

Sampling and Modeling Riparian Forest Structure and Riparian Microclimate

Bianca N.I. Eskelson, Paul D. Anderson, and Hailemariam Temesgen

Abstract

Riparian areas are extremely variable and dynamic, and represent some of the most complex terrestrial ecosystems in the world. The high variability within and among riparian areas poses challenges in developing efficient sampling and modeling approaches that accurately quantify riparian forest structure and riparian microclimate. Data from eight stream reaches that are part of the Density Management Study were used in a variety of recent studies that explored sampling and modeling approaches for riparian forest structure and microclimate, and the results are summarized here. When sixteen sampling alternatives were compared based on their performance at accurately estimating the number of conifer trees per hectare, conifer basal area per hectare, and height-to-diameter ratio in headwater stream reaches, rectangular strip-plots outperformed all other plot shapes. Strip-plots oriented perpendicular to the stream generally outperformed strip-plots parallel to the stream. Understory vegetation layers form a critical component of forest ecosystems. Hence, accurate estimation of their attributes (e.g., percent shrub cover) is gaining increasing importance. Percent shrub cover was modeled as a function of distance to stream and canopy leaf area index using techniques that easily accounted for spatial dependence within and among riparian areas. The distinct ecological processes, habitats, and biodiversity of riparian areas are due in part to microclimate characteristics such as air temperature (T_{air}) and relative humidity (RH) that differ from upland forests. Improved sampling designs and predictive models are needed to characterize riparian microclimates and their response to forest management. Height above stream and distance to stream were found to be important covariates in predicting mean maximum T_{air} in riparian areas. For small sample sizes, optimized sample patterns for T_{air} outperformed systematic sample patterns. Mean maximum T_{air} and mean minimum RH are strongly correlated, and mean minimum RH can be modeled as a function of mean maximum T_{air} and other covariates such as height above stream. Mixed effects models can account for within- and among-stream reach variability in RH. Application of these results can improve the quantitative estimates and reduce the costs associated with riparian forest structure and microclimate monitoring efforts.

Keywords: relative humidity, air temperature, shrub cover, mixed effects models, copula models, optimized sampling design.

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Introduction

Riparian forests represent some of the most complex terrestrial ecosystems in the world, play an important role in conserving the vitality of the landscape and its rivers (Naiman and Décamps 1997), and provide special habitats for birds and other terrestrial wildlife species. Suitable riparian forest management strategies and effectiveness monitoring require detailed information about the structure of riparian overstory and understory vegetation and riparian microclimate in order to ensure provision of suitable wildlife habitat, high-quality water, and other ecosystem services. Riparian forests are extremely variable and dynamic. The high variability within and among riparian areas poses challenges in developing sampling and modeling approaches that accurately quantify riparian forest structure and riparian microclimate.

The distribution and species patterns of riparian vegetation are related to local topography (e.g., height above stream channel; Naiman et al. 2005, p. 97). Typically, early-seral species are found close to the stream channel where the environment is characterized by low nutrient and high light levels. Long-lived, shade-tolerant, woody plants are found in greater proportions at higher elevations above the wet stream channel (Naiman et al. 2005, p. 99), resulting in high variability laterally from streams. Sampling methods for quantifying riparian vegetation structure need to account for variation being greater laterally from stream to upslope than along the stream, and for the potential of differences in vegetation structure on opposite sides of the stream (Marquardt et al. 2011).

Temperature, light, wind speed, and moisture are microclimate attributes that influence plant distribution through regeneration, growth, and mortality, as well as wildlife habitat selection. High productivity and species diversity of riparian vegetation have been attributed to favorable interactions of microclimate and moisture close to streams (Naiman et al. 2005, p. 156–158).

Lateral gradients in microclimate with respect to distance from stream have been characterized and tend to be nonlinear, with rates of change being greater close to the stream channel than upslope (Anderson et al. 2007; Olson et al. 2007). However, little work has been done to improve sampling and monitoring approaches for riparian microclimate attributes, and predictive models for microclimate attributes are few although they are needed to characterize riparian microclimates and their response to forest management.

Overstory and understory vegetation data as well as microclimate data collected at eight stream reaches that are part of the Density Management Study (Cissel et al. 2006) were used to explore and advance sampling and modeling approaches for riparian vegetation structure and riparian microclimate. In this manuscript, we provide an overview of the data collected at the eight stream reaches and summarize some of the studies that used the data to examine: 1) sampling methods to quantify overstory structure in riparian areas; 2) riparian shrub cover models; 3) sampling and modeling approaches for air temperature in riparian areas; and 4) modeling and monitoring relative humidity in riparian areas.

Data

Data were collected at eight stream reaches that are part of the Density Management Study (DMS; Cissel et al. 2006). The eight stream reaches are located at four DMS sites: Ten High (TH46, TH75), Bottomline (BL13), OM Hubbard (OM36), and Keel Mountain (KM17, KM18, KM19, KM21) (fig. 1). At each of the eight stream reaches, one square sample plot ($72 \text{ m} \times 72 \text{ m} = 0.518 \text{ ha}$) was randomly located along the stream, running 72 m parallel to the stream and 36 m upslope on each side of the plot center line that ran approximately parallel to the stream (fig. 2). Detailed overstory and understory vegetation data as well as microclimate data were collected in the 0.518-ha plot.

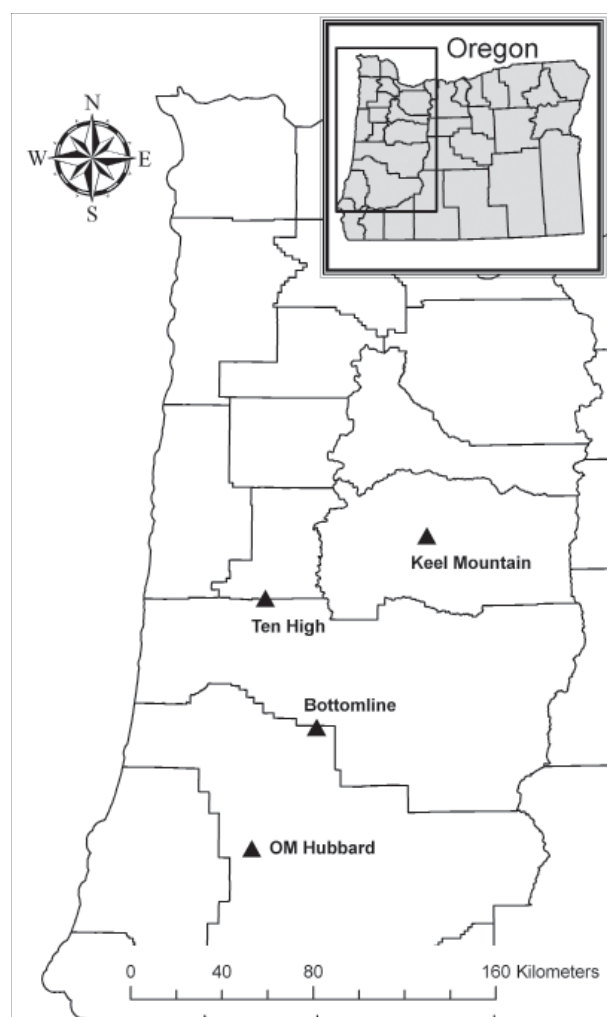
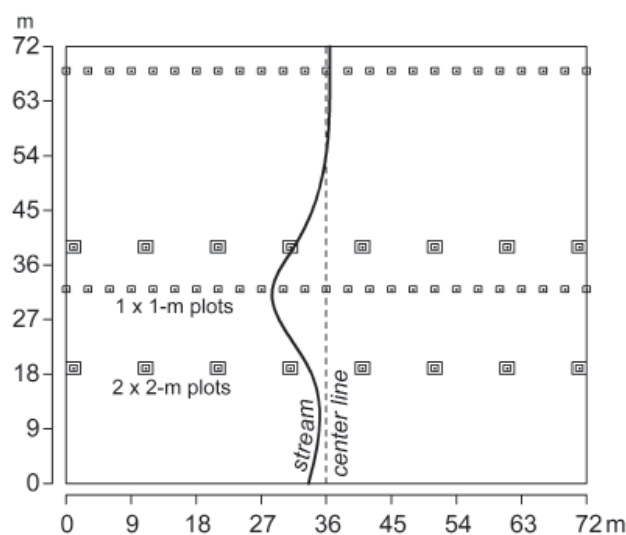


Figure 1—DMS sites where the eight stream reaches used in this study are located.



Vegetation Data

A stem map of all woody stems greater than 6.9 m tall or 7.6 cm diameter at breast height (dbh) was created for each of the 0.518-ha plots. For each mapped tree, dbh, species, condition (alive/dead), and canopy classification (dominant, codominant, intermediate, suppressed) were recorded. For live trees, the crown was classified as “live, full crown,” “partially dead crown,” or “dead crown,” or for trees with more than one crown as “two or more crowns” or “one crown broken off.” Standing dead trees (snags) were classified by size (>30 m with full bole, >30 m without full bole, >15 m and <30 m, >6 m and <15 m, <6 m). At each stream reach, 24 trees (12 on each side of the stream) were subsampled for height, crown diameter, height to crown base, and age (for details see Marquardt et al. 2011).

Information about the understory vegetation by taxonomic class (tree, shrub, fern, and forb) was visually assessed using square plots (1 m x 1 m) every three meters along two transects perpendicular to the stream (at 32 m and 68 m as measured along the center line) and every ten meters along two transects perpendicular to the stream at two random locations (<32 m, >32 m and <68 m; fig. 2). Shrubs were defined as woody vegetation less than 6 m in height. Plants less than one meter in height lacking a woody stem were classified as forbs. Percent cover of low shrubs (<1.4 m), tall shrubs (>1.4 m), forbs, ferns, and seedlings was recorded for each 1-m² plot, as well as the top height of the vegetative layers (to the nearest meter). On the transects with the 10-m spacing, the 1-m² plots were nested within 4-m² plots (2 m x 2 m), on which the present shrub species less than 6 m tall were recorded.

Figure 2—Layout of understory vegetation plots (1 m x 1 m and 2 m x 2 m) with microclimate sensors at plot center used in the modeling studies. Plots are arrayed along transect lines oriented perpendicular to a center line (dashed line) that runs approximately parallel to stream (solid line).

Microclimate Data and Canopy Closure

At the plot center and each corner of the 1-m² vegetation plots, estimates of percent canopy closure, including understory and overstory vegetation above 1-m height, were made using hemispherical detection of canopy light transmittance (plant canopy analyzer, model LAI-2000; LI-COR Biosciences, Lincoln, Nebraska). The five readings were averaged to provide a plot estimate of leaf area index (LAI, m² foliage·m⁻² ground) and the diffuse non-interceptance (DIFN), defined as the proportion of visible sky.

Three-channel humidity and dual-temperature data loggers (models GPSE 101 203 and GPSE 301 203, A.R. Harris Ltd., Christchurch, NZ) were placed at each plot center of the 1-m² vegetation plots to record air temperature, relative humidity, and soil temperature for at least 48 hours (for details see Eskelson et al. 2011a).

Synopsis of riparian structure and microclimate studies

Sampling methods to quantify overstory structure in riparian areas

A simulation study was used to explore the performance of sixteen sampling alternatives to quantify the number of conifer trees per hectare, conifer basal area per hectare, and conifer height-diameter ratio (Marquardt 2010, 2011). Some of these sampling alternatives were designed to capture the variation lateral to the stream (perpendicular strips, alternating perpendicular strips, perpendicular strips on one stream side only), while others were designed to capture the variation parallel to the stream (strips parallel to the stream). As part of the simulation study, circular fixed-area plots were randomly or systematically distributed in the 72-m x 72-m study plot that was stem mapped at each stream reach, and horizontal line sampling (Lynch 2006) and sector sampling (Iles and Smith 2006) were employed. Each of these sampling methods was applied with two plot sizes and two sampling

intensities (10 and 20 percent). The rectangular strip-plots outperformed circular fixed-area plots, horizontal line sampling, and sector sampling in terms of accuracy. Among the rectangular strip-plots, alternating perpendicular strip-plots performed best, followed by perpendicular strips, and parallel strips. Narrower strip-plots tended to be more accurate than wider strip-plots, because a greater number of narrower strips may capture the spatial variability better than fewer wider strips. Alternating perpendicular strip-plots 3.6 m wide performed best among all tested sampling alternatives (fig. 3).

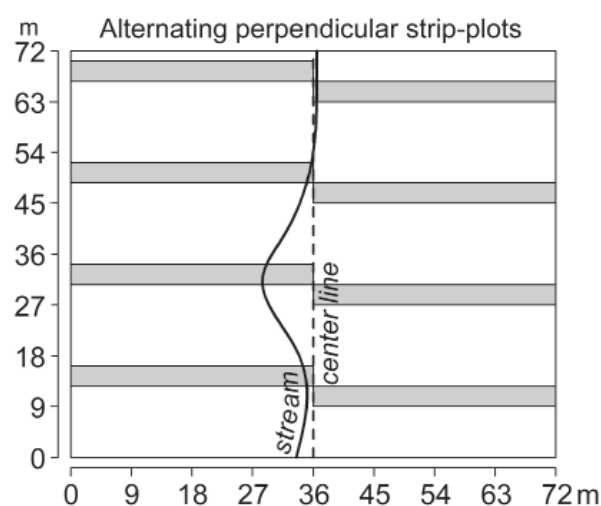


Figure 3—Example of the alternate strip-plot design (20 percent sampling intensity). The center line (dashed) of the 72-m x 72-m block was oriented approximately perpendicular to the stream (solid line).

Although the examined sampling alternatives performed quite well for quantifying conifer density and basal area per hectare in the conifer-dominated stream reaches of the study, the methods were not very accurate when used to quantify hardwood and snag abundance (Marquardt et al. 2012), which were minor components of the overall forest structure (Marquardt 2010).

Extending this work, Haxton (2010) explored the use of n-tree distance sampling to estimate density and basal area at the eight stream reaches. This method, which involves sampling the n trees

nearest a sample point, performed poorly relative to variable-radius and fixed-radius plot methods that provided more accurate estimates of basal area and density, respectively. The n-tree distance method was negatively impacted by the spatially clumped distribution of trees.

Riparian shrub cover models

Understory vegetation layers contain most of the plant biodiversity in temperate forest ecosystems (Halpern and Spies 1995), and are of great importance for wildlife species (Hagar 2007). Ground and shrub cover, as well as canopy closure, also conserve bird species richness (Miller et al. 2003). Accurate estimation of understory vegetation attributes such as percent shrub cover is gaining importance, and predictive models of understory vegetation characteristics are needed (Suchar and Crookston 2010). Eskelson et al. (2011b) modeled riparian shrub cover as a function of topography and overstory vegetation, comparing three different methods: ordinary least squares regression, beta regression, and a copula model. Distance to stream and LAI were the most important explanatory variables in the models. Height above stream and interactions of height above stream and distance to stream with LAI were also significant in the models. The copula model based on the beta distribution accounted for spatial dependence within and among riparian areas. The ordinary least squares regression model resulted in underpredictions of shrub cover, while the beta regression and copula models did not. All models had low explanatory power, which was attributed to shrub cover responding to processes and conditions that occur at a finer scale than the available overstory cover variables.

Sampling and modeling approaches for air temperature in riparian areas

Riparian microclimate characteristics such as air temperature (T_{air}) and relative humidity (RH) differ from microclimate in upland forests and provide the conditions for the distinct ecological

processes, habitats, and biodiversity of riparian areas. Since intensive sampling of microclimate to determine the spatial variation is impractical, we may have to rely on predictive models of microclimate characteristics. Predictive models of T_{air} can be used to characterize riparian microclimates and their response to forest management. Eskelson et al. (2011a) used kriging with external drift for point prediction of mean maximum T_{air} . Height above stream and distance to stream were found to be important covariates in predicting mean maximum T_{air} in riparian areas, with distance to stream outperforming height above stream as a covariate in stream reaches having steeply incised channels. Adding covariates that describe the over- and understory vegetation cover to the model improved the prediction results. The importance of understory and overstory vegetation cover was dependent on the predominant cover type, for example understory vegetation cover variables were more important in stream reaches with little overstory canopy closure.

Microclimate characteristics have typically been collected at set intervals along transects across stream-riparian gradients (Olson et al. 2007). Since the strongest stream effects on T_{air} and RH have been observed within 10 to 15 m of the stream channel (Rykken et al. 2007; Anderson et al. 2007) it has been hypothesized that microclimate sensor density should be increased close to the stream channel. Eskelson et al. (2011a) optimized the sampling patterns for T_{air} within the eight stream reaches using statistical methods that effectively inferred the spatial patterns (a simulated annealing search algorithm in combination with kriging). The performance of sample patterns based on optimization was compared to systematic sample patterns for which the sample points were evenly spread across four transects. The optimized sample patterns outperformed the systematic samples for small sample sizes. The optimized samples tended to have a higher density of sample points on three of the four transects, and points close to the stream

on the remaining transects. This suggests that it may be advantageous to focus microclimate monitoring in riparian areas on a few transects with dense sensor deployment instead of many transects with sparse sensor deployment, and that it is important to deploy sensors close to the stream (fig. 4).

Modeling and monitoring relative humidity in riparian areas

Sensors to sample and monitor RH are more expensive than sensors that measure T_{air} . We have explored the possibility to benefit from the strong correlation between mean maximum T_{air} and mean minimum RH (fig. 5), and modeled RH as a function of T_{air} , height above stream, and DIFN. Mixed effects models accounted for the within- and among-stream-reach variability in RH. Based on a simulation study that examined different subsample sizes of RH, we found that a minimum of three to five subsamples of RH per stream reach seem sufficient for estimating the random effects for localizing the mixed-

effects model (Eskelson et al. 2013). We are currently working on a model that incorporates RH measurements from previous years into the model. Application of these models can greatly reduce the costs associated with microclimate monitoring efforts.

Discussion and Management Considerations

The data set collected at the eight stream reaches that was used for the above studies is very detailed and hence provides unique opportunities to explore and advance sampling and modeling methods for riparian structure and microclimate. Microclimate, understory vegetation cover, and overstory vegetation cover are strongly linked with each other. The ability to adequately quantify under- and overstory vegetation cover is needed to improve microclimate models. However, the presence of understory vegetation is also influenced by the prevailing microclimate conditions that need to be considered, in

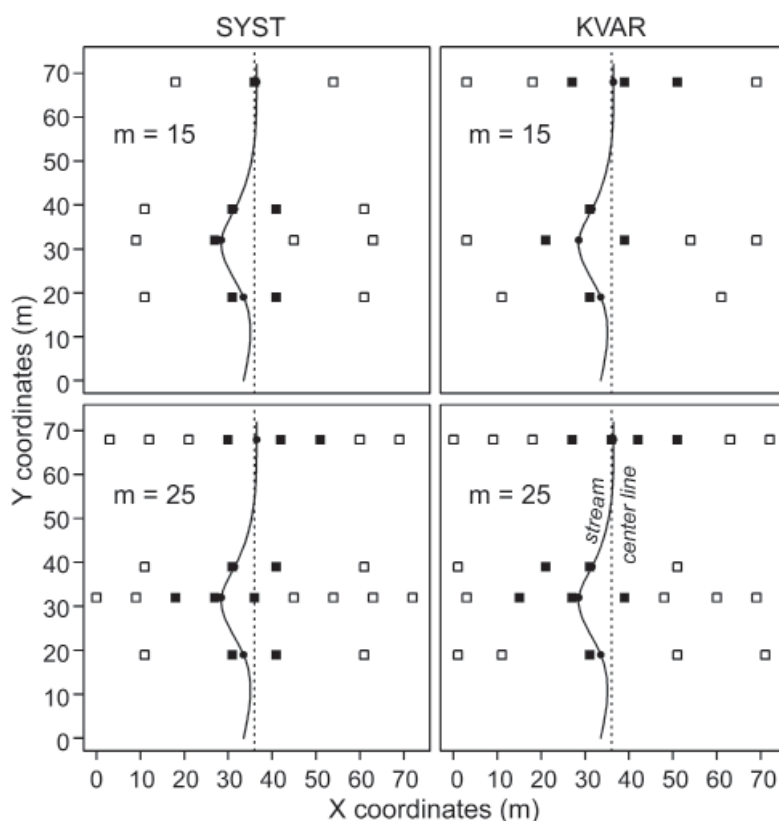


Figure 4—Illustration of optimized sampling designs for characterizing gradients in air temperature in riparian zones based on subsampling from a systematic, gridded array of potential locations (SYST) or from a statistically derived distribution of points that accounts for the inherent spatial correlation (Kriging and estimated variogram, KVAR) at two intensities of sampling—either $m = 15$ or $m = 25$ sample points. Regardless of method or intensity, the optimized sampling designs allocate more sensors to locations close to the stream, and fewer sensors upslope of the stream. Solid square, sample location within 15 m of stream; open square, distance to stream of sample location is greater than 15 m.

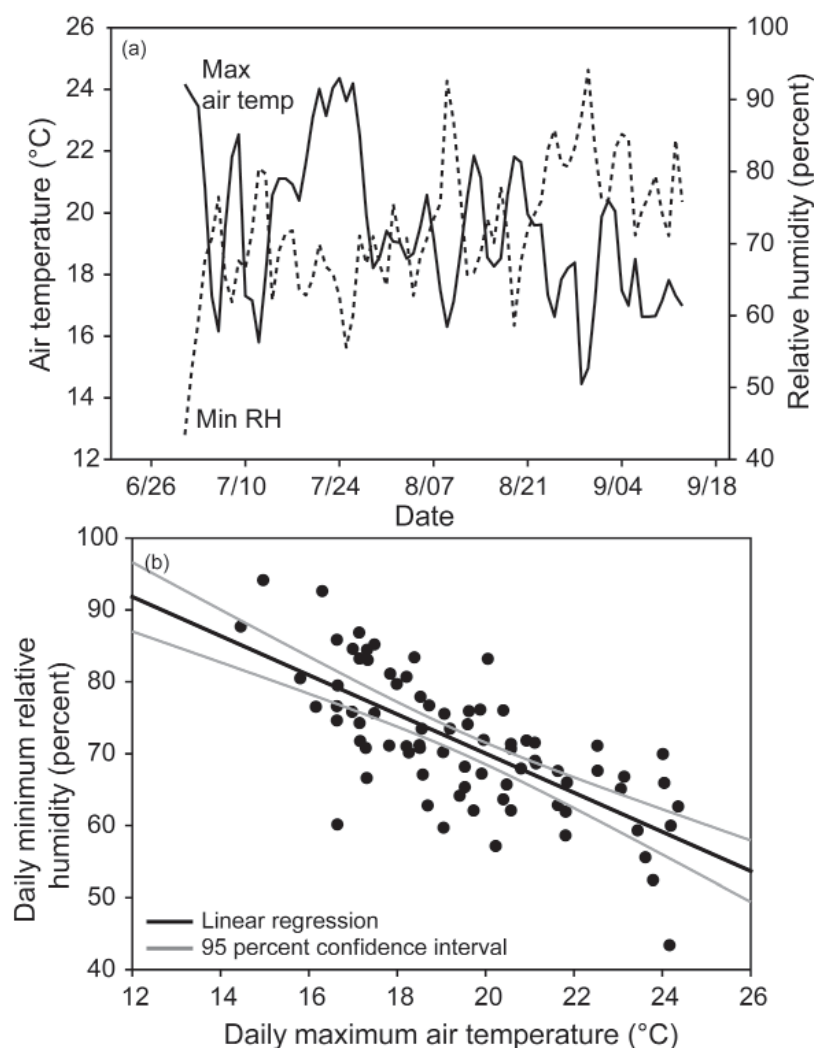


Figure 5—Relationships between summer daily maximum air temperature and daily minimum relative humidity for a stream reach (GP42): a) observed average daily values from July 1 through September 15, 2006; and b) linear regression and 95-percent confidence interval for daily minimum relative humidity versus daily maximum air temperature.

addition to the interactions between understory and overstory vegetation cover. Understanding the intricate linkages among overstory vegetation structure, understory vegetation structure, and microclimate conditions in riparian areas will allow improvement of sampling and modeling approaches.

Stream to upslope gradients of tree species composition and density have been reported (Minore and Weatherly 1994). Sampling methods in riparian areas need to be able to capture this lateral variation. We have demonstrated that alternating, rectangular strip-plots oriented perpendicular to the stream provide the most accurate estimates of conifer density and conifer basal area, and outperformed circular fixed-area plots and strip-plots parallel to the stream

(Marquardt et al. 2011). However, sampling methods that quantify minor components of riparian forests such as hardwood and snag abundance still need further improvement, since the sampling approaches that work well for quantifying abundant conifers are not appropriate to quantify the abundance of rare features such as snags and hardwoods (Marquardt et al. 2012).

Improved models of understory vegetation cover in riparian areas will provide important insights into availability of wildlife habitat and food sources. Similar to the stream-upslope gradients observed for overstory tree composition and density, stream-upslope gradients for understory vegetation have been observed (Pabst and Spies 1998). These gradients can be incorporated into models, by including covariates such as

distance to stream and by accounting for spatial correlation. The poor explanatory power of the shrub-cover models developed by Eskelson et al. (2011b) was attributed to the fact that overstory vegetation variables, which were used as covariates in the models, respond to processes at different scales than understory vegetation cover. Since the variability of soil conditions in riparian zones plays a major role in vegetation colonization and establishment and in determining plant productivity and diversity (Naiman et al. 2005, p. 92–93), variables describing microsite conditions, soil nutrient availability, and soil moisture may be necessary predictors in understory vegetation cover models. It should be investigated whether variables describing microsite conditions can improve the explanatory power of understory vegetation cover models.

Many of the microclimate variables are highly correlated. A good understanding of the relationships among individual microclimate characteristics may allow focusing monitoring efforts on a single variable such as T_{air} with increased sampling intensity. The development of RH models based on T_{air} measurements will greatly reduce microclimate monitoring costs by reducing necessary RH measurements within a stream reach. Developing similar models to predict soil temperature (T_{soil}) as a function of T_{air} will allow further reduction in monitoring costs. However, the correlation between T_{air} and T_{soil} is not as strong as the correlation between T_{air} and RH. Hence, model predictions of T_{soil} are expected to be less accurate than those of RH. Nevertheless, the development of RH and T_{soil} models that incorporate measurement information from previous years are expected to improve efficiency of microclimate monitoring tremendously.

Monitoring riparian forest structure and microclimate for purposes of general habitat or watershed assessment or in relation to specific forest management activities will benefit from sampling protocols that account for the distinct physical and biological attributes and processes

that distinguish riparian areas from adjacent terrestrial environments. Emerging from the research summarized above, we make the following suggestions for consideration by those developing riparian monitoring protocols for conifer-dominated headwater stream reaches:

1. For vegetation characterization, employ strip sampling oriented perpendicular to the stream reaches to capture important gradients from the stream channel through the riparian zone up into the upslope terrestrial zones.
2. For a given intensity of strip sampling (proportion of total area sampled), a greater number of narrow strips per length of sampled reach may provide more accurate estimates than fewer wider strips.
3. If sampling both sides of a reach, alternating the placement of strips on either side of the reach may provide better estimates.
4. Monitor microclimate using transects running lateral to the stream reaches, with the density of sensors being higher close to the stream to capture steep near-stream gradients.
5. If both air temperature and relative humidity are of interest, consider a two-phase sampling design in which relatively inexpensive air temperature measurements are made at a higher intensity (more sample points) and relatively expensive humidity measurements are made at a lower intensity (a subset of points). The strong empirical correlations between air temperature and relative humidity can be used to enhance the estimate of relative humidity when humidity is measured at a subset of the temperature monitoring locations.
6. If important structural elements such as snags or hardwoods occur infrequently or in patchy distribution, they may be estimated using perpendicular strip-plots as previously described, but the precision of estimates is likely to be lower; more precise estimation may require different sampling strategies which remain somewhat poorly defined.

Literature Cited

- Anderson, P.D.; Larson, D.J.; Chan, S.S. 2007. Riparian buffer and density management influences on microclimate of young headwater forests of western Oregon. *Forest Science*. 53: 254–269.
- Cissel, J.H.; Anderson, P.D.; Olson, D.; Puettmann, K.P.; Berryman, S.; Chan, S.S.; Thompson, C. 2006. BLM density management and riparian buffer study: establishment report and study plan. US Geological Survey. Scientific Investigations Report 2006-5087.
- Eskelson, B.N.I.; Anderson, P.D.; Hagar, J.C.; Temesgen, H. 2011a. Geostatistical modeling of riparian forest microclimate and its implications for sampling. *Canadian Journal of Forest Research*. 41: 974–985.
- Eskelson, B.N.I.; Madsen, L.; Hagar, J.C.; Temesgen, H. 2011b. Estimating riparian understory vegetation cover with beta regression and copula models. *Forest Science*. 57: 212–221.
- Eskelson, B.N.I.; Anderson, P.D.; Temesgen, H. 2013. Modeling relative humidity in headwater forests using correlation with air temperature. *Northwest Science*. 87(1): 40–58.
- Hagar, J.C. 2007. Wildlife species associated with non-coniferous vegetation in Pacific Northwest conifer forests: A review. *Forest Ecology and Management*. 246: 108–122.
- Halpern, C.B.; Spies, T.A. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. *Ecological Applications* 5: 913–934.
- Haxton, Z.A. 2010. An examination of several methods of quantifying forest structure in headwater riparian forests of western Oregon. M.S. thesis. Corvallis, OR: Oregon State University.
- Iles, K.; Smith, N.J. 2006. A new type of sample plot that is particularly useful for sampling small clusters of objects. *Forest Science*. 52: 148–154.
- Lynch, T.B. 2006. Horizontal line sampling for riparian forests without land area estimation. *Forest Science*. 52: 119–129.
- Marquardt, T. 2010. Accuracy and suitability of several stand sampling methods in riparian zones. M.S. thesis. Corvallis, OR: Oregon State University.
- Marquardt, T.; Temesgen, H.; Anderson, P.D. 2011. Accuracy and suitability of selected sampling methods within conifer dominated riparian zones. *Forest Ecology and Management*. 260: 313–320.
- Marquardt, T.; Temesgen, H.; Anderson, P.D.; Eskelson, B.N.I. 2012. Evaluation of sampling methods to quantify abundance of hardwoods and snags within conifer-dominated riparian zones. *Annals of Forest Science*. 69: 821–828. DOI 10.1007/s13595-012-0204-5. Published online: 15 May 2012.
- Miller, J.R.; Wiens, J.A.; Hobbs, N.T.; Theobald, D.M. 2003. Effects of human settlement on bird communities in lowland riparian areas of Colorado (USA). *Ecological Applications*. 13: 1041–1059.
- Minore, D.; Weatherly, H.G. 1994. Riparian trees, shrubs, and forest regeneration in the coastal mountains of Oregon. *New Forests*. 8: 249–263.
- Naiman, R.J.; Décamps, H. 1997. The ecology of interfaces-riparian zones. *Annual Review of Ecology and Systematics*. 28: 621–658.
- Naiman, R.J.; Décamps, H.; McClain, M.E. 2005. *Riparia. Ecology, conservation, and management of streamside communities*. Amsterdam: Elsevier Academic Press.
- Olson, D.H.; Anderson, P.D.; Frissell, C.A.; Welsh, H.H., Jr.; Bradford, D.F. 2007. Biodiversity management approaches for stream-riparian areas: perspectives for Pacific Northwest headwater forests, microclimates, and amphibians. *Forest Ecology and Management*. 246: 81–107.
- Rykken, J.J.; Chan, S.S.; Moldenke, A.R. 2007. Headwater riparian microclimate patterns under alternative forest management treatments. *Forest Science*. 53: 270–280.
- Pabst, R.J.; Spies, T.A. 1999. Structure and composition of unmanaged riparian forests in the coastal mountains of Oregon, U.S.A. *Canadian Journal of Forest Research*. 29: 1557–1573.
- Suchar, V.A.; Crookston, N.L. 2010. Understory cover and biomass indices predictions for forest ecosystems of the northwestern United States. *Ecological Indicators*. 10: 602–609.

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