Discussion Paper 4 (DP4): Wildlife Habitat Modeling Based on Tree-list Projections

Kevin Ceder, Hiroo Imaki, Kevin Zobrist, Bruce Lippke

Table of Contents

List of Figures

List of Tables

Introduction

Forests of the Pacific Northwest are the home for a multitude of wildlife species. Society is placing increasing demands on forest managers to provide wildlife habitat for a wide diversity of both game and non-game species. To meet these demands, many types of wildlife habitat models have been developed that can estimate both habitat quality and quantity based on tree lists and understory information available from existing forest inventory data.

Habitat Modeling Case Studies:

Modeling habitat is an evolving science. Three case studies are illustrated to characterize the type of information that can be developed. We use the Landscape Management System (http://lms.cfr.washington.edu,) which links the habitat models with current and future forest inventories, projected with forest growth and yield models, to give current and potential future habitat conditions responsive to forest growth and management treatments. The first case study demonstrates that providing wildlife habitat and harvest revenues within a forest management framework are not mutually exclusive. The second case illustrates that taking no action to reduce wildfire risk may put wildlife habitat at risk.

Identifying best habitat models can be problematic since many of the models while supported by some observations on suitable structure are still largely expert opinion. Structure based management can be used with more rigorous statistical methods to assess whether a given stand condition is similar to or different than target habitat conditions such as the conditions in the immediate vicinity of Northern Spotted Owl nests. Since owls have been largely identified with old forests, the assessment can be used to test whether a management pathway is effective at producing old forest conditions over time. In a third case study we illustrate the use of such an assessment method to select best management pathways to restore old forest structural conditions in the Olympic Experimental State Forest (OESF). The method can be used to test the goodness of any given treatment pathway in replicating any given target forest structure condition whether old forests or any other desired condition that can be identified by actual forest stands characterized by stand inventory data. The assessment procedure appears to provide a robust statistical approach for assessing whether any given management pathway can achieve any future target forest condition that can be identified by a group of stands and we illustrate use of the assessment to select best management pathways to restore old forests. Old forests are often referred to as the oldest and most complex structure when stands are split into just a few classes which has been called the course filter approach as contrasted with habitat specific modeling.

Johnson and O’Neil (2001) developed habitat suitability measures for a large number of species by characterizing stand structure into 38 structure classes, considerably more detail than the earliest course filter approaches which were based on only a few structure classes. They develop a matrix of habitat suitability for each species.

Finally we illustrate the impact of our sample management alternatives on habitat using both the assessment method to restore a desired target forest condition like old forests and also the impact on several species sensitive to different forest conditions using the Johnson and O’Neil structure classes and Habitat Suitability Indices.

Case Study 1: SATSOP Forest Habitat Evaluation

The first case study uses a Habitat Evaluation Procedure (HEP, USDI 1980) within LMS to meet the requirements of a wildlife mitigation agreement on SATSOP Forest in southwest Washington (Ceder, 2001, URL: http://silvae.cfr.washington.edu/Satsop-plan). The agreement focused on the habitat needs of 5 species, using previously defined Habitat Suitability Index (HSI) models. The species were chosen to track changes in a variety of habitat types: with the spotted towhee (*Pipilo erthrophthalmus*) tracking changes in brush habitats; the Cooper's hawk (*Accipiter cooperii*)tracking changes in mixed hardwood conifer forests; southern red-backed vole (*Clethrionomys gapperi*)tracking changes in closed canopy forests; the pileated woodpecker (*Dryocopus pileatus*)tracking changes in mature forests; and black-tailed deer (*Odocoileus hemionus*), a habitat generalist, tracking overall changes.

Twenty potential management alternatives for Satsop Forest were developed ranging from 'no harvest' to 40-year clearcut rotations with varying amounts, timings and levels of thinning between these extremes. Assessments of each alternative determined the amount of habitat and wood volume that could be produced over an 80-year planning horizon. Results indicate amounts of specific habitats based on the impact of management alternatives on forest structure that could be created through active management alternatives (Figure DP4.1). Some species were not very sensitive to forest management, even under the highest level of harvesting although some sensitivity to treatments is apparent. Cooper's hawk, southern red-backed vole, and spotted towhee habitat values changed little as harvesting increased. In contrast, habitat available for the pileated woodpecker, which is associated with older forest structures, decreased with higher harvest levels. Harvest and habitat are far from mutually exclusive but tradeoffs occur between high harvest levels and habitat requiring old forest structures.

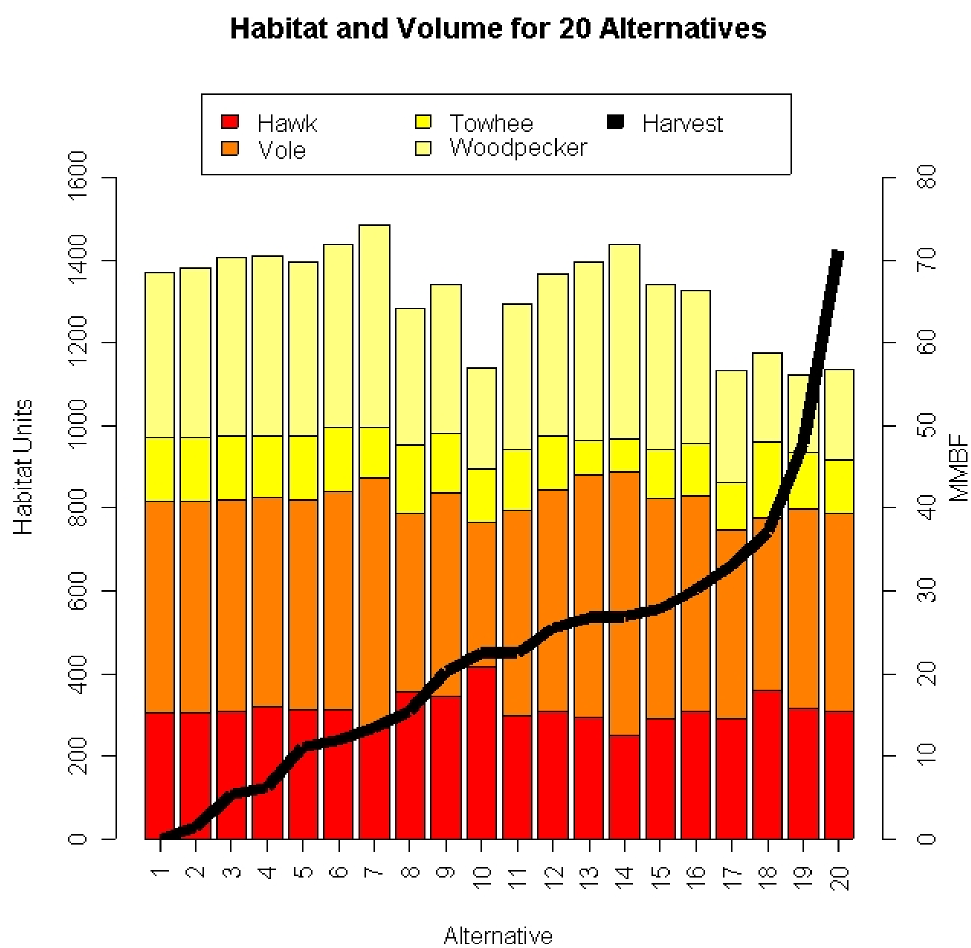

Figure DP4.1: Habitat and harvest volume production for 20 potential 80-year management alternatives for Satsop Forest.

Case Study 2: Fuel Removal Treatment Impacts on Habitat Suitability

Habitat modeling was included in the Investigation of Alternative Strategies for Design, Layout and Administration of Fuel Removal Projects (Mason et al 2003). The project examined effects of five fuel removal treatments and a wildfire simulation using data from the Fremont and Okanogan National Forests. Changes in wildlife habitat were assessed for northern goshawk (*Accipiter gentilis*), Lewis woodpecker (*Melanerpes lewis*), white-headed woodpecker (*Picoides albolarvatus*), Williamson's sapsucker (*Sphyrapicus thyroideus*), Canada lynx (*Lynx canadensis*), pileated woodpecker, northern flying squirrel (*Glaucomys sabrinus*), Townsend's big-eared bat (*Corynorhinus townsendii*) using HSI models. The wildlife habitat matrices in the ICBEMP report were used for the Canada lynx, grizzly bear, pileated woodpecker, northern flying squirrel, and Townsend's big-eared bat. Assessments of lynx and grizzly were done only for the Okanogan National Forest, as they do not occur on the Fremont National Forest.

Initial habitat and fire risk relationships showed that stands with high and moderate risk provided more habitat for the majority of the species than the low risk stands on both forests. This was particularly evident in species that are associated with older forest structures such as the northern goshawk, pileated woodpecker, and northern flying squirrel on both forests and the lynx and grizzly on the Okanogan (Figures DP4.2 and DP4.3).

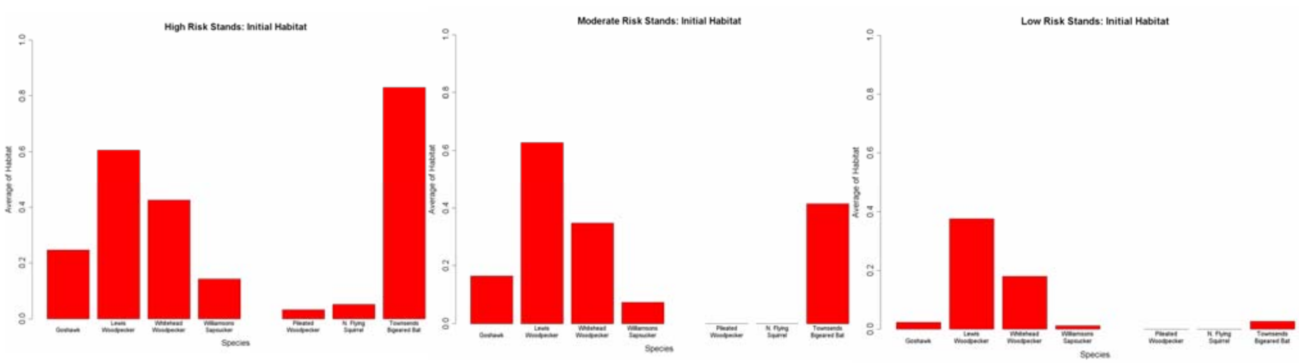

Figure DP4.2: Habitat levels for High, Moderate, and Low risk stands on Fremont NF. Wildlife species, left to right in each graph are: Northern goshawk, Lewis woodpecker, white-headed woodpecker, Williamson's sapsucker, pileated woodpecker, northern flying squirrel, and Townsend's big-eared bat.

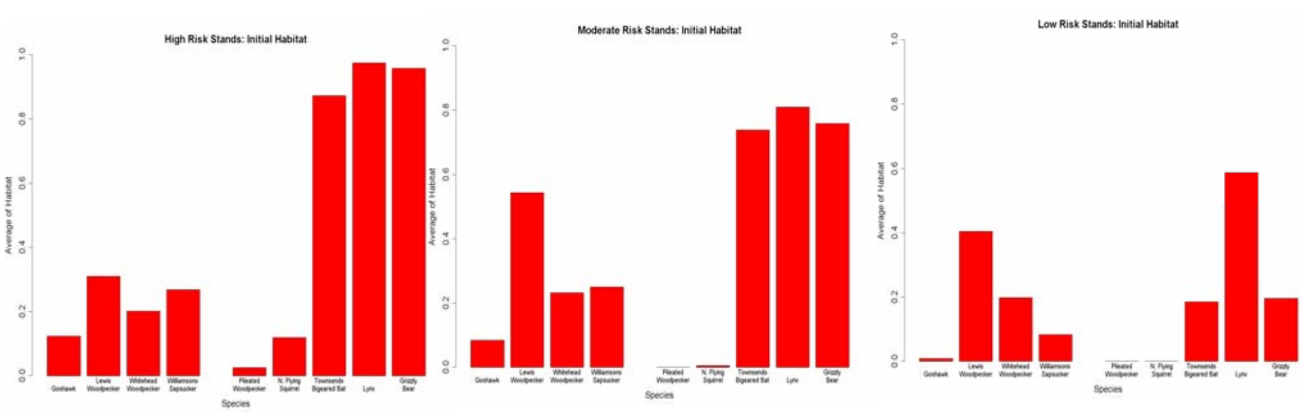

Figure DP4.3: Habitat levels for High, Moderate, and Low risk stands on Okanogan NF. Wildlife species, left to right in each graph are: Northern goshawk, Lewis woodpecker, white-headed woodpecker, Williamson's sapsucker, Pileated woodpecker, northern flying squirrel, Townsend's big-eared bat, Canadian lynx, and grizzly bear.

Response to treatments varied among species and treatments. Species associated with older forest structures had habitat levels more severely impacted by the treatments than species associated with open forest structures. As stands were opened more through thinning, habitat decreased for most species, when compared with the no action and no disturbance alternative. One exception was the Lewis woodpecker, which thrives in open forests. When regeneration was included available habitat increased, but still remained lower than no action. Grizzly habitat on the Okanogan, though, which was originally reduced by the thinning, returned to levels higher than no action after 30 years. All treatments that reduced fire risk also reduced habitat levels. However, wildfire simulations greatly reduced or eliminated habitat for all species associated with older forest structures. Both forests are in fire regime condition class 2 or 3 (FRCC, Hann and Strohm 2003), meaning that the fire regime has diverged significantly from historical conditions and the risk of severe fires is high. With this in mind, questions can be asked about historical habitats for some of the species now present in the dry interior forests: Are current habitat levels, because of fire exclusion and suppression, different than their historical levels? If forest managers perform fuel treatments to reduce the current fire risk, how will habitat availability for old forest species be affected? If habitats for some species are at high risk and need to be preserved, what are the most effective methods of creating low risk fuel and fire breaks to protect the high risk areas from wildfire?

Case Study 3: Determining most economic pathways to achieve desired ecological targets

In order to restore forest structure conditions to a target forest condition such as old forests, or forests conditions where owl nests are located, if we have a sample of these stands, a statistical procedure can be used to assess whether managed stands will achieve similar conditions as a consequence treatments and growth modeled by appropriate stand level forest growth models. Gehringer (2006) developed such a procedure and it has been used to determine the percentage of time that a simulated stand is similar to a desired target stand.

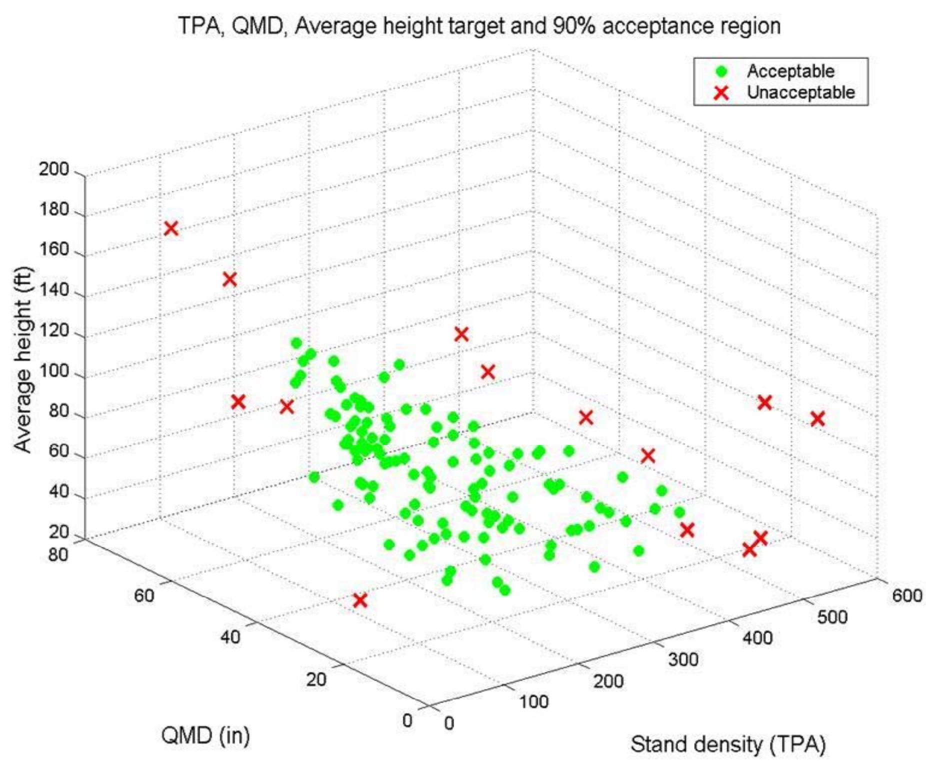

Figure DP4.4: Defining the acceptance region when a managed stand may be considered similar to a target stand structure, in this case for older unmanaged forest stands

Using non-parametric statistical evaluation he determined that quadratic mean diameter (QMD), Trees per Acre (TPA), Height and or canopy closure discriminated old forest conditions from all other conditions better than other parameters. By identifying the 90% cluster of stands closest to the median as similar to the target (Figure DP4.4) an assessment test can be devised to determine whether a managed stand is similar or not similar to the target structure. One can measure how soon and how long a treated stand is similar i.e. is within the 90% of the stands that were accepted to define the target. And, as a separate economic metric one can compare the economic performance resulting from the treatment in order to select best management treatment pathways.

For the more than 3000 stands in the Olympic Experimental State Forest, QMD and TPA provide most of the discriminating power to identify old forests greater than 80 years (in yellow) and owl nests (black diamonds) from other forests (maroon) (Figure DP4.5). Non-overlapping canopy closure was also a useful discriminating variable especially for the owl nests which were all found within the range of 80 to 95% canopy closure.

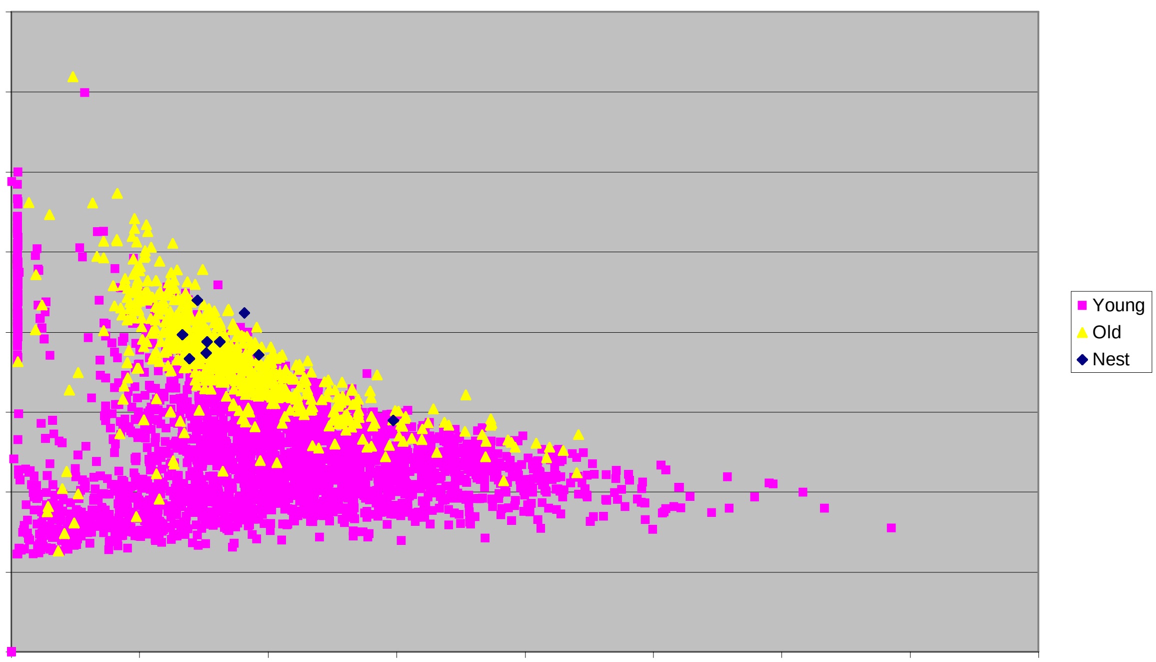

Figure DP4.5: Discriminating old forest structures from all others

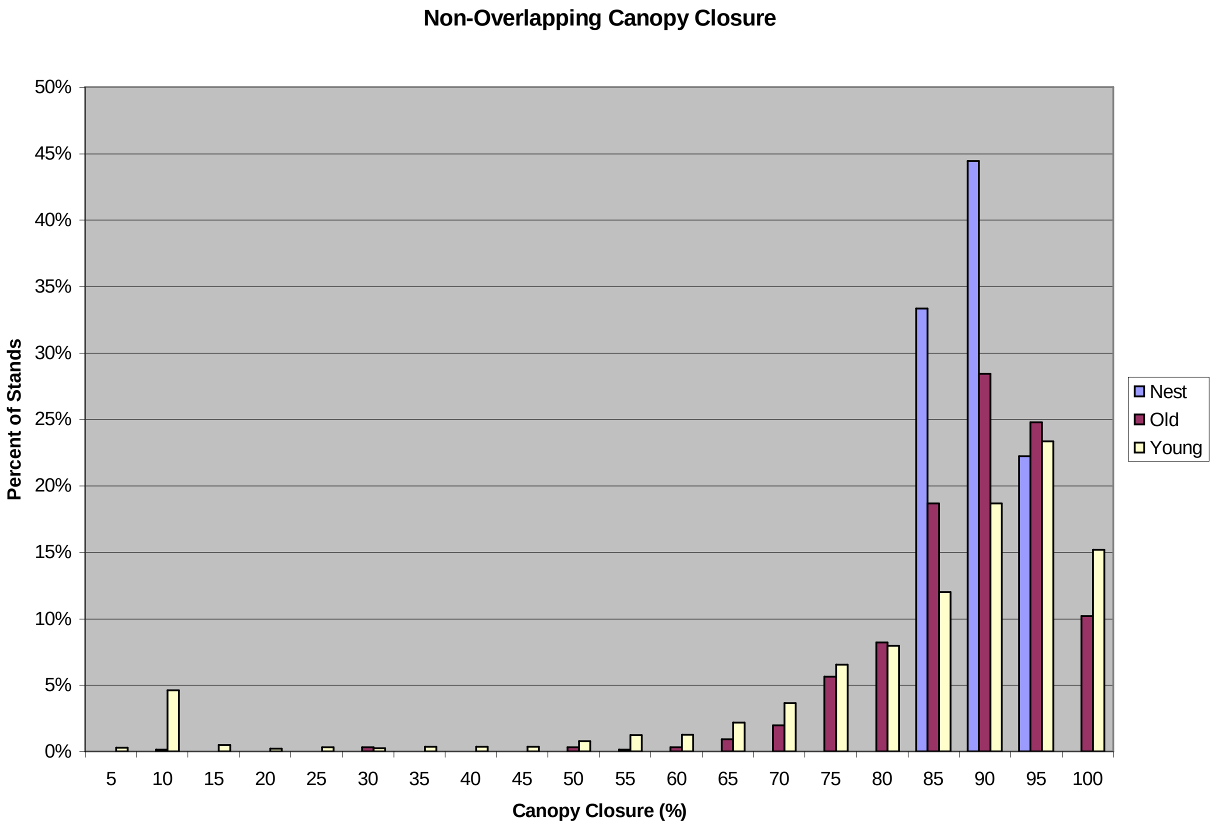

Figure DP4.6: Canopy closure as a discriminating variable for owl nests.

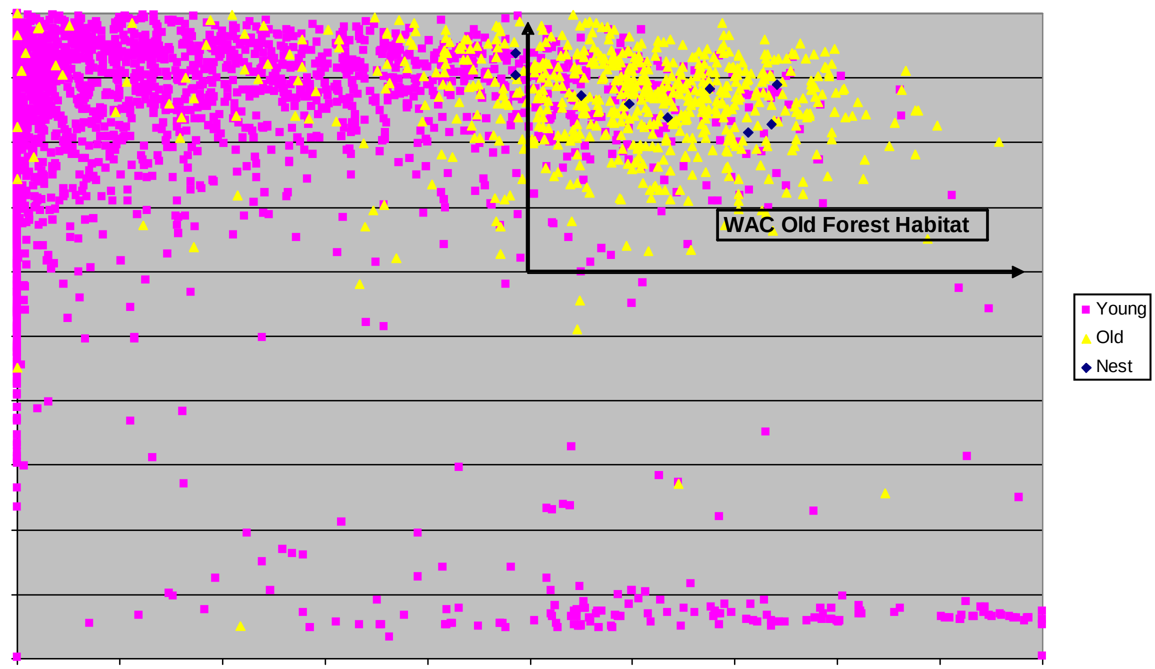

Figure DP4.7: The WAC definition of old forests as a discriminating criteria on the OESF

The WAC definition of greater than 60% canopy closure and greater than 50% canopy closure for trees greater than 20" DBH appears to isolate the old forests quite well but is not nearly as discriminating of the owl habitat nest sites for which were all within 80 to 95% canopy closure.

Figure DP4.8: The WAC criteria of number of large trees as a discriminating variable

However the WAC criteria of 75 trees greater than 20" DBH or 35 trees greater than 30"DBH appears to be unreasonable for the OESF stands although may work better for inland stands of Douglas-fir.

Using the Gehringer assessment procedure to define the target structure for old forests as a desired future condition (DFC), we can assess the suitability of management alternatives in producing that structure by tracking the percent of time any given treatment alternative falls within the DFC structure.

Environmental Outcomes of Treatment Alternatives

While shorter rotations have the economic advantage of faster investment recovery, they also result in more of the landscape being harvested at any given time. The landscape is further skewed toward younger stand structures, which may cause problems for species that utilize older structures (Curtis 1997). A shift away from thinning may also have other undesirable environmental outcomes. Stands that are maintained in a highly dense condition have a paucity of understory vegetation and do not support high levels of biodiversity (Oliver and Larson 1990). In contrast, thinning in managed stands has been found to promote understory development and promote development of multiple canopy layers (Bailey and Tappeiner 1998, Muir et al. 2002). Thinning has been linked to increased wildlife abundance (Havari and Carey 2000, Hayes et al. 2003, Suzuki and Hayes 2003; Wilson and Carey 2003) and it can accelerate the development of desirable old forest conditions (Busing and Garman 2002, Garman et al. 2003, McComb et al. 1993, Tappeiner et al. 1997).

Ultimately, different forest management approaches will result in trade-offs between economic and environmental outcomes with some choices having more consequences than others. It will be important to understand how management alternatives might be developed to minimize trade-off impacts in order to achieve multiple objectives on the landscape. Some countries, such as New Zealand (Douglas 1993), have largely separated habitat protections from timber production by partitioning the land base into government-owned forest reserves and privately managed short-rotation commercial plantations. Studies have shown that in Washington, integrated management for multiple values may be a less costly approach (Lippke 1997).

Management Alternatives:

To evaluate the habitat response to management alternatives we used the six management alternatives developed in Discussion Paper DP2 which are displayed visually in Figure DP4.9. A no action or no management beyond regeneration alternative assuming no disturbance is characterized along with three different currently practiced commercial treatments, and 2 biodiversity pathways to restore older forest structures that have been reduced in supply. These pathways were than scored by the ecological assessment metric for percent time in DFC and the economic metric Soil Expectation Value (SEV), the metric most associated with sustainable forest management as it equates to the value an investor should be willing to pay at the target discount rate (5% illustrated) for the bare land prior to the investment in regeneration.

Figure DP4.9: Stand Visualization, Trees per Acre & QMD (at 100 yrs or end of second rotation)

Figure DP4.10 illustrates that only our biodiversity pathways successfully reach the target condition for DFC even 40% of the time. Neither of the short commercial rotations without thinning reaches the condition at all and the single thin treatment essentially is just beginning to take on the characteristics of the old forest structure at the time of harvest. Thinning treatments also have the advantage of providing an attractive starting point for a b iopathway as an option after the early thinning. More importantly perhaps, the no harvest scenario barely reaches the desired condition as it takes natural mortality in regenerated stands a very long time to provide adequate thinning. The no action alternative is even slower to reach the target with 5% time in target (the last 5 years).

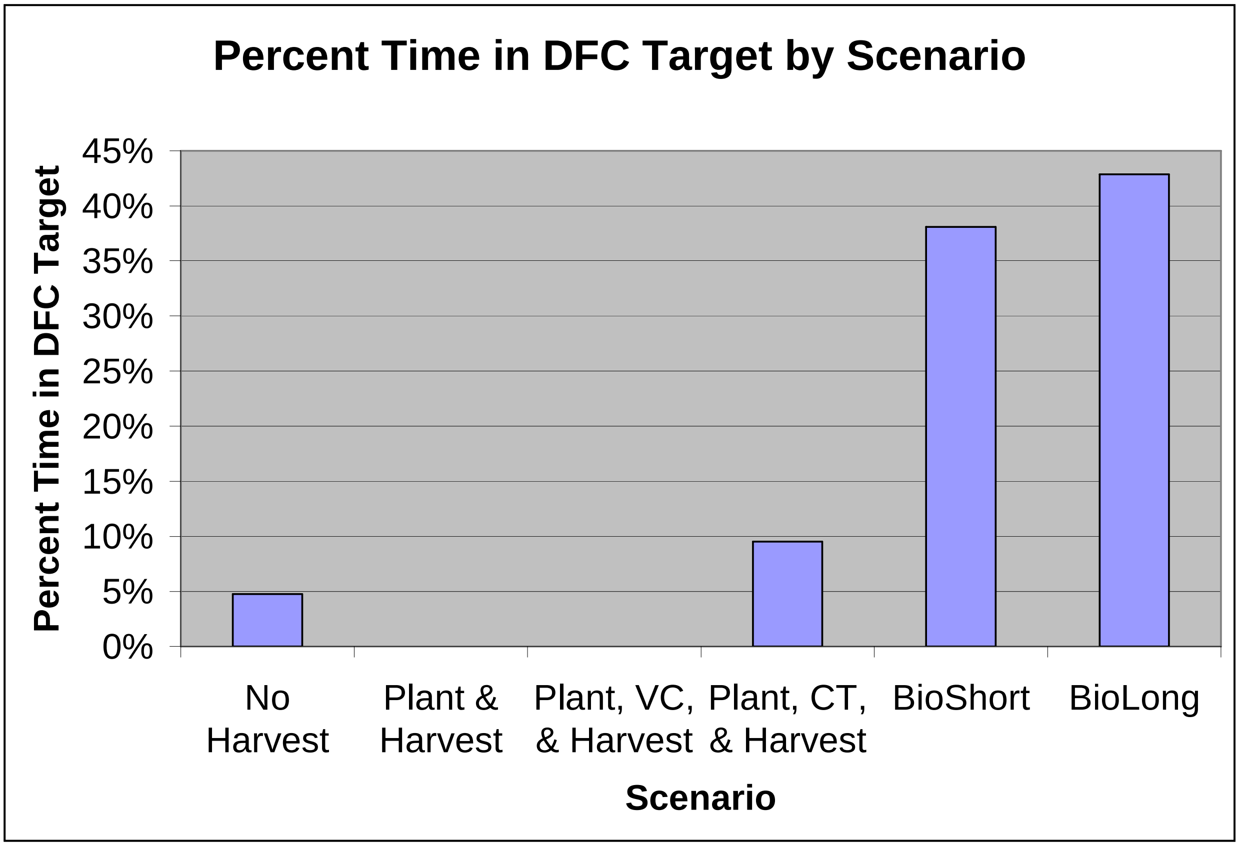

Figure DP4.10: Assessing the percent of time a managed stand is similar to the DFC

While the biodiversity pathways may reach restoration objectives as noted in Figure DP4.11 the economic loss to a landowner is large suggesting they will generally not be pursued voluntarily without compensation.

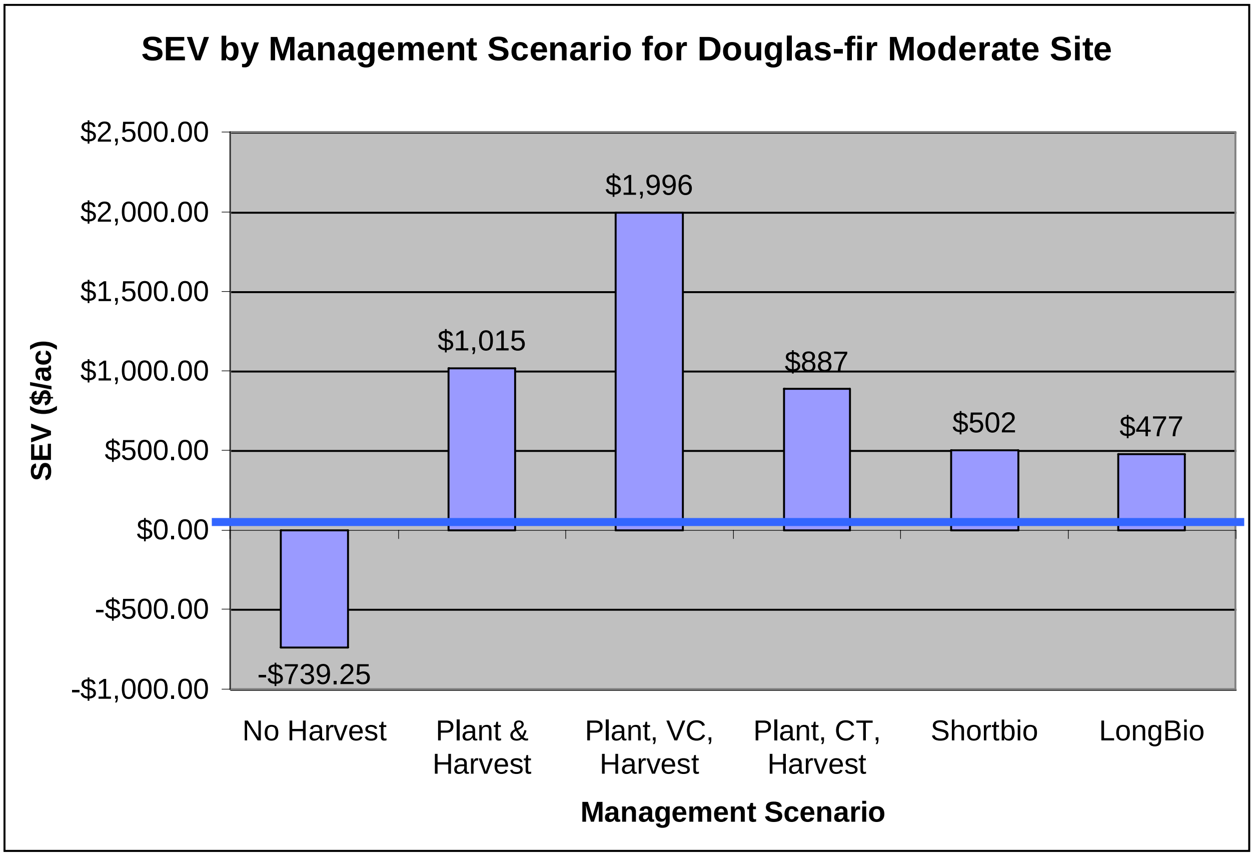

Figure DP4.11: Determining the cost of treatments to produce levels of habitat

The economic criteria demonstrates that the opportunity cost to produce old forest habitat is substantial, roughly $500/acre for a biodiversity pathway compared to historical short commercial rotations and as much as $1500 per acre compared to an effective Vegetation Control pathway. However biopathways are much more effective at producing old forest structures than No Harvest.

The opportunity cost of $1500 to produce a DFC target of 40% requires an up front incentive payment of $37.50 per percent in DFC. While expensive enough to deter voluntary biopathways, the opportunity cost of no action is $551 per percent in DFC, 15 times more costly.

Habitat Suitability using Johnson & O'Neil Structures:

Johnson and O'Neil stand structure/habitat matrix stands can be mapped into 36 mutually exclusive structure classes in order to assess the quality of habitat for specific species. For illustration we characterize the percentage of time each treatment provides either essential or supportive habitat for several species known to prefer different forest structures, The pileated woodpecker prefers *complex forest structure* much like the owl, the Douglas squirrel (*Tamiasciurus douglasii*) is identified with *coniferous forests*, the gold-crown kinglet (*Regulus satrapa*) prefers *very dense closed forest structure* and the Roosevelt elk (*C. canadensis roosevelti*) prefers *more open structures.* For the Pileated Woodpecker the short biopath provides substantially better habitat than short rotations but the long retention biopath appears to retain too few overstory trees. Whether this a weakness in the habitat criteria or not may require additional research on the role and availability of snags.

Looking across the selected species and treatments (Figures DP4.12 - DP4.15 & Table DP4.1) it is noteworthy that the old forest sensitive pileated woodpecker has the lowest amount of suitable habitat with the short-biopathway treatment providing the largest support. The Douglas squirrel receives somewhat lower score in the commercial pathways but still tolerates a large range in forest density. The golden-crown kinglet prefers dense forests but receives relatively high scores even under short rotation commercial stands. The Roosevelt elk was least sensitive to the different structures.

While these measures do not establish the monetary worth of habitat, they can be used to determine the opportunity loss associated with changing treatments to produce more of any given habitat while noting that continued research into these habitat measures will likely improve knowledge over time much like the old forest target assessment procedure appears to provide a more robust statistical test for reaching a known target forest condition.

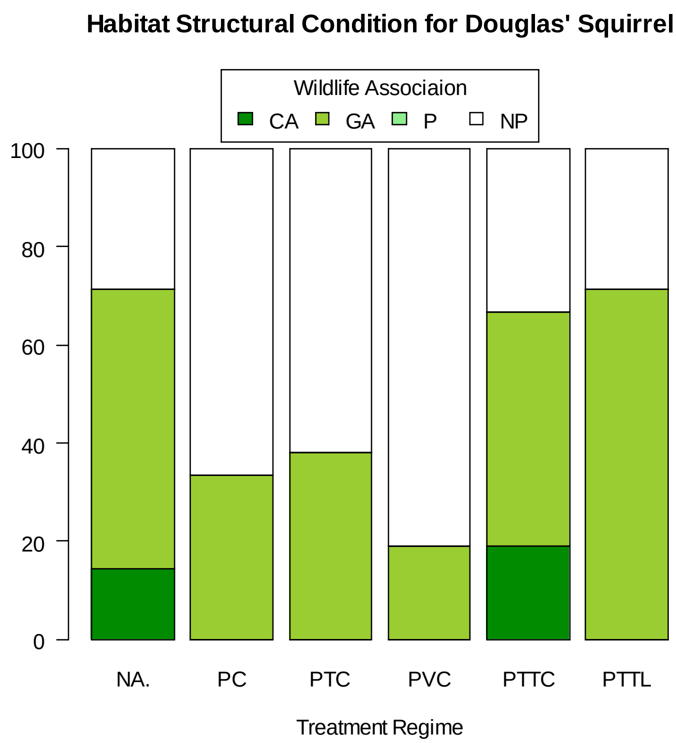

Figure DP4.12: Habitat suitability for the Douglas squirrel using different treatments

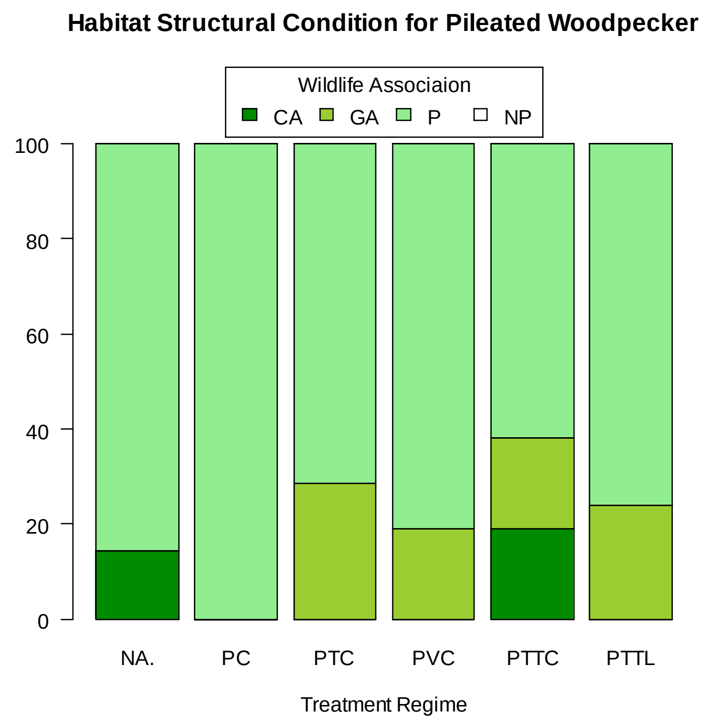

Figure DP4.13: Habitat suitability for the pileated woodpecker using different treatments

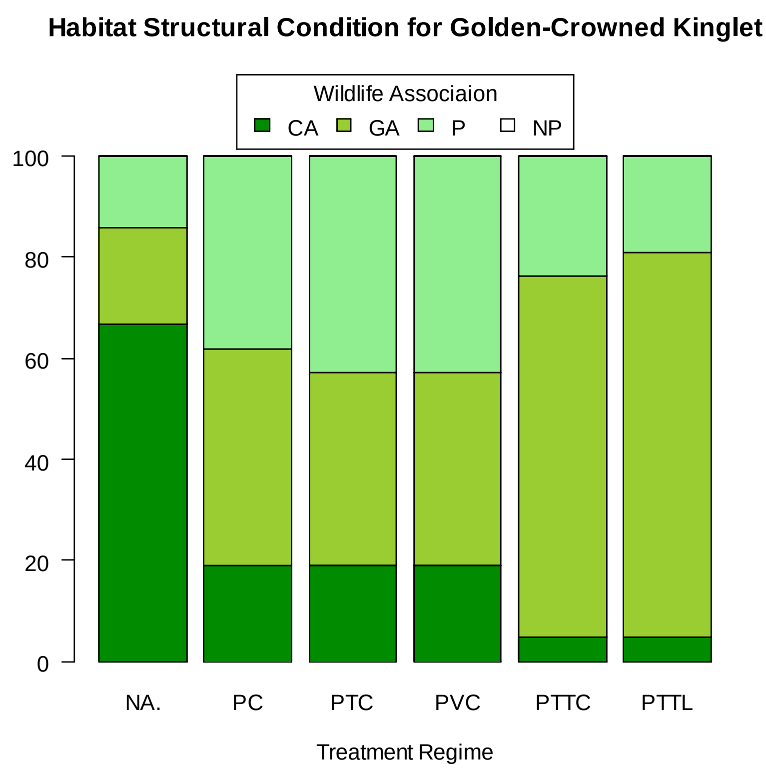

Figure DP4.14: Habitat suitability for the golden-crowned kinglet using different treatments

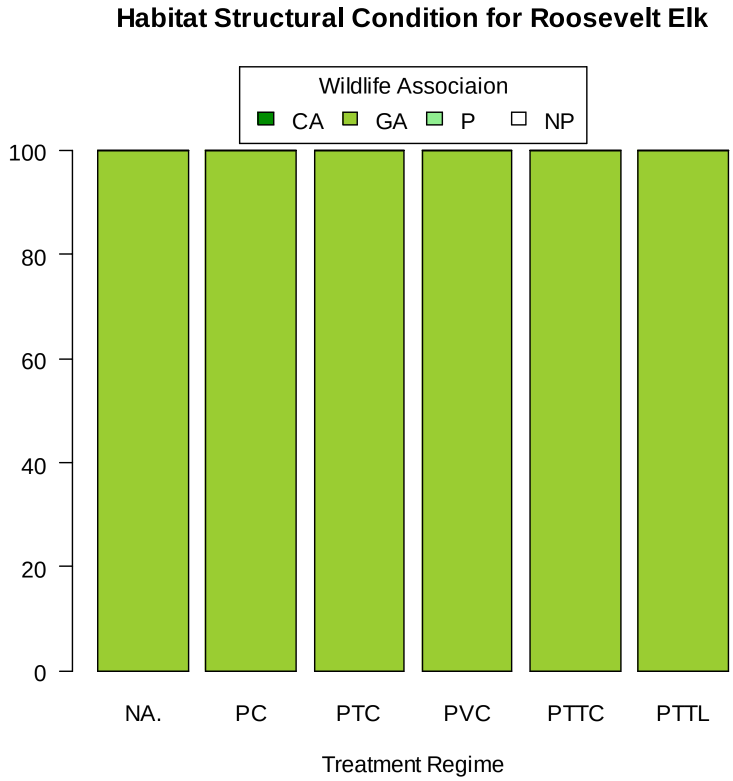

Figure DP4.15: Habitat suitability for the Roosevelt elk using different treatments

Table DP4.1: Percent of time each species has non-marginal habitat using different treatments

	NA	PC	PTC	PVC	PTTC	PTTL
pileated woodpecker	14.3	0.0	28.6	19.0	38.1	23.8
Douglas' squirrel	71.4	33.3	38.1	19.0	66.7	71.4
golden-crown kinglet	85.7	61.9	57.1	57.1	76.2	81.0
Roosevelt elk	100	100	100	100	100	100

Alternative Grouping of Structure Dependent Species:

In the search for other species to demonstrate the impact of the Johnon & O'Neil habitat matrix, we selected the northern flying squirrel with a preference for old forest structures, the northern goshawk a generalist, the red-tailed hawk (*Buteo jamaicensis*)associated with small to medium tree- single story – open structures and the Pacific jumping mouse (*Zapas trinotatus*) associated with the grass/forb stage of more open structures. We calculated the percent of time an even broader set of management alternatives provided habitat for these species as shown in Figures DP4.16 to DP4.19.

While the northern flying squirrel prefers old structures the quality of habitat only exceeds the *generally associated* preference level in Biopathway treatments or no-management treatments after many decades. The Goshawk also benefits with more habitat from these same treatments. The redtailed hawk shows somewhat less benefit from the old forest structures however all three species show varying degrees of sensitivity to old forest structures. We conclude that measures of old forest structures provide the single most important assessment for a wide variety of species. The Pacific jumping mouse is of course sensitive to more open structures and as a consequence has less quality habitat, but there is not a shortage of these structures under the commercial management alternatives or in comparison to pre-European settlement history or even under treatments designed to produce old forest structures there appear to be some stands with large enough openings to provide habitat. Large areas of no-management with fire suppression would likely be the instance of greatest concern for species dependent upon open structures.

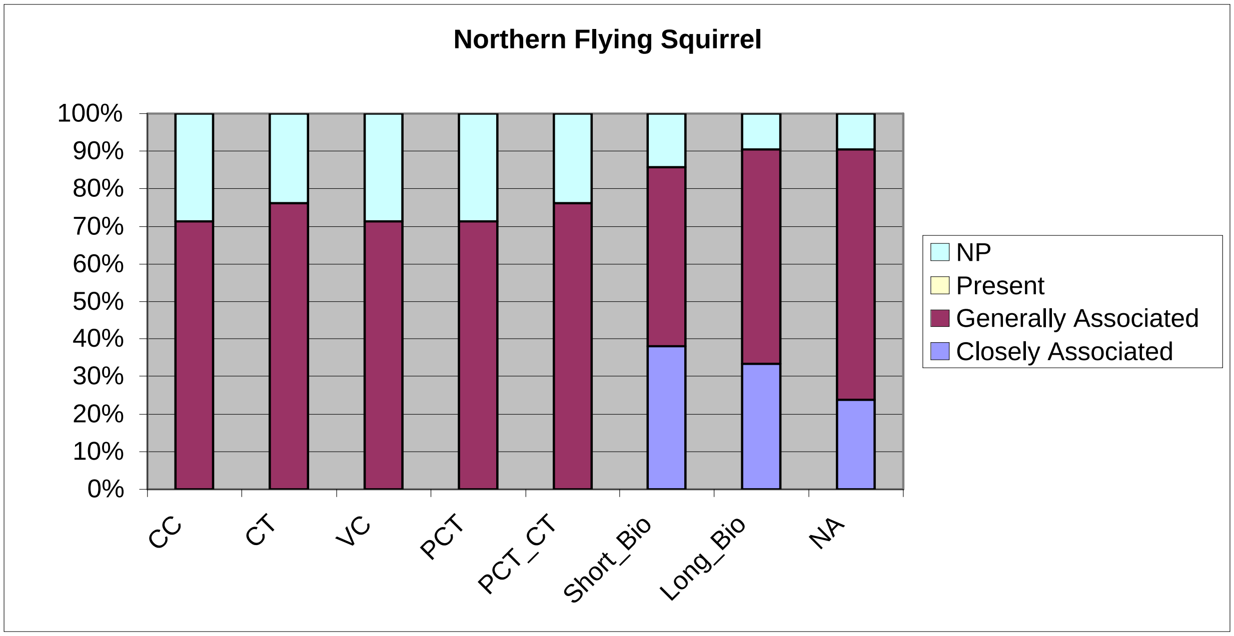

Figure DP4.16: Habitat suitability for the northern flying squirrel

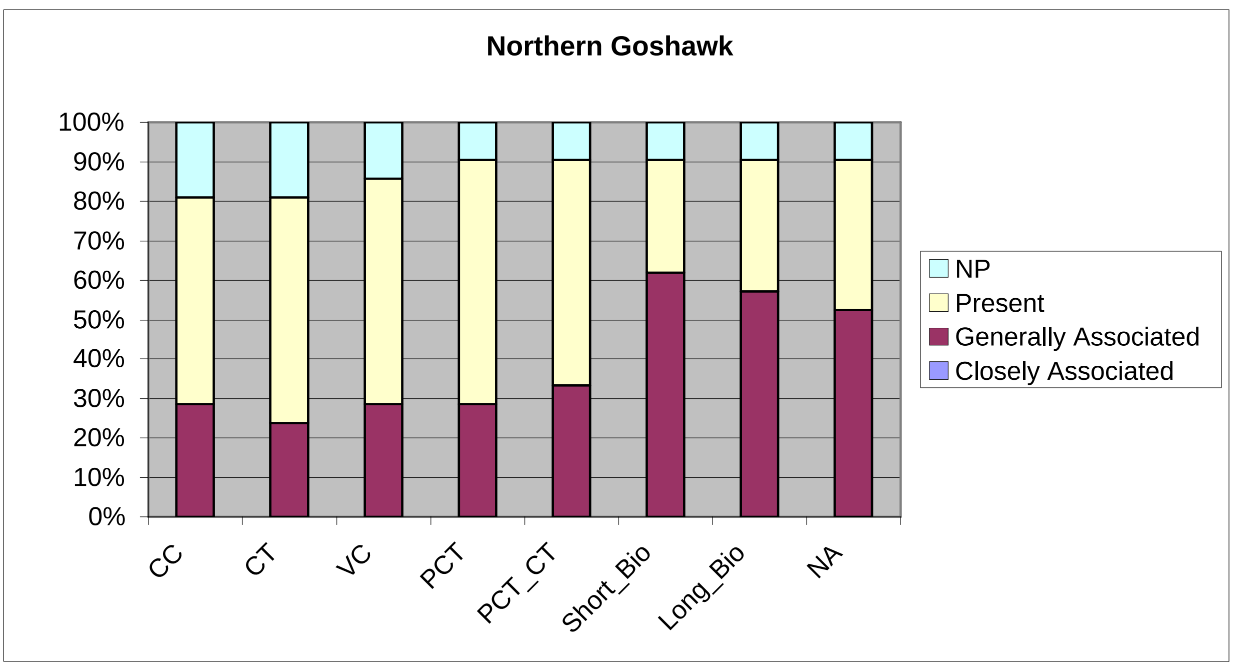

Figure DP4.17: Habitat suitability for the northern goshawk

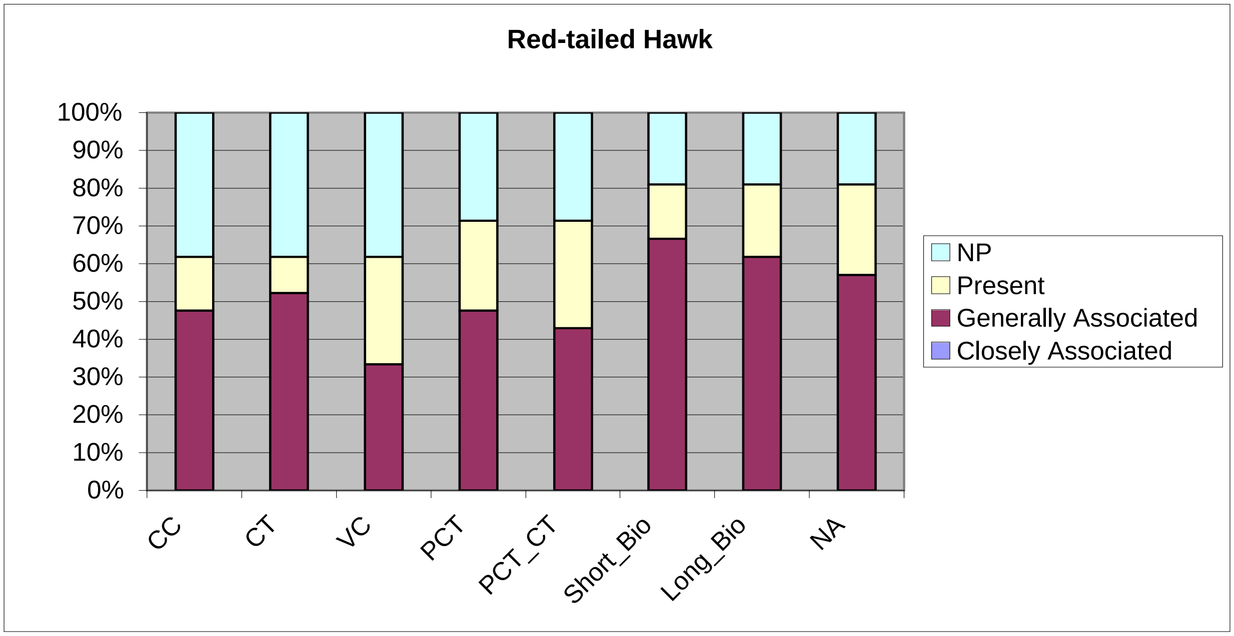

Figure DP4.18: Habitat suitability for the Red-tailed Hawk

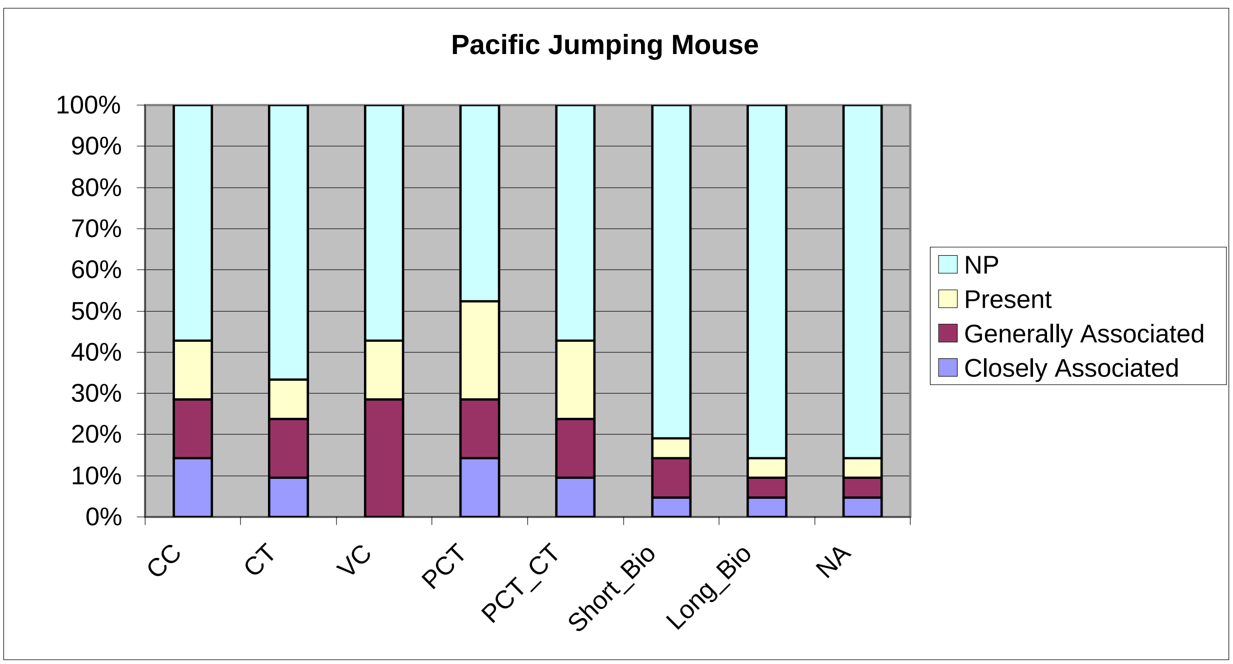

Figure DP4.19: Habitat suitability for the Pacific Jumping Mouse

Uses and Limitations

HEP, HSI, and the ICBEMP WHR matrix models along with the Johnson & O'Neil (2001) WHR matrix approach have been implemented in LMS. Other possibilities for habitat analysis include the California Wildlife Habitat Relationships (CWRH, URL: http://www.dfg.ca.gov/whdab/html/cwhr.html) with forest structures that can be quantified by forest inventory measures. Empirical models can be derived from tree measures, as with the bird population models of Hansen (1995), who generated regression models relating trees per acre in specific diameter classes to bird population. The Washington State Department of Natural

Resources quantified Nesting, Roosting and Foraging (NRF) habitats for the northern spotted owl based on tree and snag measures (WAC 222-16-085).

The models of choice may be dependent upon the region and species of interest and the stage of development of models for species of greatest interest. Appropriate models provide managers and planners with the ability to analyze many alternatives quickly and easily while holding all other assumptions constant. This consistency in assumptions provides uniform comparability between simulations so relative tradeoffs between treatment alternatives can be assessed.

Key limitations are the lack of understory models that are compatible with forest growth models and the need to field verify the habitat models. Many of the available habitat models are theoretical and have not been field verified. Without field verification, outputs from habitat models may be suspect. Understory vegetation is a key component for many wildlife species and associated models. Local understory/overstory relationships can be developed, as in the Satsop Forest project, which derived mean values for understory measures for each forest cover type, but this does increase the cost and complexity of an analysis and restricts it to local use. With these limitations in mind, habitat analysis using habitat models implemented in LMS, or other forest simulation tools, can be very useful to assess habitat availability, risks to habitat, and to communicate the potential tradeoffs among different treatments and management alternatives.

The assessment procedure to target a known structural set of characteristics like old forest structure provides a useful alternative, especially when the species of concern are associated with a decline in old forest structures. The procedure can be used for individual species so long as the target structure is known and as a consequence may be more robust than expert opinion habitat models.

Conclusion

Habitat suitability measures can be linked to tree lists projections responsive to management treatments. The mechanics of linking habit to forest structures is evolving. Statistical tests can be developed when there is a suitable sample of stands that can be considered as a representative target. Some species are very sensitive to different structural aspects and not all species thrive in the same structures. The tradeoffs across species can be complex. Large conifers, snags, downed logs, openings, density are important characteristics for some species. Understory vegetation is most difficult to model and may be limited to local conditions. Managed stands are generally more dense than historic natural stands as a result of commercial management to increase yield. Hemlock stands are more dense and moist than Douglas-fir with the disturbance regime more likely to be wind blowdown than fire. Short rotations generally preclude reaching old forest structure conditions, however thinnings generally improve structure diversity for many species.

The course filter approach can improve habitat aims to maintain a variety of structures and species but as a consequence may be more costly than more targeted approaches. The individual species approach provides sharper targets but complicates reaching multiple objectives.

References:

Bailey, J.D. and J.C. Tappeiner. 1998. Effects of thinning on structural development in 40- to100-year-old Douglas-fir stands in western Oregon. *Forest Ecology and Management* 108:99-113.

Busing, R.T. and S.L. Garman. 2002. Promoting old-growth characteristics and long-term wood production in Douglas-fir forests. *Forest Ecology and Management* 160(1):161-175

Ceder, K.R. 2001. Using Silviculture to Sustain Wildlife Habitat: Assessing Change and Tradeoffs in Forest Habitats Using a habitat Evaluation Procedure Within the Landscape Management System. University of WA. College of Forest Resources. Seattle. WA. 76pp.

Curtis, R.O. 1997. The role of extended rotations. Pages 165-170 in K.A. Kohm and J.F. Franklin, eds. *Creating a forestry for the 21st century*. Island Press, Washington, DC.

Douglas, R. 1993. Unfinished Business. Random House New Zealand Ltd. Auckland, New Zealand

Garman, S.L., J.H. Cissel, and J.H. Mayo. 2003. *Accelerating development of late-successional conditions in young managed Douglas-fir stands: A simulation study*. General Technical Report PNW-GTR-557. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. 57p.

Gehringer, K.R. 2006. Structure-based nonparametric target definition and assessment procedures with an application to riparian forest management. *Forest Ecology and Management* 223(1-3):125-138

Hann, W..J., D.J. Strohm. 2003. Fire regime condition class and associated data for fire and fuels planning: methods and applications. p 337-443. In: Omi, Philip N.; Joyce, Linda A., technical editors. Fire, fuel treatments, and ecological restoration: Conference proceedings; 2002 16-18 April; Fort Collins, CO. Proceedings RMRS-P-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 475 p.

Hansen, A. J., W. C. McComb, et al. (1995). Bird habitat relationships in natural and managed forests in the west Cascades of Oregon. Ecol appl 5(3): 555-569.

Havari, B.A., and A.B. Carey. 2000. Forest management strategy, spatial heterogeneity, and winter birds in Washington. *Wildlife Society Bulletin* 28(3):643-652.

Hayes, J.P., J.M. Weikel, and M.M.P. Huso. 2003. Response of birds to thinning young Douglas fir forests. *Ecological Applications* 13(5):1222-1232.

Johnson, D. H. and T.A. O'Neil. 2001. Wildlife habitat relationships for Washington and Oregon. Oregon State University Press. Corvallis, OR.

Lippke, Bruce R. 1997 . The Role of Economics in Producing Non-Market Forest Amenities. Proceedings of IUFRO 1.14.00: The Uneven-Aged Management Symposium compiled by William Emmingham, Sept. 15-26, 1997, Oregon State University, Corvallis, OR.

Marzluff, J.M., J.J. Millspaugh, K.R. Ceder, C.D. Oliver, J. Withey, J.B. McCarter, C.L. Mason, J. Comnick (2002). "Modeling changes in wildlife habitat and timber revenues in response to forest management" Forest Science 48 (2): pp. 191-202

Mason, C.L., K. Ceder, H. Rogers, T. Bloxton, J. Comnick, B. Lippke, J. McCarter and K. Zobrist. 2003. Investigation of Alternative Strategies for Design, Layout, and Administration of Fuel Removal Projects. Rural Technology Initiative, College of Forest Resources, University of Washington, Seattle. 91p. Available online at: URL: http://www.ruraltech.org/pubs/reports/fuel_removal/

McComb, W.C., T.A. Spies, and W.H. Emmingham. 1993. Douglas-fir forests: Managing for timber and mature-forest habitat. *Journal of Forestry* 91(12): 31-42.

Muir P.S., R.L. Mattingly, J.C. Tappeiner II, J.D. Bailey, W.E. Elliot, J.C. Hagar, J.C. Miller, E.B. Peterson, and E.E. Starkey. 2002. *Managing for biodiversity in young Douglas-fir forests of Western Oregon*. Biological Science Report USGS/BRD/BSR-2002-0006. U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, OR. 76 p.

Oliver, C.D. and B.C. Larson. 1990. *Forest stand dynamics*. McGraw Hill, New York. 419 p.

O'Neil, T. A., K. A. Bettinger, et al. (2001). Structural conditions and habitats of Oregon and Washington. Wildlife-habitat relationships in Oregon and Wasington. D. H. Johnson and T. A. O'Neil. Corvallis OR, Oregon State University Press**:** 115-139.

Suzuki, N. and J.P. Hayes. 2003. Effects of thinning on small mammals in Oregon coastal forests. *Journal of Wildlife Management* 67(2):352-371.

Tappeiner, J.C., D. Huffman, D. Marshall, T.A. Spies, and J.D. Bailey. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. *Canadian Journal of Forest Research* 27:638-648.

USDI. 1980. Habitat evaluation procedures 102 ESM. Washington DC, USDI Fish and Wildlife service.

Wilson, S.M. and A.B. Carey. 2000. Legacy retention versus thinning: influences on small mammals. *Northwest Science* 74(2):131-145.