Methods to Predict Beaver Dam Occurrence in Coastal Oregon

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Abstract

Pools provided by beaver (*Castor canadensis*) contribute to critical habitat requirements of salmonids in fluvial systems of the Pacific Northwest, therefore more land managers are interested in managing watersheds that include beavers or engaging in beaver-related restoration projects. We evaluated the utility of applying an existing beaver habitat suitability model to better understand beaver dam site characteristics in coastal Oregon, identify optimum dam site locations, and guide future beaver-related restoration efforts. We used a combination of *t*-tests, Wilcoxon rank sum tests, and a stepwise discriminant function analysis to examine stream habitat associations with field data collected at known and predicted dam sites at reach and pool/riffle levels. We found bank-full width, valley floor width, and channel gradient performed well in predicting dam locations across the Alsea River Basin. Known dam sites had wider valley floors, shallower shoreline slopes, and fewer larger, deeper pools than predicted sites. Overall, our results suggest the beaver habitat suitability model combined with a digital elevation model can be used to guide where beaver dams may occur within the Alsea River Basin, yet they do not capture fine scale habitat associations that may lead to a settling response in beavers. For example, presence of large deep pools may be necessary for beavers to escape predation before and during dam building. Results from our study may be used to prioritize potential dam sites in other coastal basins that have similar geomorphic characteristics.

Keywords: beaver, dam habitat, salmon, stream restoration

Introduction

American beaver (*Castor canadensis*, hereafter beavers) are considered ecosystem engineers where their dam building changes abiotic and biotic components of communities (Jones et al. 1994, Wright, et al. 2002, Gibson and Olden 2014). Dam-building beavers also are a keystone species (Paine 1969, Power et al. 1996) because the efforts of a few individuals (i.e., dam construction) can yield disproportionately large effects (Naiman et al. 1986). In many fluvial systems of the Pacific Northwest, beavers coexist with, and may benefit, anadromous salmonids, including populations of coho salmon (*Oncorhynchus kisutch*) that are protected under the US Endangered Species Act (ESA). Managing beavers to enhance stream habitat may be an attractive alternative to expensive and disruptive anthropogenic activities such as placing large wood and boulders (Leidholt-Bruner et al. 1992, DeVries et al. 2012), although the efficacy of beaver-related restoration is not yet supported by scientific research (Pilliod et al. 2017).

Limited data exist on the contribution of beaver populations to dam construction in the Pacific Northwest. Furthermore, dam-building attempts in this region typically occur during low-flows in August through October; most dams are destroyed during winter high-flow events (Maser et al. 1981, Leidholt-Bruner et al. 1992, Petro et al. 2015) because these stream systems generate significant

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stream force following winter rains (Roni et al. 2015). Beaver impacts to stream systems are also cyclical (Baker and Hill 2003), but the rate of colonization and abandonment of sites remains unknown throughout the Pacific Northwest.

Previous studies have documented the importance of vegetative and geomorphic characteristics associated with beaver dam locations (Howard and Larson 1985, Beier and Barrett 1987, McComb et al. 1990, Barnes and Mallik 1997, Suzuki and McComb 1998). More recently, georeferenced data have been used to identify stream reaches suitable for beaver habitat in Washington (Dittbrenner et al. 2018), South Carolina (Jakes et al. 2007), Utah (Macfarlane et al. 2015), and Great Britain (IUCN 2013). Most of these studies focus on reach level characteristics and lack detailed descriptions of pool/riffle characteristics that may also influence where beavers build dams. Sufficient pool volume may be critical for security and foraging by beavers using small active channels, such as those common in the Oregon Coast Range. Few studies have investigated microhabitat characteristics such as frequency of pools near instream wood structures (MacCracken and Lebovitz 2005), stream cross-sectional area (Barnes and Mallik 1997), and stream depth (Beier and Barrett 1987).

Suzuki and McComb (1998) developed a beaver habitat suitability index (HSI) model to predict beaver dam site occurrence in the Drift Creek sub-basin of the Alsea River watershed, central Oregon Coast Range. Based on field observations, they found dam sites were predicted primarily by three reach level geomorphic characteristics (Suzuki and McComb 1998). Our goal was to evaluate the HSI model (Suzuki and McComb 1998) as a tool for informing future beaver-related restoration in the broader Alsea River Basin. Our objectives were to: 1) determine if present day dam sites meet the HSI model classifications, 2) determine if reach level (coarse-grain) geomorphic stream characteristics identified by Suzuki and McComb (1998) are comparable between recent and historic dam sites, and 3) determine if new dam habitat associations exist at the reach level (coarse-grain) and/or pool/riffle level (fine-grain) for identifying stream reaches suitable for beaver damming. We conducted this research as part of a larger study that evaluated relocating nuisance beaver colonies into unoccupied sites (Petro et al. 2015) following the Oregon state guidelines established for private landowners (ODFW 2017).

Methods

Study Area

The Alsea River Basin is located in the central Oregon Coast Range (Figure 1). This river drains directly into the Pacific Ocean, near the town of Waldport. The basin is approximately 1,213 km^2 and consists of four sub-basins: Drift Creek, 5 Rivers, Upper Alsea River, and Lower Alsea River. Elevation ranges from sea level to 1,249 m. Average annual precipitation is 203 to 254 cm near the coast and 203 to 356 cm in higher elevations (WRCC 1990). Most precipitation occurs as rainfall during the winter. Land cover is primarily mixed conifer forest and ownership is divided among federal agencies (63%), private industrial forest landowners (23%), private non-industrial (13%), and state land (> 1%). Common tree species include Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), red alder (*Alnus rubra*), and bigleaf maple (*Acer macrophyllium*). Dominant understory vegetation includes salmonberry (*Rubus spectabilis*), elderberry *(Sambucus racemosa*), osoberry (*Oemleria cerasiformis*), stinking currant *(Ribes bracteosum*), red huckleberry (*Vaccinium parvifolium*), vine maple (*Acer circinatum*), and sword fern (*Polystichum munitum*).

Site Classes

Beaver dam site characteristics were examined by classifying study sites into two groups of dam sites: 1) predicted and 2) known. Suzuki and McComb (1998) found stream bank-full width, valley floor width, and channel gradient had more predictive power than vegetative characteristics. Their model provided an index score for each of these geomorphic variables at a given site. The minimum score for all variables was then selected as the site's HSI score assuming one variable cannot substitute for another to improve

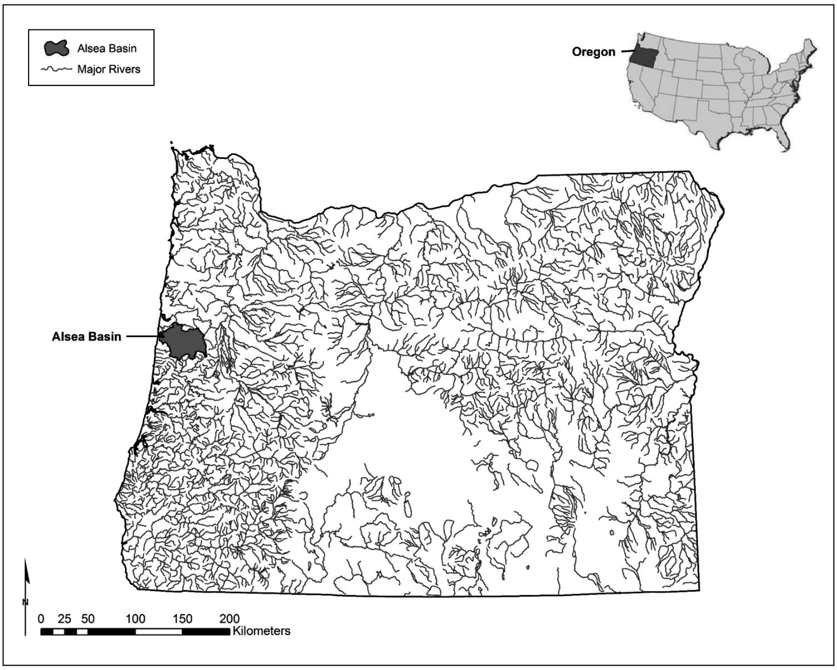

Figure 1. Location of Alsea River Basin in western Oregon.

the suitability for damming at the site. Instead of calculating index scores for all stream reaches in the Alsea Basin to identify potential dam sites, we used conservative criteria to identify optimum locations for dam establishment or "predicted" study sites (Group 1) based on our interpretation of stream reaches where Suzuki and McComb (1998) reported the highest frequencies of beaver dams. We defined predicted study sites as having a) 3–4 m bank-full width, b) 25–30 m valley floor width, and c) ≤ 3% channel gradient. A stream network developed from a 10 m digital elevation model (DEM; Clarke et al. 2008) was used to output model parameters in ArcGIS (version 9.3; ESRI, Redlands, California). We felt confident the DEM was a reasonable source to apply dam site criteria based on high correlations previously noted between field-based and modeled values (Clarke et al. 2008). Known dam sites (Group 2) were locations where we identified active beaver dams by field surveys in the Alsea River Basin.

Field Data Collection

During low flow periods in 2011 and 2012, all known and predicted dam sites were surveyed using methods similar to Barnes and Mallik (1997). Two 100 m x 30 m plots were placed at each site. Plot dimensions were determined using the average length of predicted dam sites (~ 100 m) and the average beaver foraging distance from shoreline (30 m; Jenkins 1980). The survey location for vegetative data collection was randomly selected for one plot and the paired plot was offset immediately up or downstream. For predicted sites, an in-stream point was centrally placed within the site to separate the upstream and downstream plots (Figure 2). For known dam sites, a point at stream center was located immediately upstream and downstream of the dam impoundment where the stream returned to its original width (Figure 2). This arrangement resembled plot layout Barnes and Mallik (1997) used for active dam sites and assumed measurements would reflect pre-dam habitat conditions. Plot and transect sampling methods were the same for both groups.

Fifteen habitat variables were quantified at each site, representing vegetative and geomorphic features for reach and pool/habitat levels (Table 1). We randomly selected four locations in each plot to collect vegetation data using a belt transect. Each 1 m x 30 m belt transect was oriented perpendicularly to the valley aspect from the streambank (Figure 2). Woody stem species ≥ 1 cm in diameter at stump height (30 cm above ground; Johnston and Naiman 1990) were measured and recorded. Percent overstory canopy cover was recorded at 0, 15, and 30 m along each transect using a spherical densitometer at chest height.

TABLE 1. Habitat characteristics sampled at predicted and known beaver dam sites in the Alsea River Basin.

Level	Type	Variable	Description of measurements
Reach	Vegetative	Vine maple	Stem density (%)
		Red alder	Stem density (%)
		Salmonberry	Stem density (%)
		Willow species	Stem density (%)
		Canopy cover	Average over-story canopy cover (%)
	Geomorphic		
		Valley floor width	Average 100-year floodplain (m)
		Wood jams	Total number of wood jams present
		Large wood	Total number of pieces that contribute to pool creation or potential dam anchoring material
		Bank-full width	Average bank-full width (m)
		Channel gradient	Average gradient within bank-full (%)
		Shoreline slope	Average gradient outside of bank-full (%)
Pool/Riffle	Geomorphic	Residual pool depth	Average difference between pool max depth and pool tail crest depth for all primary and secondary pools sampled (cm)
		Primary pool habitat	Amount of primary pool habitat recorded along the channel thalweg (%)
		Number of pools	Total number of primary and secondary pools sampled
		Max depth	Average max depth of all primary and secondary pools (cm)

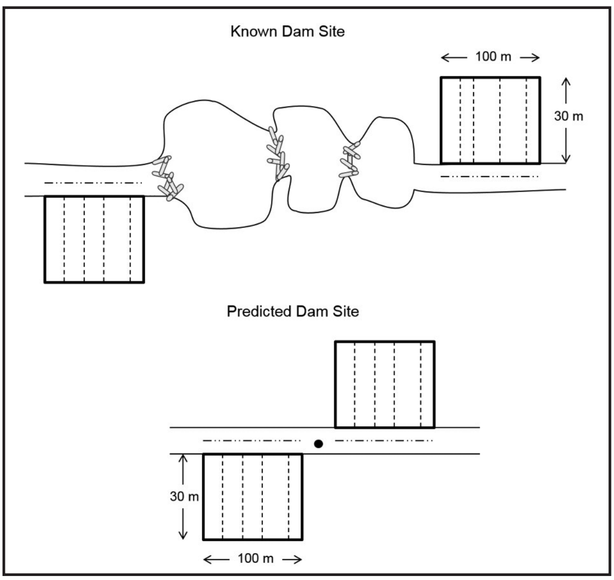

Figure 2. Illustration of plot layouts used at study sites to collect geomorphic and vegetative habitat variables in the Alsea River Basin.

The stream was delineated into primary and secondary units throughout each 100 m plot to collect pool/riffle habitat data. Looking upstream, habitat units were identified as riffle, pool, or glide (Bisson et al. 1982). A primary habitat unit comprised ≥ 50% of the wetted channel width; a secondary habitat unit comprised < 50% of the wetted channel width. Starting and ending distances were recorded to the nearest 10 cm for each primary and secondary habitat unit along a meter tape that followed the channel thalweg (i.e., line of fastest flow or deepest water). A meter stick was used to measure maximum depth and pool tail crests (i.e., deepest point water exits a pool) to the nearest 1 cm. Bank-full width was determined by evidence of scouring from the 1.5-year return flood interval, and was measured to the nearest 10 cm with a meter tape at 20 m intervals perpendicular to the thalweg throughout each plot (5 per plot). Valley floor width was recorded to the nearest 10 cm with a meter tape, perpendicular to the direction of the 100-year floodplain at the 50 m plot distance (1 per plot). Percent channel gradient and shoreline slope was measured with a handheld clinometer at the 25 m and 75 m points within our plots. Channel gradient was measured over 20 m in each direction (up and downstream) of the plot distances. Shoreline slope was recorded within 20 m of the active channel. The number of large wood pieces and jams in the bank-full channel were counted in each 100 m plot. Large wood length and diameter were measured with a meter tape to the nearest 5 cm. Pieces were only measured if they were each ≥ 10 cm in diameter and ≥ 1 m in length and served as a potential anchoring location for dam establishment or aided in pool formation. The number of debris jams that occurred within the 100 m plot were visually recorded. This study distinguished a debris jam as having ≥ 2 intersecting pieces of large wood that met the large wood size criteria listed above.

Measurements of geomorphic and vegetative characteristics were averaged across both plots for each sampled site. Due to the large quantity of woody vegetative species sampled, only species commonly observed in beaver foraging and damming activities were retained for analysis.

Statistical Analysis

Tests for normality and homogeneity of variance were conducted using the R statistical software program (version 2.15R Development Core Team 2013). Log and square root transformations were applied to variables with non-normal distributions. Non-parametric tests were performed when applicable to analyze data that could not be transformed to a normal distribution. One predicted site was removed before analysis because the reach was dry during field data collection and assumed an unreliable inventory of stream habitat. Willow (*Salix)* species were rare, occurring in fewer than three study sites, and were subsequently eliminated from analysis.

We used a Wilcoxon rank sum test to compare the DEM-derived HSI classifications for known dam sites and an equal number of random locations generated with ArcGIS. This approach determined if reaches with present day dam sites meet the HSI criteria for suitable damming beyond our interpretation of what we qualified as optimum dam establishment habitat for predicted sites. Random sites were constrained to 1st through 4th order tributaries based on dam site observations from Suzuki and McComb (1998). Welch's two sample *t*-tests were used to determine if reach level (coarse-grain) geomorphic stream characteristics identified by Suzuki and McComb (1998) are comparable between recent and historic dam sites. For this objective, we compared field-derived estimates of the HSI model input variables (i.e., bank-full width, valley floor width, and channel gradient) for dam sites sampled by Suzuki and McComb (1998) to recent field sampled dam sites. This would allow us to explore potential temporal changes in dam site establishment.

We tested for differences in dam habitat associations at the reach level (coarse-grain) and pool/riffle level (fine-grain) between known and predicted dam sites using univariate and multivariate analyses. For the univariate approach, we used Welch's two sample *t*-tests or Wilcoxon rank sum tests to compare individual stream habitat variables between predicted and known dam sites. Multivariate dam habitat associations were explored with stepwise discriminant function analysis (DFA) in SPSS (version 19.0; IBM Corp. Armonk, NY), which allowed us to identify the vegetative and geomorphic characteristics that best distinguished known and predicted dam sites. This eigenanalysis technique was chosen because it maximizes separation of pre-defined groups through linear analysis of among group variation (McCune and Grace 2002). The linearity of all variables among both groups were visually assessed with a scatterplot matrix using the "lattice" package in R (Sarkar 2008). This assumption was met for DFA due to strong linear relationships observed among pool/riffle variables. Variation among groups was assessed with Wilks' Lambda. The discriminant function classifications were evaluated with cross validations or "jack-knife" classification. A confusion matrix was created to assess the classification accuracy. Statistical significance was assumed when $\alpha \leq 0.05$ for all tests.

Results

Of 3,761 stream km in the Alsea River Basin, the DEM-based stream network identified only 7 km (mean segment length 80 m, SD 15, range 48–130 m, $n = 96$) that were predicted to be optimum for beaver dam establishment based on our criteria. Field data were collected at 47 stream sites (26

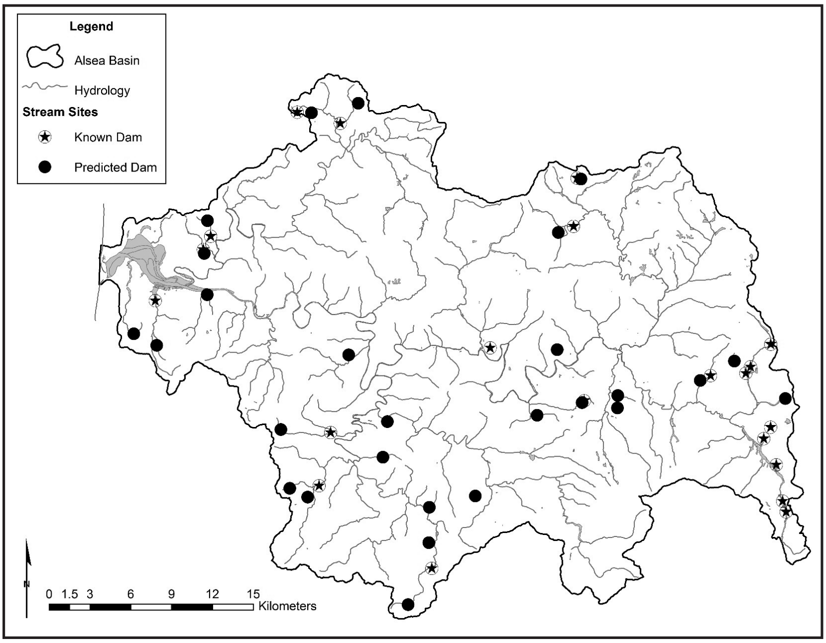

Figure 3. Distribution of sites sampled for reach and pool/riffle level characteristics of beaver dam habitat in the Alsea River Basin.

TABLE 2. Comparison of mean (SD) field-derived habitat values at known beaver dam sites sampled by Petro (2013) and Suzuki and McComb (1998) in the Alsea River Basin, Oregon.

	Dam Sites		
	2011–2012	1988–1989	
Variable	(*n* = 21)	(*n* = 40)	*P*-value
Bank-full width (m)	4.8 (2.7)	4.1 (0.6)	0.548
Valley floor width (m)	38.9 (6.3)	32.8 (12.6)	0.658
Channel gradient (%)	2.0 (0.9)	2.2 (1.2)	0.349

predicted dams and 21 known dams; Figure 3). Known dam sites had higher HSI values for dam establishment (mean = 0.60) than random locations identified within the Alsea River Basin (mean = 0.10, W = 403, $P < 0.01$). Reach level (coarse-grain) values for channel gradient, valley floor width, and bank-full width were comparable between known dam sites sampled by Suzuki and McComb (1998) and those sampled for this study in 2011 and 2012 (Table 2).

The outlier analysis (SPSS) for stream habitat characteristics, using a Mahalanobis distance, indicated no outliers ($F_{14} = 36.1$, $P < 0.01$). Field measurements of reach and pool/riffle variables, including valley floor width and shoreline slope, differed between predicted and known dam sites (Table 3). Known dam sites had wider valley floors, shallower shoreline slopes, and fewer larger, deeper pools than predicted sites. Reach level vegetative characteristics were not significantly different among known and predicted dam sites. We found no evidence that reach level geomorphic variables including abundance of wood jams or large wood, bank-full width, and channel gradient differed between known and predicted dam sites (Table 3).

The stream habitat data matrix used for the DFA did not meet the multivariate normality assumption due to non-normal distributions of two habitat variables (canopy cover and channel gradient). However, violations of the normality assumption only affect the robustness of an analysis if the violation is caused by outliers, rather than skewness (Tabachnick and Fidell 2007). The DFA found variation among predicted and known dam sites (Wilks Lambda = 0.46, P < 0.01), and the significant discriminant function explained 54% of between group variability. The multivariate analysis noted increases of primary pool habitat area and valley floor width were positively associated with known dam sites (Figure 4). The discriminant scores separated more effectively for both predicted groups than the discriminant scores for original group membership. Classification results indicated 85% of the stream sites were correctly classified into both original groups while 81% of cross-validated sites were correctly classified.

TABLE 3. Habitat mean values (SD) for predicted and known beaver dam sites in the Alsea River Basin.

Level	Type	Variable	Predicted (n = 26)	Known (n = 21)	P-value
Reach	Vegetative	Vine maple	10.3 (12.0)	11.3 (12.6)	0.722
		Red alder	2.4 (3.0)	3.2 (2.7)	0.120
		Salmonberry	65.8 (21.5)	62.0 (19.8)	0.549
		Canopy cover	93.7 (6.5)	90.5 (11.2)	0.483
	Geomorphic	Valley floor width	21.4 (1.5)	38.9 (6.3)	0.001
		Wood jams	3.5 (0.8)	4.1 (2.2)	0.271
		Large wood	3.6 (0.8)	4.1 (4.5)	0.949
		Bank-full width	3.9 (0.2)	4.8 (12.1)	0.445
		Channel gradient	2.2 (0.2)	2.0 (4.0)	0.392
		Shoreline slope	36.6 (2.9)	28.0 (16.2)	0.001
Pool/Riffle	Geomorphic	Residual pool depth	22.1 (5.0)	33.5 (13.0)	0.052
		Primary pool habitat	47.6 (15.0)	73.7 (14.4)	0.001
		Number of pools	39.0 (7.5)	32.2 (14.8)	0.035
		Max depth	20.8 (3.0)	82.7 (15.3)	0.001

Discussion

Dam Habitat Associations

Our results suggested the HSI model (Suzuki and McComb 1998) was effective in predicting potential dam sites within the Alsea River Basin. The beaver HSI model (Suzuki and McComb 1998) successfully distinguished known dam sites from random locations in the Alsea River Basin. These findings are consistent with studies that noted strong correlations of geomorphic variables to dam sites including watershed area, stream cross-sectional area, stream gradient (Barnes and Mallik 1997, Jakes et al. 2007, Dittbrenner et al. 2018), along with both stream width and depth (Beier and Barrett 1987).

Targeting optimum dam sites based on the HSI (Suzuki and McComb 1998) criteria to narrow the scope of potential release sites for beaver relocation seemed a useful approach (Petro et al. 2015). Applying the beaver HSI model to identify release sites may have contributed to the finding that beavers moved shorter distances (3.3 stream km) after release in the Alsea River Basin (Petro et al. 2015) than other relocation studies conducted in Colorado (16.7 stream km; Denney 1952), North Dakota (14.6 stream km; Hibbard 1958), Wisconsin (76.2 stream km; Knudsen and Hale 1965), northern Quebec (18 air km; Courcelles and Nault 1983), and Wyoming (> 10 stream km; McKinstry and Anderson 2002). However, we found imposing an upper limit on valley floor widths was unnecessary because known dam sites had significantly wider valley floors than predicted sites (Figure 4), and valley floor width was important in the discriminant model. It is important to reiterate however, this study was part of a larger effort to identify prime relocation sites for beaver, and where dam building would be most probable (Petro et al. 2015). Although more of the Suzuki and McComb (1998) dam sites were found in the 25–30 m class than any other single valley floor width class, approximately 75% of all dams in their study occurred in valleys wider than 25 m. The combination of these findings supports targeting valley floor widths that are > 25 m.

Our results also suggested that pool/riffle characteristics are important in understanding dam site selection, and these criteria could not be estimated with the DEM. Primary pool habitat was the strongest discriminator between predicted and known dam site locations within the Alsea River Basin. We acknowledge the challenges of sampling pre-existing channel conditions, specifically sites

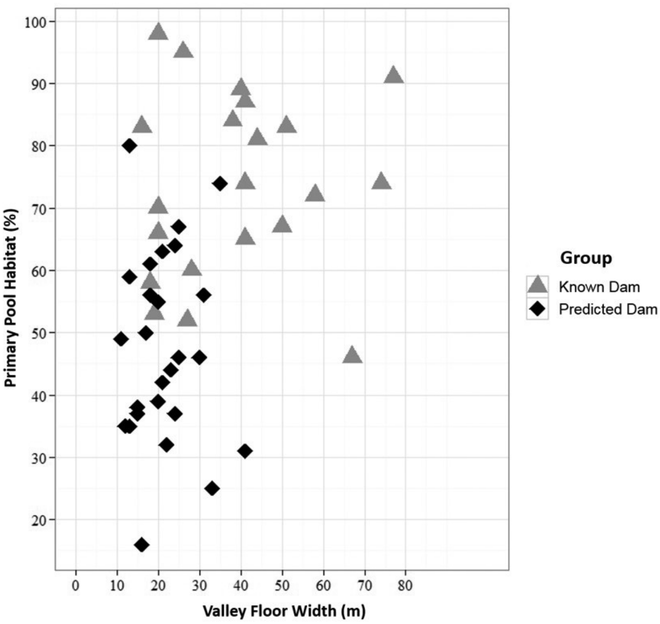

Figure 4. Scatterplot illustrating the relationship of primary pool habitat and valley floor width between predicted and known beaver dam sites.

modified by beaver, and used the best methods available since there is no foolproof method to estimate pre-existing channel conditions with a beaver dam in place. We are comfortable that our technique removed the influence of the dam presence and therefore are confident in our findings. Our results support the position that beavers require sufficient pool size and depth for escape cover and food resource accessibility (Beier and Barrett 1987, MacCracken and Lebovitz 2005). It is important to note that pool metrics (e.g., water depth) may be cues for dam building rather than a result of dam building, as beavers require escape cover when establishing territories prior to dam building.

Our analyses revealed that vegetative variables had little explanatory power for identifying dam site locations in the Alsea River Basin. Barnes and Mallik (1997) noted it was unlikely beavers used presence of food as a cue for dam establishment. The first discriminant analysis conducted by Suzuki and McComb (1998) found reductions in shrub and red alder cover combined with increases in grass/sedge cover were positively associated with dam sites. However, they excluded these variables from further analysis due to the assumption that the beavers may have altered the growth of these vegetation types at plot sites, reducing their potential to act as indicators of dam locations (Suzuki and McComb 1998). In contrast, the presence of an adequate and accessible food supply influenced colony establishment in semi-arid environments where dam sites were associated with reaches that had > 7% hardwood tree cover (McComb et al. 1990). Macfarlane et al. (2015) also included available riparian vegetation for identifying damming habitat, but disclosed riparian vegetation might yield inconsistent results over time due to fluctuations in vegetative communities. Interestingly, the three HSI geomorphic variables (channel gradient, valley floor width, bank-full width) that Suzuki and McComb (1998) identified as predictors of beaver dam sites in the Alsea River Basin provided consistent results at dam sites sampled approximately 25 years later for this study.

Additional Characteristics That May Influence Dam Locations

Dam site establishment may be influenced by factors other than vegetative and geomorphic characteristics within this basin. Petro et al. (2015) observed a high rate of beaver mortality caused by mountain lions (*Puma concolor*) in the Alsea River Basin. It is possible that some dam building sites are underutilized where predation risk precludes establishment, although this has not been evaluated in the Pacific Northwest. Other density dependent processes may also influence the distribution of established dam sites. Beavers are territorial and more likely to colonize optimum reaches first, limiting colonization of expanding populations to less optimum reaches (Fretwell and Lucas 1969). Furthermore, beaver populations are dispersing across stream systems that rarely resemble historic conditions of natural resource communities due to changes in land-use practices and management, rapid establishment of non-native species, and shifted distributions of native species (Gibson and Olden 2014, Pearl et al. 2015).

Implications and Conclusions

Our approach for identifying optimum damming locations may aid other projects interested in beaver relocation or beaver-related stream restoration, although there are caveats. GIS-based digital data offers a useful approach for modeling release sites at large scales, but we may miss detail at small scales that cause a settling response in beavers. For example, interested managers could apply our HSI based method as a coarse scale filter to identify suitable dam locations and then incorporate a pool/riffle assessment of primary pool habitat at those sites using high resolution datasets such as LiDaR or field surveys. Predictive models that do not account for beavers' physical security (i.e., adequate pool width and depth) prior to dam establishment may fail in predicting dam occurrence.

One should also understand the subtle difference in models that predict beaver occurrence and those that predict dam building. Not all beavers build dams and one may posit that the best beaver habitat is where beavers do not have to build dams. Habitat suitability index models for evaluating beaver occurrence (i.e., lacustrine, palustrine, and riverine based habitats) were developed for northern British Columbia (Slough and Sadlier 1977), and northern California (Beier and Barrett 1987), with the US Fish and Wildlife Service beaver HSI model (USFWS Beaver HSI; Allen 1983) used for applications across the geographic range of beaver in North America. Later models primarily focused on dam establishment locations and were developed for central Massachusetts (Howard and Larson 1985), western Oregon (Suzuki and McComb 1998), eastern Oregon (McComb et al. 1990), and northern Ontario (Barnes and Mallik 1997), with the Beaver Restoration Assessment Tool (BRAT) focusing on dam building capacity of stream reaches (Macfarlane et al. 2015). An intrinsic potential model was recently developed for the Snohomish River Basin in Washington, but the authors did not specify if it was designed to model beaver occurrence or dam habitat (Dittbrenner et al. 2018).

Limitations inadvertently exist for managers when considering which available spatial model to use for informing beaver-related restoration. Broad scale models like the BRAT (Macfarlane et al. 2015) and the USFWS Beaver HSI are unlikely to successfully predict dam locations across the beavers' geographic range because they are not sensitive to local variations in beaver habitat associations. For example, Suzuki and McComb (1998) found the USFWS Beaver HSI classified 78% of unoccupied reaches as optimum beaver habitat in the Alsea River Basin. Macfarlane et al. (2015) revealed realized beaver dam capacity was only 1–16% of the BRAT predicted dam capacity throughout various watersheds in Utah. Managers should start with available models closest to their area of interest and refine accordingly (Suzuki and McComb 1998, McComb et al. 1990, Barnes and Mallik 1997, Petro et al. 2015). Furthermore, focusing on the dam building capacity of stream systems fails to recognize the importance of biological factors that influence dam prevalence including inter-colony interactions, minimum home range size, local population density, and colony longevity.

Despite numerous applications of beaver habitat models for conservation and management of wildlife habitat, their practicality is still debated. Defining classes of habitat suitability based on the presence/absence of beaver may not accurately represent other habitat variables associated with unoccupied locations. In addition, the performance of beaver habitat models may be affected by the spatial and temporal variability associated with field sampling limitations. Factors related to population dynamics other than habitat may have predictive power, but are logistically difficult to obtain. Even with these caveats, identifying sites for beaver assisted stream restoration using beaver habitat models seems more supportable than using the traditional approach of expert opinion, which can be biased and inconsistent.

Although it was not a focus of this study, our approach could be used to predict where human-wildlife conflicts may arise through beaver dam building in the Alsea River Basin. Managers could apply similar filters to identify where dams may create unwanted flooding, so that proactive management actions could prevent or lessen negative effects. For example, areas susceptible to damming and flooding could be fit with flow devices (Taylor and Singleton 2014) to keep beavers in the area and minimize flooding.

Adopting beavers as a stream restoration tool may provide managers the ability to address beaver-human conflict issues while restoring degraded stream habitat for coho salmon. Therefore, stream locations that encourage beaver damming activities and salmon productivity are highly preferred as restoration sites (ODFW 2007). Increasing beaver population size has been suggested as a means to create coho habitat (Pollock et al. 2004), and this often implies beaver relocation. However, relocation should not be considered without an understanding of beaver presence/use of the area (Maenhout 2013). Long term success of integrating beaver into stream restoration ultimately depends on the ability of systems to support beaver populations, not their dam building capacity. Future modeling efforts should focus on further delineating beaver habitat use into dam and non-dam sites due to the potential influence of population dynamics between both groups.

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Literature Cited

Allen, A. W. 1983. Habitat Suitability Index Models: Beaver. Western Energy and Land Use Team, Division of Biological Services, US Fish and Wildlife Service: Fort Collins, CO.

Baker, B. W., and E. P. Hill. 2003. Beaver (*Castor canadensis*). *In* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman (editors). Wild Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press: Baltimore, MD. Pp. 288-310.

Barnes, D. M., and A. U. Mallik. 1997. Habitat factors influencing beaver dam establishment in a northern Ontario watershed. Journal of Wildlife Management 61:1371-1377.

Beier, P., and R. H. Barrett. 1987. Beaver habitat use and impact in Truckee River Basin, California. Journal of Wildlife Management 51:794-799.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. *In* N. B. Armantrout (editor), Proceedings of Symposium—Acquisition and Utilization of Aquatic Habitat Inventory Information, American Fisheries Society: Western Division, Betheseda, MD. Pp. 62-73.

Clarke, S. E., K. M. Burnett, and D. J. Miller. 2008. Modeling streams and hydrogeomorphic attributes in Oregon from digital and field data. Journal of the American Water Resources Association 44:459-477.

Courcelles, R., and R. Nault. 1983. Beaver programs in the James Bay area, Quebec, Canada. Acta Zoologica Fennica 174:129-131.

Denney, R. N. 1952. A summary of North American beaver management, 1946–1948. *Colorado* Game and Fish Department 28:1-58.

DeVries, P., K. L. Fetherson, A. Vitale, and S. Madsen. 2012. Emulating riverine landscape controls of beaver in stream restoration. Fisheries 37: 246-255.

Ditterbrenner, B. J., M. M. Pollock, J. W. Schilling, J. D. Olden, J. J. Lawler, and C. E. Torgersen. 2018. Modeling intrinsic potential for beaver (*Castor canadensis*) habitat to inform restoration and climate change adaptation. PLOS ONE, https://doi.org/10.1371/journal.pone.0192538.

Fretwell, S. D., and H. L. Lucas. 1969. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical Development. Acta Biotheoretica 19:16-36.

Gibson, P. P., and J. D. Olden. 2014. Ecology, management, and conservation implications of North American beaver (*Castor canadensis*) in dryland streams. Aquatic Conservation: Marine and Freshwater Ecosystems 24:391-409.

Hibbard, E. A. 1958. Movements of beaver transplanted in North Dakota. Journal of Wildlife Management 22:209-211.

Howard, R. J., and J. S. Larson. 1985. A stream habitat classification system for beaver. Journal of Wildlife Management 49:19-25.

IUCN. 2013. Guidelines for reintroductions and other conservation

Translocations. IUCN Species Survival Commission, Gland, Switzerland.

Jakes, A. F., J. W. Snodgrass, and J. Burger. 2007. *Castor candensis* (beaver) impoundment associated with geomorphology of southeastern streams. Southeastern Naturalist 6:271-282.

Jenkins, S. H. 1980. A size-distance relation in food selection by beavers. Ecology 61:740-746.

Johnston, C. A., and R. J. Naiman. 1990. Browse selection by beaver: effects on riparian forest composition. Canadian Journal of Forest Resources 20:1036-1043.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Oikos 69:373-386.

Knudsen, G. J., and J. B. Hale. 1965. Movements of transplanted beavers in Wisconsin. Journal of Wildlife Management 29:685-688.

Leidholt-Bruner, K., D. E. Hibbs, and W. C. McComb. 1992. Beaver dam locations and their effects on distribution and abundance of coho fry in two coastal Oregon streams. Northwest Science 66:218-223.

MacCracken, J. G., and A. D. Lebovitz. 2005. Selection of instream wood structures by beaver in the Bear River, southwest Washington. Northwestern Naturalist 86:49-58.

Macfarlane, W. C., J. M. Wheaton, N. Bouwes, M. L. Jensen, J. T. Gilbert, N. Hough-Snee, and J. A. Shivik. 2015. Modeling capacity of riverscapes to support beaver dams. Geomorphology 277:72-99.

Maser, C., B. R. Mate, J. F. Franklin, and C. T. Dyrness. 1981. Natural History of Oregon Coast Mammals. Pacific Northwest Forest and Range Experimental Station, USDA Forest Service General Technical Report PNW-133, Portland, OR.

Maenhout, J. L. 2013. Beaver ecology in Bridge Creek, a tributary to the John Day River. M.S. Thesis, Oregon State University, Corvallis.

McComb, W. C., J. R. Sedell, and T. D Buchholz. 1990. Dam-site selection by beavers in an eastern Oregon basin. Great Basin Naturalist 50:273-281.

McCune, B., and J. B. Grace. 2002. Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR.

McKinstry, M. C., and S. H. Anderson. 2002. Survival, fates, and success of transplanted beavers, *Castor canadensis*, in Wyoming. Canadian Field Naturalist 116:60-68.

Naiman, R. J., J. M. Melillo, and J. E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). Ecology 67:1254-1269.

Oregon Department of Fish and Wildlife (ODFW). 2007. Oregon Coast Coho conservation plan for the state of Oregon. Oregon Department of Fish and Wildlife, Salem.

Oregon Department of Fish and Wildlife. 2017. Guidelines for relocation of beaver in Oregon. Oregon Department of Fish and Wildlife, Salem.

Paine, R. T. 1969. A note on trophic complexity and community stability. American Naturalist 103:91-93.

Pearl, C. A., M. J. Adams, P. K. Haggerty, and L. Urban. 2015. Using occupancy models to accommodate uncertainty in the interpretation of aerial photograph data: status of beaver in central Oregon, USA. Wildlife Society Bulletin 39:319-325.

Petro, V.M. 2013. Evaluating "nuisance" beaver relocation as a tool to increase coho salmon habitat in the Alsea River Basin of the central Oregon Coast Range. MS Thesis, Oregon State University, Corvallis.

Petro, V. M., J. D. Taylor, and D. M. Sanchez. 2015. Evaluating landowner-based beaver relocation as a tool to restore salmon habitat. Global Ecology and Conservation 3:477-486.

Pilliod, D. S., A. T. Rohde, S. Charnley, R. R. Davee, J. B. Dunham, H. Gosnell, G. E. Grant, M. B. Hausner, J. L. Huntington, and C. Nash. 2017. Survey of beaver-related restoration practices in rangeland streams of the western USA. Environmental Management 61:58-68.

Pollock, M. M., G. R. Pess, and T. J. Beechie. 2004. The importance of beaver ponds to coho salmon production in the Stillaguamish River Basin, Washington, USA. North American Journal of Fisheries Management 24:749-760.

Power, M. E., D. Tilman, J. A. Estes, B. A. Menge, W. J. Bond, L. S. Mills, G. Daily, J. C. Castilla, J. Lubchenco, and R. T. Paine. 1996. Challenges in the quest for keystones. BioScience 46:609-620.

R Development Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at http://www.R-project.org (accessed 15 March 2013).

Roni, P., T. Beechie, G. Pess, and K. Hanson. 2015. Wood placement in river restoration: fact, fiction, and future. Canadian Journal of Fisheries and Aquatic Science 72:466-478.

Sarkar, D. 2008. Lattice: Multivariate Data Visualization with R. Springer, New York, NY.

Slough, B. G., and R. M. F. S. Sadlier. 1977. A land capability classification system for beaver (*Castor canadensis* Kuhl). Canadian Journal of Zoology 55:1324-1335.
Suzuki, N., and W. C. McComb. 1998. Habitat classification models for beaver (*Castor canadensis*) in the streams of the central Oregon Coast Range. Northwest Science 72:102-110.
Tabachnick, B. G., and L. S. Fidell. 2007. Using multivariate statistics. Pearson Education, Inc., Boston, MA.

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Taylor, J., and R. Singleton. 2014. The evolution of flow devices used to reduce flooding by beavers: a review. Wildlife Society Bulletin 38:127-133.
Western Regional Climate Center (WRCC). 1990. Average Annual Precipitation Maps. Western Regional Climate Center, Reno, NV. Available online at https://wrcc.dri.edu/Climate/precip_map_show.php?simg=or.gif (Accessed 09 April 2018).
Wright, J. P., C. G. Jones, and A. S. Flecker. 2002. An ecosystem engineer, the beaver, increases species richness at the landscape scale. Oecologia 132:96-101.