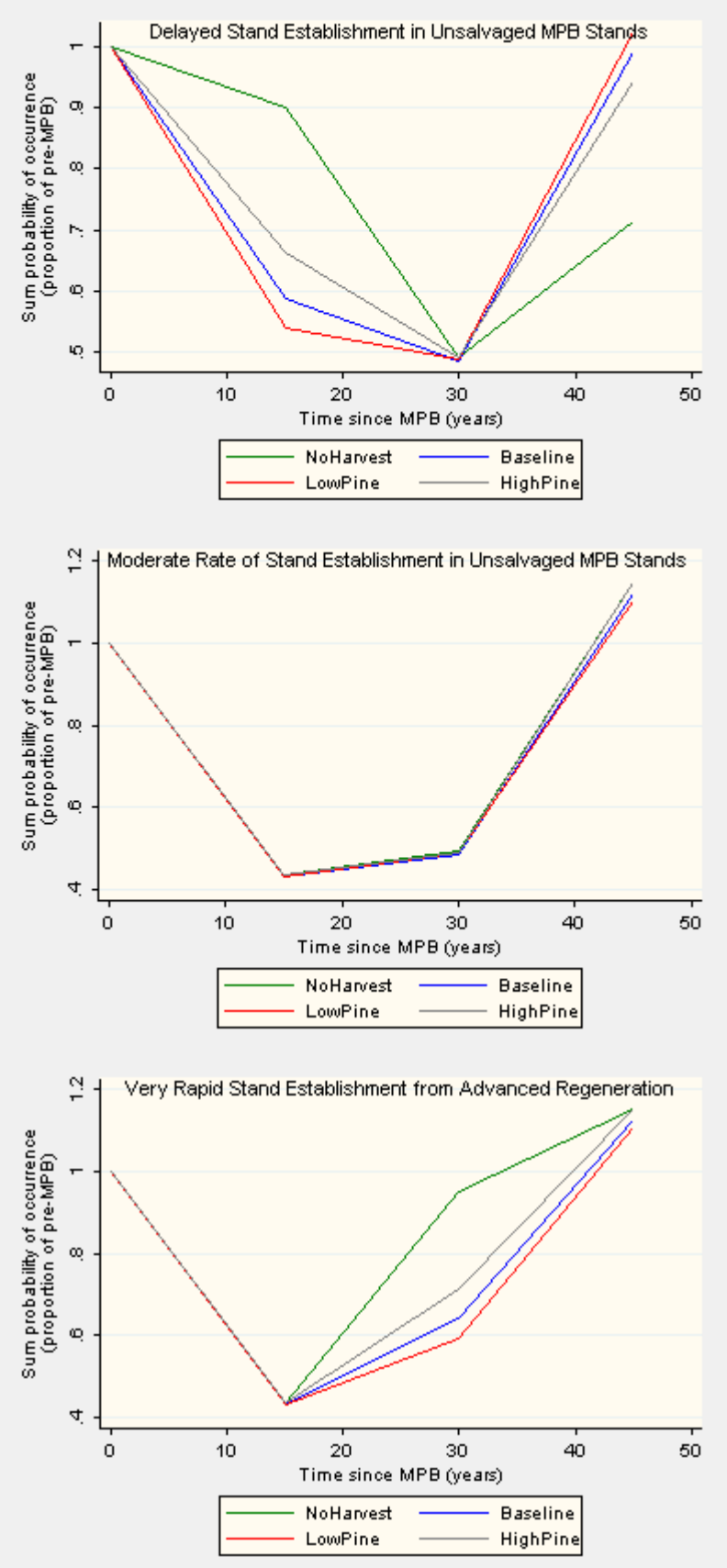
Least Flycatcher



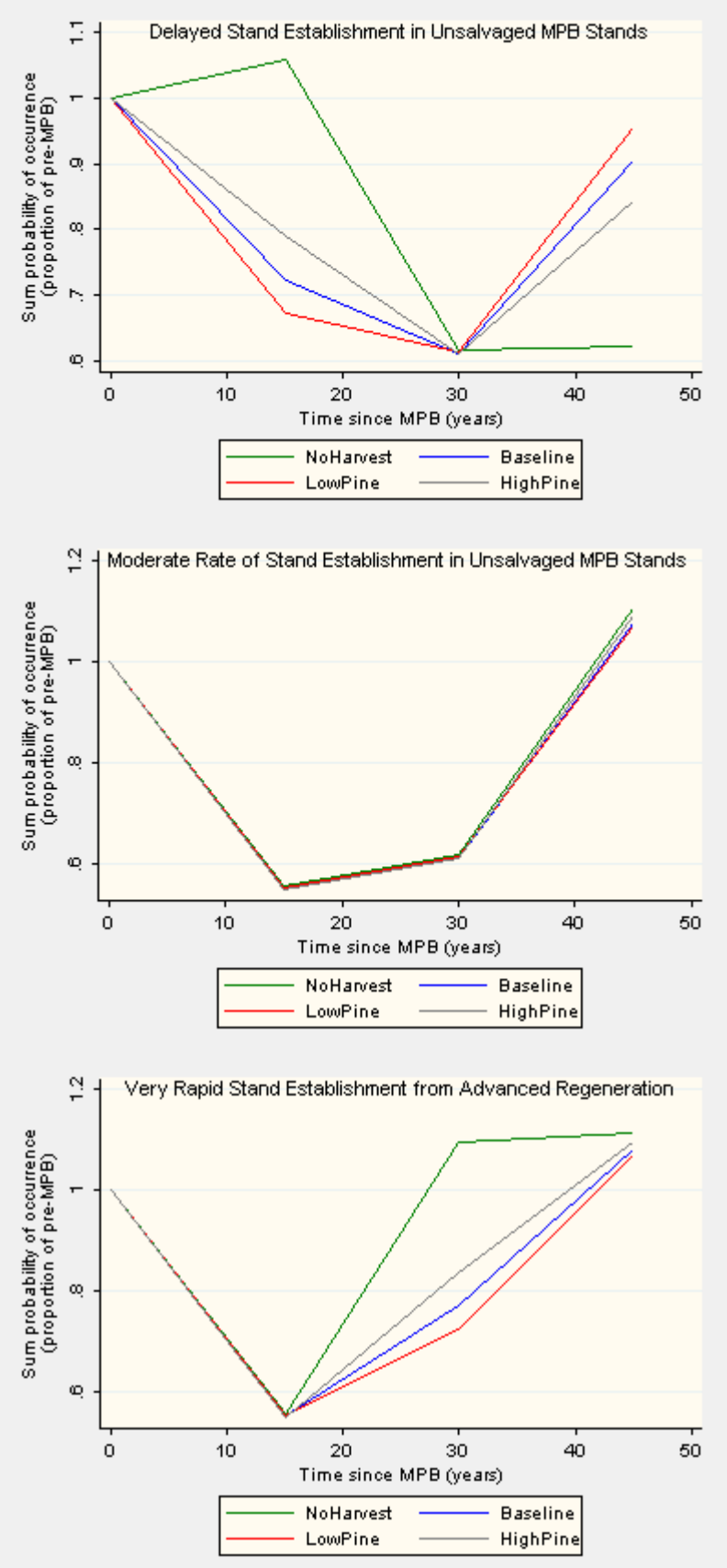
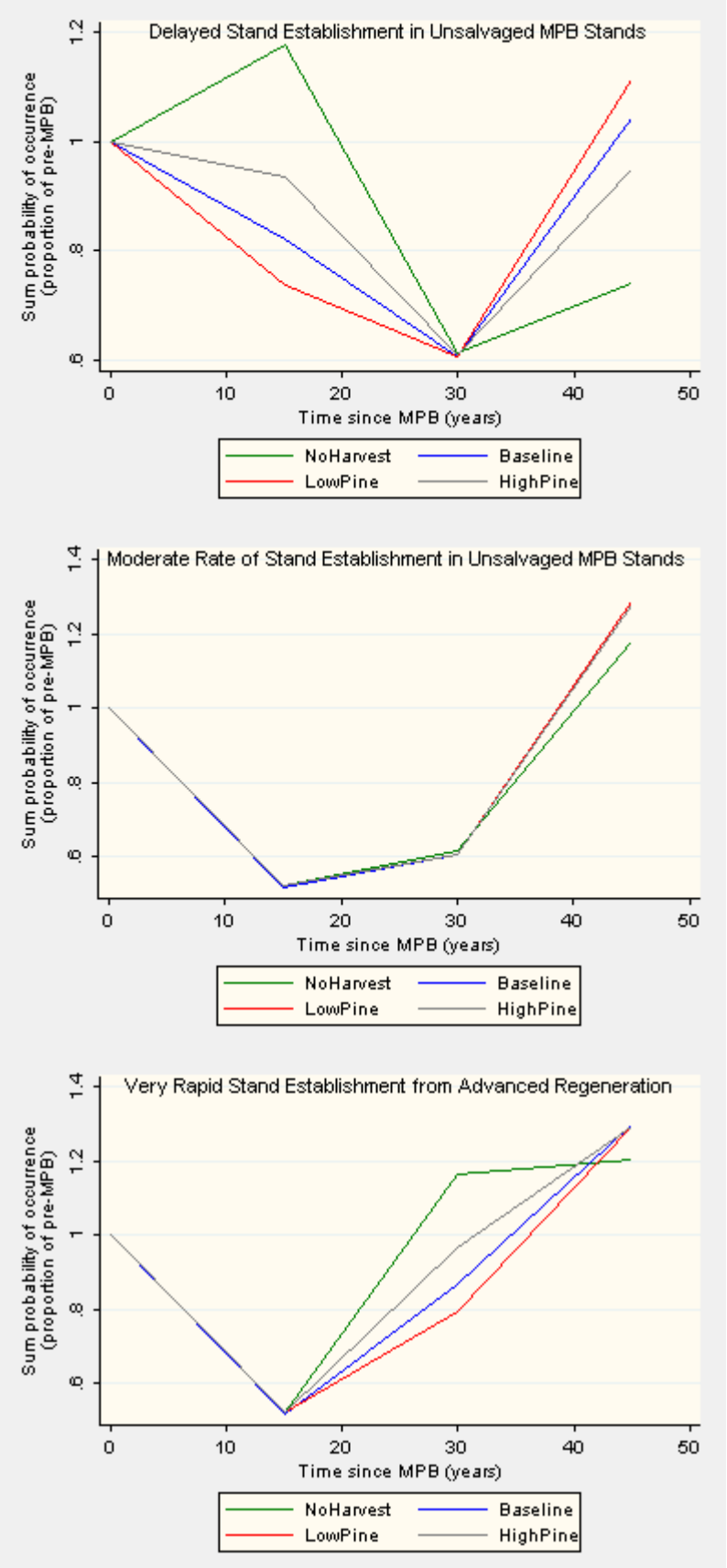
Red-eyed Vireo



Townsend's Warbler



Varied Thrush



Western Tanager