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Habitat Classification Models for Beaver (*Castor canadensis*) in the Streams of the Central Oregon Coast Range

Abstract

During 1988-1989, 22 stream habitat attributes were measured and compared between 40 beaver-dam sites and 72 unoccupied-stream sites to identify attributes associated with dam-site selection by beaver (*Castor canadensis*) in streams of the Drift Creek Basin, Lincoln County, Oregon. Beaver built dams in areas with wide valley-floors; narrow, low gradient streams; high grass/sedge cover; and low red alder (*Alnus rubra*) and shrub cover. Unoccupied sites lacked these characteristics. A discriminant function model correctly classified 83% of beaver-dam sites and 88% of unoccupied-stream sites with a chance-corrected classification rate of 69% (Cohen's *Kappa* statistic). We used 3 geomorphic attributes (stream width, gradient, and valley floor width) and developed a new Habitat Suitability Index (HSI) model for the basin. Land managers can use the discriminant function model or the HSI model to inventory potential beaver-dam sites along streams of the Oregon Coast Range. Information obtained from our habitat classification models can be incorporated into plans to preserve unique riparian habitats maintained by beaver.

Introduction

Over 60 million beaver (*Castor canadensis*) are estimated to have inhabited rivers, streams, and lakes of North America (Seton 1929). Prior to settlement by Europeans, drainage systems, which supported these large beaver populations, were characterized by having multiple main channels braided with numerous small side channels and sloughs (Sedell and Froggatt 1984). Following settlement, fur trappers exploited beaver populations to near extinction by 1900 (Anderson 1964). Subsequently, human activities drastically altered the ecological characteristics of streams and rivers. Stream cleanings removed in-stream structures, such as large woody debris and boulders, from channels to secure navigation on rivers and simplified complex channel structures (Sedell and Froggatt 1984). As a result, many small side-channels and sloughs, which once were occupied by numerous beaver colonies, have disappeared from large streams and rivers (Sedell and Froggatt 1984). In recent years, population management and reintroduction efforts have brought beaver populations back to 6-12 million individuals in North America (Anderson 1964, Brayton 1984, Apple 1985, Naiman et al. 1988). Characteristics of stream geomorphology and hydrology, and the distribution of suitable beaver habitats in the modern drainage systems, have become quite different from those in the pre-settlement systems. In mountain streams of the Oregon Coast Range, beaver dams are now more commonly found in small, lower-order tributaries than in large channels within the drainage systems. A recent estimate indicates that there are approximately 70,000 beaver in Oregon of which half occur in these coastal streams (Guthrie and Sedell 1988).

To evaluate habitat suitability for beaver, various habitat classification models have been developed (Slough and Sadleir 1977, Allen 1983, Howard and Larson 1985, Beier and Barrett 1987). Among these models, the U.S. Fish and Wildlife Service developed a Habitat Suitability Index (HSI) model that was potentially applicable throughout the range of the beaver (Allen 1983). Despite its wide geographical scope, the U.S. Fish and Wildlife HSI model was not sensitive enough to accommodate variability in local conditions of the Oregon Coast Range, and it classified an unusually high proportion (78%) of beaver-unoccupied sites as optimal habitats (Suzuki 1992).

To our knowledge, no habitat classification models have been developed for the streams of the Oregon Coast Range, and none of the existing models are applicable in the region. Our objectives were: 1) to describe the distribution and abundance of beaver dams in the Drift Creek Basin of the Oregon Coast Range, 2) to describe habitat variables associated with beaver dams in the basin, and 3) to develop habitat classification models for beaver that identify stream reaches potentially suitable for beaver dam sites within the basin.

Study Area and Methods

The Drift Creek Basin is located in the western slope of the central Oregon Coast Range, Lincoln County, Oregon (Figure 1). Drift Creek and its tributaries drain 179 km^2 in area, and elevation of the drainage ranges from sea level to 860 m. Red alder (*Alnus rubra*) and Douglas-fir (*Pseudotsuga menziesii*) were the most common tree species found throughout the area. Other tree species included western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and bigleaf maple (*Acer macrophyllum*). Salmonberry (*Rubus spectabilis*) was the dominant understory-shrub species. Other understory vegetation included vine maple (*A. circinatum*), elderberry (*Sambucus racemosa*), thimbleberry (*R. parviflorus*), stinking currant (*Ribes bracteosm*), California hazel (*Corylus cornuta*), huckleberry (*Vaccinium parvifolium*), devil's-club (*Oplopanax horridum*), western swordfern (*Polystichum munitum*), sedges (*Carex* spp.), and various forbs and grasses.

In the fall of 1988 and 1989, we surveyed streams of the Drift Creek Basin on foot and located beaver dams on topographic maps (scale 1:24000). Surveys conducted by fisheries scientists

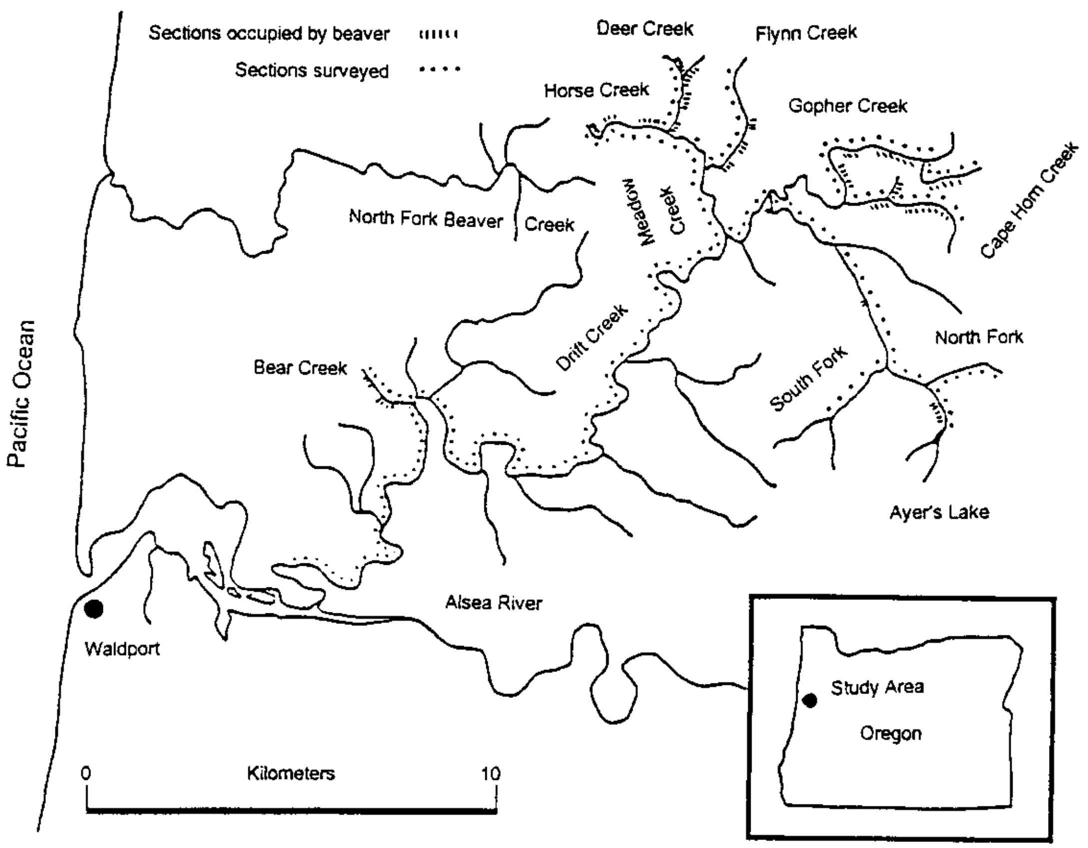

Figure 1. Location of the Drift Creek Basin and map showing the stream section surveyed and the stream section occupied by beaver, Lincoln County, Oregon, 1988-1989.

in the summer of 1988 and 1989 provided additional locations of beaver dams and measurements of channel geomorphology in other streams in the basin (Schwartz 1991). Based on beaver dam locations, each stream was divided into beaver-occupied and beaver-unoccupied sections (Figure 1). Beaver-occupied sections were characterized by presence of dams and ponds that were actively maintained by beavers. Unoccupied sections were stream sections without beaver dams; however, these sections might be occupied by bank-dwelling beavers.

We conducted a habitat survey at 40 randomly selected beaver dam sites within the beaver-occupied sections and 72 randomly selected points within the beaver-unoccupied sections of streams. Because very few dams were found on the 4th-order and 5th-order sections of Drift Creek, all sampling points for habitat survey were selected in 1st- to 3rd-order streams. Twenty-two variables, which represent channel geomorphology, cover by vegetative layers, and cover by shrubs and tree species, were measured during the survey (Table 2, Suzuki 1992). We measured stream width and valley-floor width with a meter tape and stream depth with a measuring stick. Measurements of stream width and depth reflected the bank-full dimensions of channels. At each beaver dam-site, stream width and depth were measured at a point immediately downstream from the dam. Thus, the measurement reflected the original channel characteristics. Valley-floor width was measured to reflect the width of a 100-year flood plain. Stream gradient was measured by sighting a clinometer over the distance of 20-m upstream and 20-m downstream from a sampling point, and the average gradient was calculated for each site. We used a clinometer and measured the angle of bank slope over the distance of 20 m upslope from the channel center. The average slope of banks on both sides of the stream was calculated for each site. Vegetative variables were ocularly estimated within a 20-m radius plot and within a nested 10-m radius plot. These plots were centered on a randomly assigned stream bank. Percent cover of trees and shrubs was estimated within the 20-m radius plot, and percent cover of herbaceous vegetation (grass/sedge, forb, and fern) was estimated within a nested 10-m radius plot.

Habitat variables were examined for normality by normal-probability plot and *W*, the Shapiro-Wilk statistic (SAS Institute Inc. 1990:627). Logarithmic and square root transformations were attempted on all non-normal variables. Either original or transformed variables with near normal distributions were compared between dam sites and unoccupied sites with Student's *t*-tests (SAS Institute Inc. 1989:1633). Non-normal variables, which could not be transformed ($W < 0.7$), were compared between dam sites and unoccupied sites with Wilcoxon rank-sum tests (SAS Institute Inc. 1989:1198).

We used stepwise discriminant analysis to select a combination of variables which best separated dam sites from unoccupied sites (SAS Institute Inc. 1989:1493). The variable selection did not rely on the results of the *t*-tests. Linear correlations between all possible pairs of the variables were examined with Pearson's correlation coefficient (Devore and Peck 1986:113). Multicollinearity among the variables was reduced by testing correlated variables ($r > 0.6$) separately in a stepwise discriminant analysis. All possible combinations of these variables were tested. Linear discriminant function analysis, using the selected combination of variables, was used to develop a habitat classification model (SAS Institute Inc. 1989:45). The linear combination of variables that maximized the correct classification level with a linear discriminant function analysis was chosen as a final classification model.

We developed a new Habitat Suitability Index (HSI) model for beaver in the Drift Creek Basin using variables that the discriminant function analysis identified as potentially important in distinguishing between dam-sites and unoccupied sites. Using relative frequency distribution of beaver dams over the gradient of each habitat variable (Figure 2), we adjusted values of all the indices to meet characteristics of the stream habitat used by beaver in the basin.

Results

Density and Distribution of Beaver Dams

The stream survey covering 65 km of Drift Creek and its tributaries found 170 beaver dams of which 166 dams (98%) were found in 1st- to 3rd-order streams (map scale 1:24000). Only 4 dams (2%) were found in the 4th-order section, and none were found in 5th-order section of Drift Creek. Average stream widths increased from 1st-order tributaries to the 5th-order main stem of the Drift Creek while average stream gradients decreased (Table 1). Dam

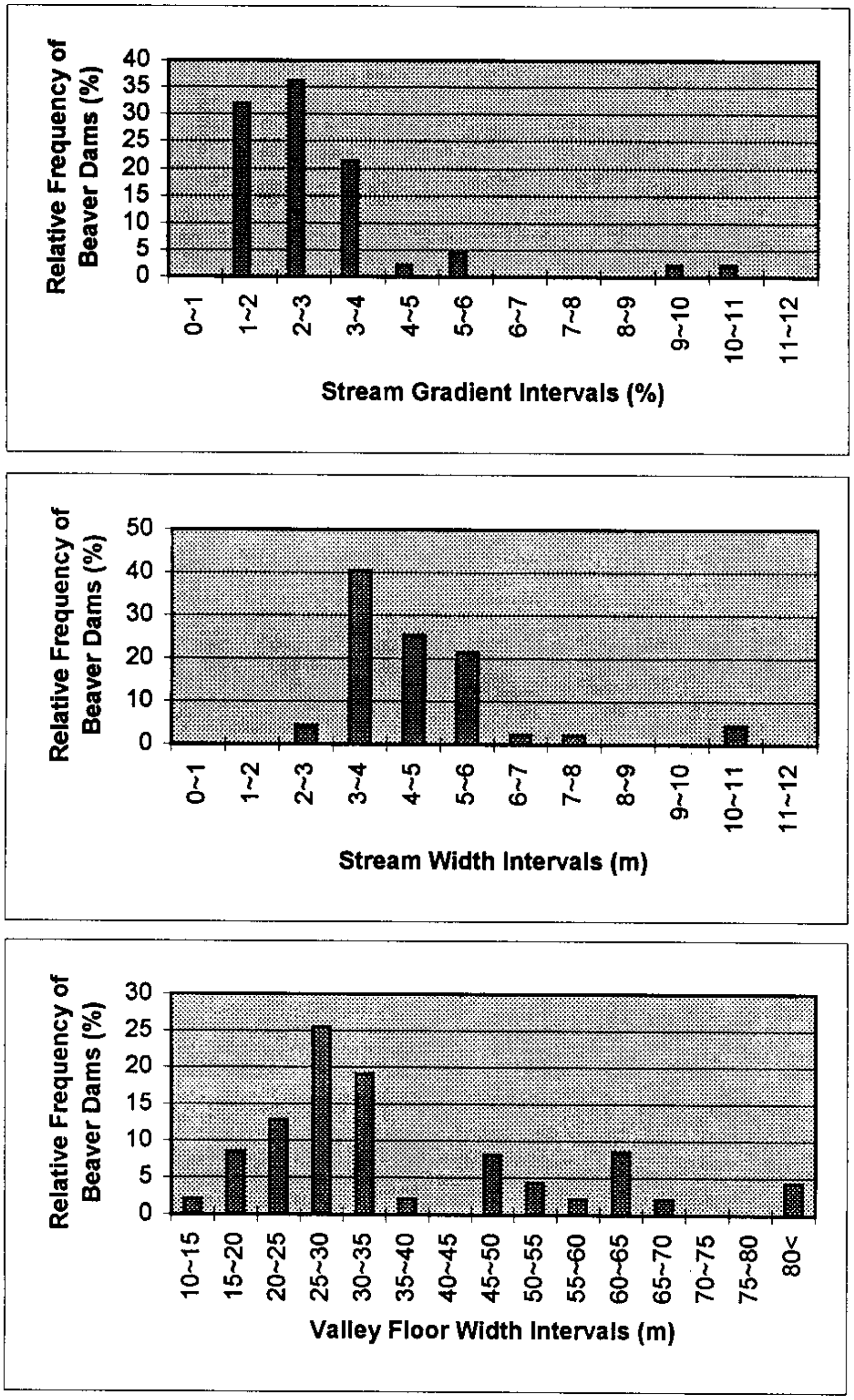

Figure 2. Relative frequency of beaver dams at different stream gradients, stream widths, and valley-floor widths in the Drift Creek Basin, Lincoln County, Oregon, 1988-1989.

density was high in 1st-order and 2nd-order streams and decreased in 3rd-order streams and 4th-order streams (Table 1). The overall dam density was 2.6 dams/km.

TABLE 1. Comparison of mean (SE) stream widths and stream gradients, and beaver dam density among streams with different orders, Drift Creek Basin, Lincoln County, Oregon, 1988-1989.

Stream order[1]	Width (m)	Gradient (%)	Dams/km
1st	3.7(0.1)	3.0(0.3)	4.2
2nd	4.6(0.1)	3.0(0.3)	4.5
3rd	6.2(0.2)	1.3(0.1)	1.5
4th	14.2(0.2)	1.2(0.1)	0.5
5th	26.3(0.3)	0.7(0.1)	0.0

[1]The stream order was determined from the U.S. Geological Survey topographic map (scale 1:24000).

Comparison of Habitat Variables

Percent cover of California hazel, thimbleberry, and huckleberry could not be transformed to attain normal distributions. None of these three variables were different between dam sites and unoccupied-stream sites with Wilcoxon rank-sum tests (Table 2). We were able to test 19 normally-distributed variables with Student's t-tests. Stream gradient and bank slope were lower at dam sites and the valley floor width was wider at dam sites than at unoccupied-stream sites (Table 2). Beaver-dam sites had higher percent cover by forbs and grasses/sedges and had lower percent cover by ferns, shrubs, midstory trees, and total tree canopy than unoccupied-stream sites. Red alder, salmonberry, and stinking currant cover were lower at dam sites than at unoccupied sites. Elderberry cover was higher at dam sites than at unoccupied-stream sites.

Discriminant Analysis

Strong correlations were found between stream width and depth ($r = +0.60$), valley floor width and bank slope ($r = -0.70$), shrub cover and salmonberry cover ($r = +0.70$), and tree-canopy cover and red alder cover ($r = +0.92$). Correlated variables were tested separately in discriminant analyses. Other variables included in the discriminant analysis were forb cover, fern cover, grass/sedge cover, and Douglas-fir cover.

Three untransformed geomorphic variables (stream width, stream gradient, and valley floor width) and 3 untransformed vegetative variables (total shrub cover, grass/sedge cover, and red alder cover) best separated dam sites from unoccupied sites (Table 3). Increasing valley floor width and grass/sedge cover, and decreasing stream width, stream gradient, red alder cover, and shrub cover were positively associated with dam sites. The model correctly classified 83% of beaver-dam sites and 88% of unoccupied stream sites with the chance-corrected classification rate (Cohen's *Kappa* statistic) of 69% (Titus et al. 1984). The linear discriminant function model was:

$$\begin{aligned} DF = &+ 0.069 * (\text{valley floor width [m]}) \\ &- 0.364 * (\text{stream gradient [\%]}) \\ &- 0.545 * (\text{stream width [m]}) \\ &- 0.064 * (\text{red alder cover [\%]}) \\ &- 0.098 * (\text{shrub cover [\%]}) \\ &+ 0.024 * (\text{grass/sedge cover [\%]}) \\ &+ 9.167. \end{aligned} \quad (1)$$

TABLE 2. Comparison of mean (SE) habitat variables between the beaver-dam sites and unoccupied-stream sites, Drift Creek Basin, Lincoln County, Oregon, 1988-1989.

Variables	Dam sites (n=40)	Unoccupied (n=72)	*P*-value
Geomorphic			
Stream width (m)	4.1 (0.1)	4.8 (0.2)	0.1192
Stream depth (m)	0.7 (0.1)	0.7 (0.1)	0.2589
Stream gradient (%)	2.2 (0.2)	3.9 (0.4)	0.0007
Valley floor width (m)	32.8 (2.0)	22.7 (1.4)	0.0001
Bank slope (%)	31.8 (2.0)	45.6 (2.8)	0.0015
Vegetative			
Tree canopy (%)	38.8 (2.4)	52.9 (2.3)	0.0001
Overstory tree (%)	22.6 (3.4)	27.8 (2.7)	0.2412
Midstory tree (%)	20.3 (3.1)	29.7 (3.2)	0.0378
Shrub canopy (%)	56.0 (1.6)	65.1 (1.8)	0.0001
Bare ground (%)	9.0 (1.4)	7.6 (1.1)	0.4426
Grass/sedge cover (%)	59.0 (5.0)	25.2 (2.4)	0.0001
Forb Cover (%)	45.0 (2.0)	38.9 (1.7)	0.0280
Fern cover (%)	12.5 (1.7)	18.2 (1.4)	0.0138
Red alder (%)	34.5 (2.9)	47.7 (2.8)	0.0030
Douglas-fir (%)	8.0 (1.8)	8.1 (1.4)	0.9802
Salmonberry (%)	46.5 (2.5)	58.2 (1.8)	0.0003
Elderberry (%)	16.0 (2.3)	10.1 (1.3)	0.0468
Vine maple (%)	13.1 (2.1)	14.3 (1.6)	0.6613
Stinking current (%)	4.9 (2.1)	11.0 (1.5)	0.0039
California hazel (%)	2.0 (0.9)	2.9 (0.9)	0.7465[a]
Thimble berry (%)	7.8 (1.9)	5.2 (1.3)	0.1720[a]
Huckleberry (%)	1.7 (0.7)	0.9 (0.4)	0.1422[a]

[a] *P*-values of California hazel, thimbleberry, and huckleberry were based on Wilcoxon rank sum tests, and *P*-values of other variables were based on Student's *t*-tests.

TABLE 3. Unstandardized and standardized discriminant function coefficients for habitat variables measured at beaver-dam sites and unoccupied sites, Drift Creek Basin, Lincoln County, Oregon, 1988-1989.

Variables	Unstandardized	Standardized	r^1
Valley floor width (m)	+0.069	+0.855	+0.521
Stream gradient (%)	-0.364	-1.001	-0.414
Stream width (m)	-0.545	-0.960	-0.264
Red alder cover (%)	-0.064	-1.419	-0.394
Shrub cover (%)	-0.098	-1.139	-0.502
Grass/sedge cover (%)	+0.024	+0.594	+0.774
Constant	-9.167		

[1]Correlations between habitat variables and a discriminant function axis.

Using DF = 0 as a dividing point, the discriminant function classified positive values (DF>0) as dam sites and negative values (DF<0) as unoccupied sites. Three geomorphic variables, (stream gradient, stream width, and valley floor width) alone correctly classified 83% of dam sites and 67% of unoccupied sites with the chance-corrected classification rate (*Kappa* statistic) of 50%. The linear discriminant function model of geomorphic variables was:

$$DF = -0.484 * (\text{stream width [m]}) + 0.060 * (\text{valley floor width [m]}) - 0.239 * (\text{stream gradient [\%]}) + 1.210. \quad (2)$$

Developing a New Habitat Suitability Index (HSI) Model

We developed a new HSI model using the habitat data collected from the Drift Creek Basin. Three geomorphic attributes, which were selected in the discriminant analysis, were used to construct the following indices: stream gradient index, stream width index, and valley floor width index. Each index produces index scores (IS) for a particular attribute ranging from IS = 0.0 for unsuitable to IS = 1.0 for optimum condition for dam sites (Figure 3). An index score of each attribute is interpolated from the index diagram for a value of that attribute measured at a given site (Figure 3). Scores for the 3 indices are obtained for a site and compared to determine an HSI score, which represents a measure of overall habitat suitability of a site for dam building. In this HSI model, the minimum score among the 3 index scores is selected as an HSI score of a given site.

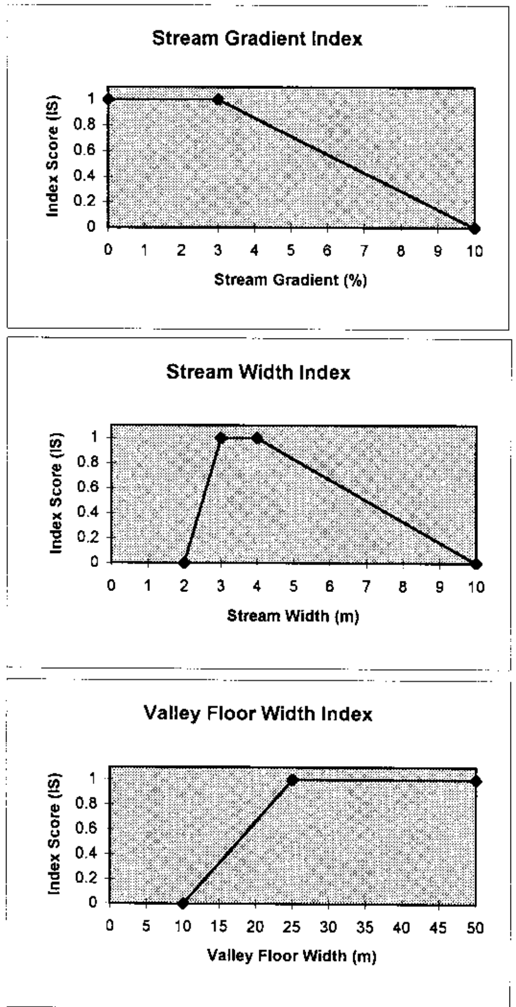

Figure 3. Diagrams of index scores for stream gradient, stream width, and valley-floor-width index in the new HSI model for beaver based on the data from the Drift Creek Basin, Lincoln County Oregon, 1988-1989.

Stream Gradient Index

In the Drift Creek Basin 67% of beaver dams were found on the streams that had gradient < 3% (Figure 2). Frequency of dams decreased as stream gradient increased from 3% to 10%. No beaver dams were observed on streams with a gradient > 10%. Therefore, stream gradients < 3% were considered optimum (IS = 1.0) for dam sites, stream gradients > 10% were considered unsuitable (IS = 0.0), and the suitability of stream gradient was assumed to decline linearly from gradient 3% to 10% (Figure 3).

Stream Width Index

We found beaver dams most frequently on the streams 3 - 4 m wide (Figure 2). Dam frequency decreased as the streams became wider. No beaver dams were found in the streams that had widths > 10 m or < 2 m. Therefore, streams 3 - 4 m wide were considered optimum for dam sites (IS = 1.0, Figure 3), while stream widths < 2 m or > 10 m were considered unsuitable for dam sites (IS = 0.0). Suitability of stream width was assumed to decline linearly from 3 m to 2 m and also from 4 m to 10 m.

Valley Floor Width Index

In the Drift Creek Basin, beaver dams were most frequently found on streams that had valley floors 25 - 30 m wide (Figure 2). Seventy-seven percent of dams were found on streams that had valley floors > 25 m wide. In the U.S. Fish and Wildlife HSI model, streams that had valley floors > 46 m wide were considered optimum as dam sites (Allen 1983). Although such wide valley floors were rare in the 1st- to 3rd-order mountain streams of the Drift Creek Basin, we found beaver dams on almost all the stream survey sites with valley floor widths > 50 m. No beaver dams were found on the streams that had valley floors < 10 m wide. Therefore, valley floor widths > 25 m were considered optimum for beaver dam sites (IS = 1.0, Figure 3) and valley floor widths < 10 m were considered unsuitable for dam sites (IS = 0.0). Suitability of the valley floor width was assumed to decline linearly from 25 m to 10 m.

HSI scores

To determine an HSI score for a given site, index scores (IS) for stream gradient, stream width, and valley floor width are obtained from the index diagrams (Figure 3). We assume stream gradient, stream width, and valley floor width cannot substitute for one another to improve overall habitat quality. Among these three attributes, we assume that the one with the least favorable condition for dam building, indicated by the lowest index score, is limiting the overall habitat suitability of the site. For example, beaver cannot build dams in very wide streams (>10 m) even though stream gradients are at optimum conditions (<3%). In these cases, the unfavorable stream width is limiting the overall habitat suitability of dam sites (Table 1). Based on the concept that one factor can limit habitat suitability (U.S. Fish and Wildlife Service 1981:103-ESM-3-31), the model uses the lowest index score (IS) of either stream gradient index, stream width index, or valley floor width index as the HSI score of the site, which represents the measure of overall habitat suitability of the site for dam building. For example, a hypothetical stream section with a gradient of 3%, a stream width of 6 m, and a valley floor width of 15 m would have IS = 1.0 for gradient index, IS = 0.7 for stream width index, IS = 0.3 for valley floor width index, and HSI score = 0.3 (Figure 3). In this scenario, the model considers valley floor width as limiting the overall habitat suitability of the site.

Discussion

Vegetative and Physical Characteristics of Beaver Dam Sites

Decreasing red alder cover and shrub cover, and increasing grass/sedge cover were positively associated with dam sites in the first discriminant function model (equation 1, Table 3). If the observed differences in vegetative variables between dam sites and unoccupied sites were the result of alteration by beaver, the vegetative variables would not be good predictors of potentially suitable sites prior to the colonization by beaver (Beier and Barrett 1987). Beaver can alter species composition of riparian plant communities by removing preferred species and stimulating the growth of avoided species (Barnes and Dibble 1988, Johnston and Naiman 1990). In the Oregon Coast Range beaver selectively forage on red alder and salmonberry and avoid foraging on elderberry (Bruner 1990). Thus, the selective foraging by beaver probably reduced the red alder and salmonberry cover and indirectly increased the elderberry cover at the dam sites. Abundance of herbaceous vegetation at the dam sites was probably a result of removal of tree and shrub cover and increased soil moisture around the beaver pond (Beier and Barrett 1987). Consequently, the discriminant model, when vegetative variables were included, would not likely identify potential dam sites in streams of the Oregon Coast Range.

Physical characteristics of stream habitats have been found to be more important factors of dam-site selection than vegetative characteristics (Howard and Larson 1985, Beier and Barrett 1987). We found that decreasing gradients and stream widths and increasing valley floor widths were positively associated with dam sites. Beier and Barrett (1987) and Howard and Larson (1985) also indicated that decreasing gradients were positively correlated with dam occurrence, but that decreasing stream widths were negatively correlated with dam site presence.

Frequency of beaver dams in the Drift Creek basin decreased as streams became steeper or wider (Figure 2). The force created by stream flow is probably too large for beaver to build and maintain dams on high-gradient streams (>10%) or on wide streams (>10 m) with deep channels that carry large volume of water per unit length (McComb et al. 1990). Taylor (1970:142) indicated that flood damage to beaver dams was most evident on slightly steep and undivided stream channels. Bruner (1990) reported that nearly all beaver dams in 4th- and 5th-order coastal streams of Oregon were washed out annually.

Valley floor width was also important to dam-site location in the basin. Beaver dams that flood a wide valley floor create ponds with large surface area and long perimeter relative to volume (Johnston and Naiman 1987). During a flood, water tables may rise only a few cm; a series of such ponds effectively store water and reduce peak discharge (Parker et al. 1985). Beaver dams can also significantly reduce velocity of increased discharge by spreading stream flow over a wider valley floor (Parker et al. 1985). In contrast, beaver ponds constructed on a high-gradient stream with a narrow valley floor tend to be small in surface area and perimeter relative to volume (Johnston and Naiman 1987). During a flood, the water level of such ponds can increase drastically; therefore, the ponds are not effective at reducing peak discharge and flow velocity. Consequently, beaver dams in narrow valleys are probably more susceptible to being washed out during floods than those in wide valleys.

Classification Models and Management Implications

Based on the 3 geomorphic variables (stream width, stream gradient, valley floor width), the new HSI model can be used to evaluate suitability of stream sites as dam sites. Alternatively, the discriminant function model with the same geomorphic variables (equation 2) can be used to classify stream sites as either dam sites or unoccupied sites.

The HSI model and the discriminant function model can be best applied for streams of the Drift Creek Basin and should be applicable for other streams of the Oregon Coast Range as long as geomorphology and hydrology are similar to those of the Drift Creek Basin. We recommend that our models be tested in watersheds in different geographic locations with various environmental conditions to ensure a wider geographic scope of applicability.

Our habitat models cannot predict local beaver populations or habitat suitability for bank-dwelling beavers; however, wildlife managers can use these models to inventory potential beaver-dam sites along streams of the Oregon Coast Range. Information obtained from our models can be incorporated into plans to preserve riparian habitats because beaver dams and associated beaver activities influence various ecological attributes and processes, including abundance and community structures of aquatic and terrestrial organisms (Rutherford 1955, Reese and Hair 1976, McDowell and Naiman 1986, Bruner 1990), vegetation dynamics (Barnes and Dibble 1988, Johnston and Naiman 1990), biochemical pathways (Naiman et al. 1986, Naiman et al. 1988), and sediment transport (Parker et al. 1985). Ultimately, these new habitat classification models will help land managers consider how to minimize the adverse influence of land use practices on unique riparian habitats maintained by beaver.

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