

Predicting the Occurrence of a Rare Mollusk in the Dry Forests of North-central Washington

Abstract

We used information from all of the sites in which Chelan Mountainsnail is known to occur (N=79) to characterize their macro-habitat, distribution, and to develop predictive maps of their likely occurrence. Chelan Mountainsnails were most often located in areas that had >10% tree canopy closure, <1000m in elevation, and on slopes <30°. They were not found on true south-facing slopes and occurred most often in Douglas-fir series forests. This provides the best characterization of their habitat currently available. Our predictive maps showed that 18% of the study area had a high relative probability of Chelan Mountainsnail occurrence, 35% moderate, and 47% low to very low. These results can be used to prioritize areas for surveys and identify locations on the landscape where managers would need to carefully evaluate the effects of management activities on the Chelan Mountainsnail.

Introduction

The Chelan Mountainsnail (*Oreohelix sp.*) is listed on the U.S. Forest Service Region 6 Sensitive Species list and was formerly a Survey and Manage species under the Northwest Forest Plan (USFS 1994). The Chelan Mountainsnail is endemic to the Wenatchee National Forest (WNF) and its known range is believed to be restricted to the dry forest portions of the Entiat and Chelan subbasins, south of Lake Chelan, Washington (Burke et al. 1999). This snail is considered to be a separate species but has not yet been formally described (Frest and Johannes 1993, 1995, Burke 1999). As a result of this species formerly being listed under the Survey and Manage program, pre-disturbance surveys were required following the protocol described in Duncan et al. (2003). These surveys were implemented on portions of the Okanogan and Wenatchee National Forests from 1998 until 2004, when the Survey and Manage program was dissolved (USFS 2004). These surveys resulted in 79 Chelan Mountainsnail locations being identified, a sizeable addition to the 14 sites known as of 1999 (Burke et al. 1999).

When the Chelan Mountainsnail was added to the Region 6 Sensitive Species list (USFS 2004) the conservation of the species was largely transferred to the WNF. Sensitive species requires managers to consider the effects of their activities on habitat, and managers must determine whether

or not species surveys are necessary. There are several challenges that make the conservation of this species particularly difficult including lack of formally published taxonomy, little information on habitat relationships, and unknown effects of management actions (Burke et al. 1999). Our objective was to address one of these information gaps by using information from the sites in which Chelan Mountainsnail is known to occur to quantify their habitat relationships and develop a predictive model that managers can use to guide future survey and conservation efforts.

Study Area

The known range of the Chelan Mountainsnail (Burke et al. 1999) was used to identify our study area (Dunk et al. 2004). All of these sites were located on the Chelan and Entiat Ranger Districts, WNF (Figure 1). We limited our analysis to dry forests because these areas encompassed all of the known Chelan Mountainsnail locations and these broad habitats were identified by Burke et al. (1999) as being associated with this species. Dry forests were identified as the ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and dry grand fir (*Abies grandis*) plant associations (Lillybridge et al. 1995). Elevations ranged from 150 to 1200 m, and average annual moisture ranged from 25-50 cm, falling mostly as snow. Our study area was approximately 115,900 ha in size.

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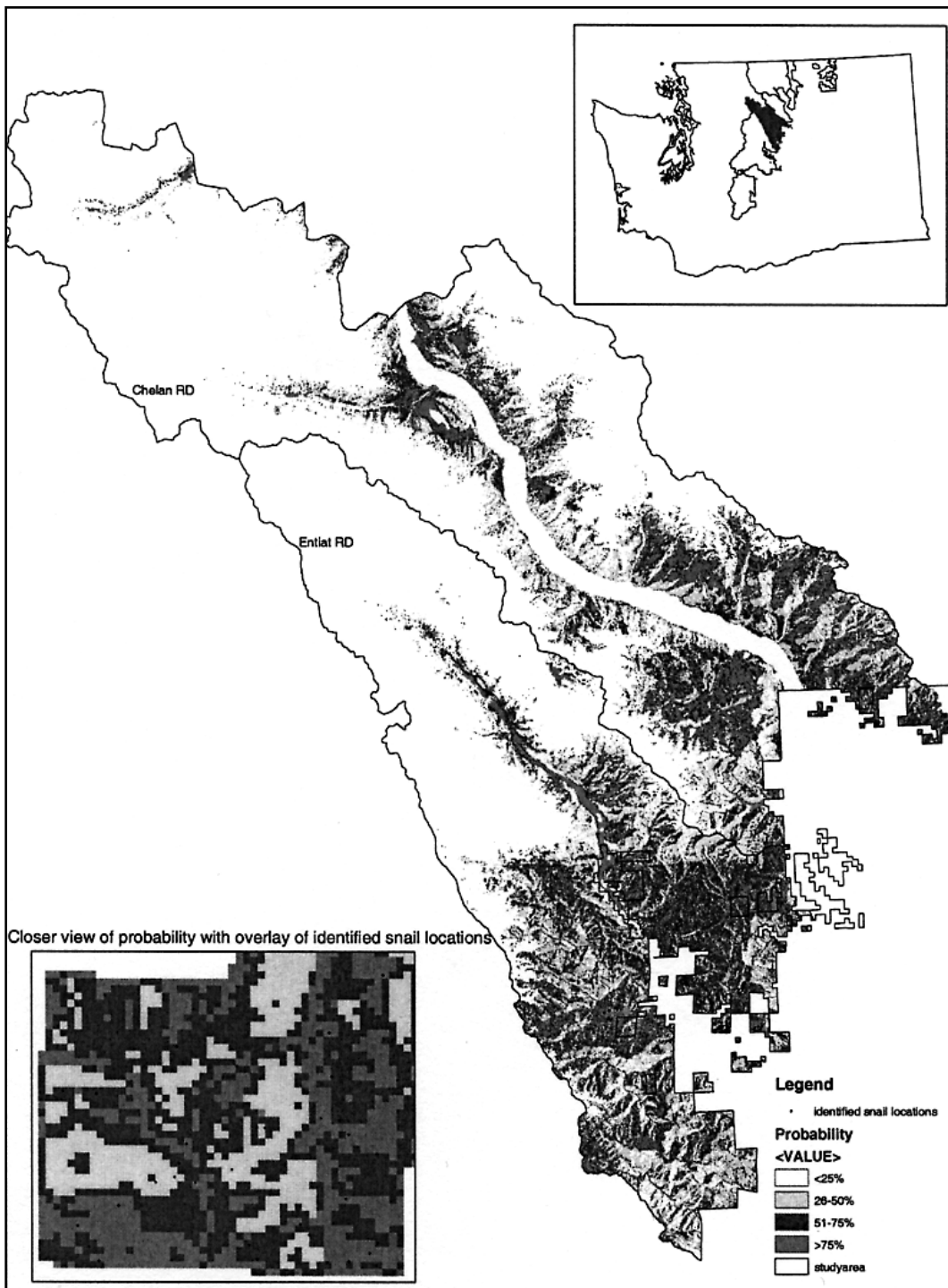


Figure 1. Study area for analysis of Chelan Mountainsnail habitat, Okanogan & Wenatchee National Forests. This map also illustrates the probability of finding a Chelan Mountainsnail within dry forest types on the Chelan and Entiat Districts (based on a logistic regression model developed with variables of aspect, canopy, elevation, and slope).

Methods

Surveys

Surveys for the Chelan Mountainsnail were carried out following the protocol described in Duncan et al. (2003) over large areas (2,000 to 8,000 hectares) that were proposed for dry forest restoration projects. These surveys included time-constrained searches of 60 minutes per 4 ha of survey area. Surveys were conducted during the spring and fall when soil temperature and soil moisture was best to locate mollusks. Fall surveys occurred in late September through October following at least three days of moderate to heavy rains and when the soil was wet to a depth of ≥ 2.5 cm. Surveys continued into the fall until soil temperatures were $< 0^{\circ}\text{C}$. In the spring, surveys generally occurred in late April through mid-June after the snow was melted and the ground was thawed. Soil temperatures were $> 5^{\circ}\text{C}$. Once the top 1.25 cm of soil was dry, or the daytime air temperatures remained above 27°C for three consecutive days, surveys were terminated. Surveys were conducted from 1998 until 2004 covering approximately 6500 ha or 7% of the known range of the Chelan Mountainsnail. Each site where a Chelan Mountainsnail was detected was georeferenced with a GPS.

We used the following characteristics to identify the Chelan Mountainsnail and distinguish it from other similar species (such as *O. strigosa*): < 18 mm in diameter, presence of periostracal fringes, smooth ventral surface, and gritty-appearing dorsal surface. These characteristics were provided to us by regional mollusk experts (T. Frest, pers. comm., Hohenlohe 2003) and were used in combination with the field guide (BLM 1999). In addition to using these characteristics, a single specimen was collected from each site for laboratory iden-

tification by experienced staff on the Okanogan and Wenatchee National Forests and these were reviewed by Regional Mollusk experts from the Survey and Manage program (Dr. P. Hohenlohe), and an independent contractor, Dr. T. Frest, an expert in mollusk taxonomy.

Habitat Modeling

We developed *a priori* models (Anderson and Burnham 2002) of Chelan Mountainsnail habitat based on spatial data that were readily available and that we believed to be associated with Chelan Mountainsnail locations based upon our field observations. These spatial data included vegetation information on tree size classes, tree canopy cover, and Plant Association Group (PAG) (Table 1). In addition, we included digital terrain data for aspect, elevation, and slope (Table 1).

We modeled habitat for the Chelan Mountainsnail using a binary logistic regression of habitat variables at the 79 sites of known occurrence vs. habitat variables at 157 random points within the study area. The 157 random points were used to assess habitat availability within the study area for comparison with the sites of known Chelan Mountainsnail occurrence. We used a general guideline of at least $n=10$ per each variable in the model (T. Max, pers. comm.). Since our sample size of known Chelan Mountainsnail occurrences was $n=79$, we limited the number of variables in our model to eight.

After determining a set of potential variables (tree size, aspect, canopy, elevation, PAG, slope), we identified 12 *a priori* binary logistic regression models of Chelan Mountainsnail habitat. We performed our analyses using SAS Enterprise Guide, V.3.0.1.396 (SAS Institute, Inc. 2004). We evaluated each of the models separately using the

TABLE 1. Variables and GIS layers used to develop habitat and predictive models for the Chelan Mountainsnail.

Variable Name	Description	Type
Tree size	Size classes of trees within the stand	Continuous
Aspect	Aspect (degrees)	Continuous
Canopy Cover	Canopy cover of forested stands (%)	Continuous
Elevation	Elevation (feet)	Continuous
Plant Association Group (PAG)	Included Plant Associations in: Shrub Steppe Ponderosa Pine Series Douglas-fir Series Grand Fire Series	Categorical
Slope	Slope (degrees)	Continuous

“Enter” method, where all variables are entered in a single step, regardless of their influence on the model. We applied Akaike’s Information Criterion (Anderson et al. 2001, Burnham and Anderson 2002), adjusted for small sample sizes (AIC_c), to determine which of the models best approximated the structure of our dataset.

As suggested by Burnham and Anderson (2002:168), we also calculated the relative importance of each model variable (sum of the Akaike weights (w_i) for each model where the variable of interest is present). Those variables with the largest total Akaike weights are considered most important.

To test the stability of our selected model, we ran the “best” model ($\Delta_i = 0$) through a jackknife cross-validation procedure (Dunk et al. 2004). We removed 10 randomly chosen data points from the dataset and ran the new dataset through the selected model, repeating this procedure 10 times. We were looking for differences in fitted functions between those from the cross-validation and those from the entire data set. Large differences would indicate models that were not stable and not useful for prediction in new areas (Dunk et al. 2004).

We used the model with the lowest Δ_i score to map the relative probabilities of detecting a Chelan Mountainsnail. We used GIS to classify each 30 x 30 m pixel into one of the following relative probability classes based on its combination of habitat attributes: very low probability (<25%),

low probability (25-50%), moderate probability (51-75%), and high probability (>75%).

Results

Logistic regression results showed a combination of variables were important in describing Chelan Mountainsnail habitat (Table 2) and resulted in two models that best described our dataset. Evidence ratios for the other models were generally exponentially greater than the chosen models.

Model #11 was the most parsimonious model (Table 2). The second best model, Model #10, also had substantial empirical support. Both models contained the variables of aspect, canopy cover, elevation, and slope. Model #10 also contained the tree size variable, however, Model #11 was marginally better than Model #10, based on AIC_c weights. All variables in each of the top ranked models were relatively important ($\sum w_i \approx 1$) with the exception of tree size. Tree size was only moderately important ($\sum w_i = 0.49$).

Canopy cover was an important variable in Model #11 and had a positive ($\beta = 0.0165$) relationship with Chelan Mountainsnail habitat (Table 3). Snails were generally located in areas with >10% canopy cover (Fig. 3). Aspect was included in the model, and Chelan Mountainsnails occurred on fewer sites on south facing slopes compared to available in the study area (Fig. 2). Elevation ($\beta = -0.0006$) and slope ($\beta = -0.0847$) both had a negative relationship, showing snails were located

TABLE 2. The linear models used to describe Chelan Mountainsnail habitat on the Okanogan and Wenatchee National Forests. We used Akaike’s Information Criteria (AIC_c), adjusted for small sample sizes, to determine the best models given the available data structure. Models are ranked in this list according to the Δ_i value. Plant Association Group (PAG) was not included in more than one model due to a quasi-complete separation of data points. In all models, sample size $n = 79$ (used) and $n = 157$ (available).

Model #	Model Variables	AIC_c	Δ_i
11	Aspect + Canopy Cover + Elevation + Slope	263.1	0
10	Treesize + Aspect + Canopy Cover + Elevation + Slope	264.1	1.1
12	Aspect + Canopy Cover + Elevation + Slope + Canopy Cover*Treesize	265.2	2.2
3	PAG	278.2	15
9	Treesize + Aspect + Canopy Cover + Elevation	284.1	21
8	Treesize + Aspect + Canopy Cover	289.9	27
6	Slope	291.9	29
4	Canopy Cover	292.4	29
2	Aspect	297.1	34
5	Elevation	297.6	35
7	Treesize + Aspect	298.7	36
1	Treesize	307.2	44

TABLE 3. Values of β , SE, P , and confidence intervals for influential habitat variables in the top-ranked model for Chelan Mountainsnails within the Chelan-Entiat study area on the Okanogan and Wenatchee National Forests.

Covariate	$\beta \pm SE$	P	95% Confidence Interval for β
Aspect	0.00326 \pm 0.00145	0.02	0.00004, 0.0061
Canopy Cover	0.0165 \pm 0.00475	0.0005	0.0072, 0.0258
Elevation	-0.00056 \pm 0.00173	0.001	-0.0009, -0.0002
Slope	-0.0847 \pm 0.02	<0.0001	-0.1238, -0.0456

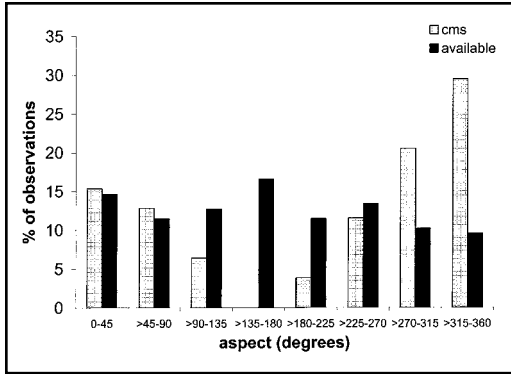


Figure 2. The aspect associated with 79 known Chelan Mountainsnail locations compared to 157 random points in the Chelan-Entiat Study Area, WA.

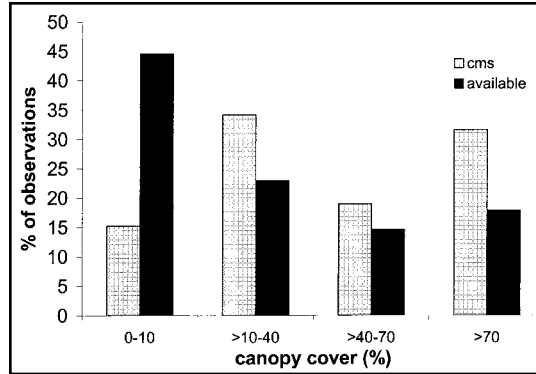


Figure 3. The canopy cover associated with 79 known Chelan Mountainsnail locations compared to 157 random points in the Chelan-Entiat Study Area, WA.

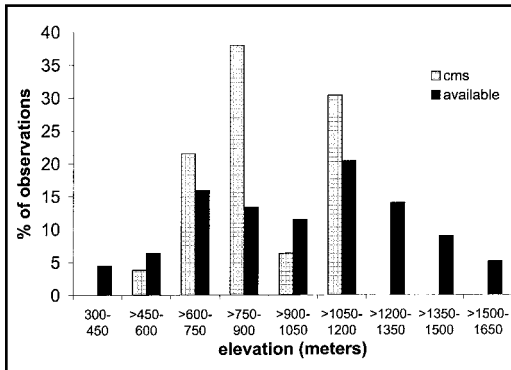


Figure 4. The elevations of 79 known Chelan Mountainsnail locations compared 157 random points in the Chelan-Entiat Study Area, WA.

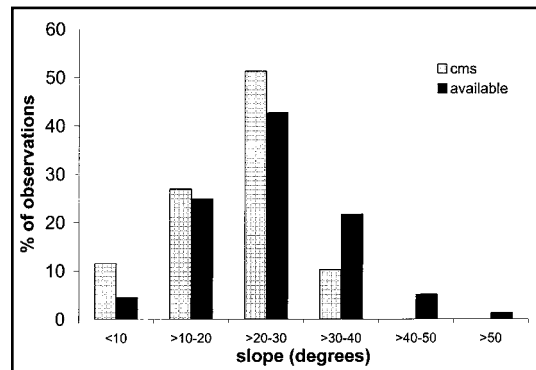


Figure 5. The slope associated with 79 known Chelan Mountainsnail locations compared to 157 random points in the Chelan-Entiat Study Area, WA.

on less steep, lower elevation slopes relative to available (Fig. 4 and 5). No snails were found at elevations >1200 m or on slopes >40°. Plant association group (PAG) was not included in more than one model due to a quasi-complete separation of data points. Snails were found primarily in Douglas-fir plant association groups.

The cross-validation of Model #11 suggested the model was stable. The maximum likelihood estimates for the four variables (aspect, canopy,

elevation, and slope) varied little and the resulting cross-validation AIC_c scores were all less than the AIC_c score for the original model (Table 4). These results indicate that this model should be useful in predicting the occurrence of the Chelan Mountainsnail.

Using the results from Model #11, we created a predictive map and intersected the known snail locations to examine the proportion that fell into each category. The highest proportion (44%) of

TABLE 4. Results of 10-fold cross-validation of the top-ranked model for Chelan Mountainsnails within the Chelan-Entiat study area on the Okanogan and Wenatchee National Forests. Range of Maximum Likelihood Estimate values and AIC_c scores for 10 cross-validation runs and the original model are presented.

Model	Maximum Likelihood Estimate (range)				AIC _c
	Aspect	Canopy Cover	Elevation	Slope	
Cross-Validation	0.0026–0.0035	0.0138–0.0186	-0.0005–0.0006	-0.0780–0.092	227.9–246.8
Model #11	0.0033	0.0165	-0.0006	-0.085	263.05

the locations in which Chelan Mountainsnail are known to be present were in the high probability category, 42% were in the moderate probability category, 14% were in the low probability category, and no known locations fell in the very low probability category. The proportion of the study area that fell within each of these categories was: 18% in the high, 35% in the moderate, 33% in the low, and 14% in the very low.

Discussion

There is precedent and value for developing exploratory models based on few animal locations, however, the accuracy of predicting species' distributions generally improves with increasing sample sizes (Pearce and Ferrier 2000). We concur with the conclusions of Dunk et al. (2004) that probability based approaches for evaluating habitat of rare species with small ranges can provide extremely useful information for managers. Our analyses included all of the known locations of the Chelan Mountainsnail. Because we sampled over a relatively large portion of this species' limited range, we likely accounted for a broader spectrum of habitat conditions associated with this species. Thus, we believe our results provide useful information for managers to consider when developing conservation strategies for this species. For example, our predictive model and probability maps could be used to focus limited survey resources on areas that have the highest probability of detecting the Chelan Mountainsnail. Our analysis showed that Chelan Mountainsnail sites were most often found in areas that had >10% tree canopy closure, <1000 m in elevation, and on slopes <30°. They were not found on true

south-facing slopes. In addition, they occurred most often in Douglas-fir series forests. This provides the best characterization of their habitat currently available.

As with other Survey and Manage species, the Chelan Mountainsnail was presumed to be associated with late-successional forests (Burke et al. 1999). While we did find an association with increasing canopy closure, we did not find a relationship with tree size, which is often used as a proxy for late-successional forest characteristics (USDA and USDI 2001). Thus, at the broad scale of our analysis, it remains inconclusive as to how highly associated this species is with late-successional forests. We suggest a fine-scale assessment would be more appropriate to test this assumption.

While our results can be used to identify sites in which management activities should be evaluated for their effects on the Chelan Mountainsnail, the broad scale of our analysis makes it difficult to draw inferences about how management actions might affect this species. An experimental design with careful monitoring of different management actions represents the next logical step in determining the appropriate conservation strategy for the Chelan Mountainsnail.

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Literature Cited

- Anderson, D.R., and K.P. Burnham. 2002. Avoiding pitfalls when using information-theoretic methods. *Journal of Wildlife Management* 66(3):912-918.
- Anderson, D.R., W.A. Link, D.K. Johnson, and K.P. Burnham. 2001. Suggestions for presenting the results

of data analysis. *Journal of Wildlife Management* 65:373-378.

- Bureau of Land Management (BLM). 1999. Field guide to Survey and Manage terrestrial mollusk species from the Northwest Forest Plan. USDI, Bureau of Land Management, Oregon State Office, Portland, Oregon. 114p.

- Burke, T.E., J.S. Applegarth, and T.R. Weasma. 1999. Management recommendations for Survey and Manage terrestrial mollusks. USDA Forest Service, Pacific Northwest Region, Portland, Oregon.
- Burnham, K.P., and D.R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Second Edition. Springer-Verlag, New York, USA.
- Duncan, N., T. Burke, S. Dowlan, and P. Hohenlohe. 2003. Survey protocol for Survey and Manage terrestrial mollusk species from the Northwest Forest Plan. USDA Forest Service, Pacific Northwest Region, Portland, Oregon.
- Dunk, J.R., W.J. Zielinski, and H.K. Preisler. 2004. Predicting the occurrence of rare mollusks in northern California forests. *Ecological Applications* 14(3):713-729.
- Frest, T.J., and E.J. Johannes. 1995. Mollusk species of special concern within the range of the northern spotted owl. Deixis Consultants, Seattle, Washington.
- Frest, T.J., and E.J. Johannes. 1993. Interior Columbia Basin mollusk species of special concern. Deixis Consultants, Seattle, Washington.
- Hohenlohe, P. 2003. Identification of Survey and Manage mollusk. Unpublished report on file at USDA Forest Service, Region 6, Portland, Oregon.
- Lillybridge, T.R., B.L. Kovalchik, C.K. Williams, and B.G. Smith. 1995. Field guide for forested plant associations of the Wenatchee National Forest. USDA Forest Service, PNW-GTR-359.
- Pearce, J., and S. Ferrier. 2000. An evaluation of alternative algorithms for fitting species distribution models using logistic regression. *Ecological Modeling* 128:127-147.
- USDA Forest Service (USFS). 2004. Record of Decision to remove or modify the Survey and Manage mitigation measure standards and guidelines. USDA Forest Service, Pacific Northwest Region, Portland, Oregon.
- USDA Forest Service (USFS). 1994. Record of Decision: Northwest Forest Plan. USDA Forest Service, Pacific Northwest Region, Portland, Oregon.
- USDA Forest Service and USDI Bureau of Land Management. 2001. Standards and guidelines for Survey and Manage, certain cavity-nesting birds, Canada lynx, and some bat roosts, and management recommendations for certain cavity-nesting birds and some bat roosts. USDA Forest Service and USDI Bureau of Land Management, Portland, Oregon.

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