AN ABSTRACT OF THE THESIS OF

Vanessa M. Petro for the degree of Master of Science in Forest Science presented on August 14, 2013.

Title: Evaluating "Nuisance" Beaver Relocation as a Tool to Increase Coho Salmon Habitat in the Alsea Basin of the Central Oregon Coast Range

Abstract approved:

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Many stakeholders involved with stream restoration in the Pacific Northwest have discussed the potential benefits of using beaver dam construction activities (*Castor canadensis*) as a management tool to improve degraded stream habitat for anadromous salmon species. In addition, there has been growing interest in using nuisance beavers, primarily controlled by lethal methods, to alleviate human-wildlife conflict issues and subsequently improve Coho salmon (*Oncorhynchus kisutch*) rearing habitat. To understand the efficacy of using beavers as a stream restoration tool, I studied the movement, survival, and dam construction of nuisance beavers relocated to the Alsea Basin of the Oregon Coast Range. I trapped and transported 38 individuals to the nine release sites where dams constructed by beavers would benefit coho salmon productivity. All adult and sub-adult beavers were equipped with tail-mount transmitters. Beavers moved an average of 3.3 ± 0.2 (SE) stream km from release sites. The maximum distance moved from a release site was 29.2 stream km. Post-release movements did not differ significantly by age or sex. All radio-tagged individuals dispersed from their release sites. Survival 16 weeks post-release was 47%. Twelve of the radio-tagged beavers died within 90 days of release. Three cause-specific sources of mortality were identified including predation, natural causes, and human related. Mountain lions (*Puma concolor*) were responsible for the majority of predation based mortalities. Of the 38 nuisance beavers relocated, only five individuals contributed to the nine dams constructed post-release. Six of these dams were built by one male: female pair. All dams constructed by relocated beavers were ephemeral. In addition to monitoring post-release beaver responses, I also assessed the utility of pre-existing models to identify release site locations. Thus, I explored dam habitat relationships of extant and relocated colonies throughout the Alsea Basin. I determined the utility of locally developed spatial models was reasonable. Analysis revealed primary pool habitat and valley floor width variables as strong indicators of beaver dam sites. I conclude beaver relocation as a tool for stream restoration in the Alsea Basin may not offer an effective solution to lethal control measures and coho habitat enhancement due to low survival rates, unwanted movement and establishment outside of suitable release sites, and lack of dam construction.

Evaluating “Nuisance” Beaver Relocation as a Tool to Increase Coho Salmon Habitat in the Alsea Basin of the Central Oregon Coast Range

by

Vanessa M. Petro

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Vanessa M. Petro, Author

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CONTRIBUTION OF AUTHORS

Dr. Jimmy D. Taylor assisted with design, data collection, interpretation of data, and writing of Chapters 2 and 3. Dr. Dana Sanchez was involved with design, interpretation of data, and writing of Chapters 2 and 3. Dr. Kelly Burnett assisted with design, interpretation of data, and writing of Chapter 3.

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DEDICATION

I dedicate this thesis to the three individuals that had the most influence with shaping the person I am today.

To my high school ecology teacher, Randy Young:

You showed me memorizing and identifying flora and fauna was actually fun, and taught me there was more to delineating a watershed than just drawing an ambiguous circle on a map.

To my watershed resource management professor, Farley Brown:

You taught me how the "three-legged step stool" was involved in the successful management of resources located within a watershed, introduced me to the wonderful world of stream ecology, and inspired me to interact with landowners and agencies the way you do.

To my father, Wayne Petro:

You may never realize how much you impacted my life by agreeing to take me out hunting when I first showed you my hunter safety card. All of our time spent in the woods together fostered my desire to learn more about the natural world.

CHAPTER 1: GENERAL INTRODUCTION

Resource managers in the Pacific Northwest have recognized the positive influences of beaver (*Castor canadensis*) dam construction on aquatic environments and are interested in using beavers as a management tool to augment in-stream complexity (Finnegan and Marshall 1997, DeVries et al. 2012). Often labeled "ecosystem engineers", beavers positively influence biological and fluvial components of stream systems with their dam construction activities (Jones et al. 1997, Wright et al. 2002). Beaver dams retain sediment, reduce water velocity (Naiman et al. 1988) and bank erosion (Olson and Hubert 1994), and augment low flows through increased water retention (Collins 1993, Pollock et al. 2003). The combination of these conditions positively influence fish productivity by altering aquatic prey abundance and community structure (Naiman et al. 1988), and providing areas where fish can expend less energy for foraging (Pollock et al. 2003, 2004), all of which have been found to be uncommon in non-impounded stream sections (Snodgrass and Meffe 1998, Pollock et al. 2004).

In the Pacific Northwest, beavers occupy stream systems with several anadromous fish species including the ESA-listed threatened Coho Salmon (*Oncorhynchus kisutch*). In western Oregon, coho salmon fry were three times more abundant in beaver-created habitat than in pools created by other fluvial processes (Leidholt-Bruner et al. 1992). Overwinter survival and growth of coho salmon smolts was suggested to be positively correlated with the availability of beaver pond habitat in the Cooper River Delta of Alaska (Lang et al. 2006). Given the potential of beavers to influence degraded stream habitats and productivity of coho salmon, managers are interested in using beavers as a stream restoration tool throughout the Coast Range of Oregon, where freshwater habitat is a limiting factor for coho populations and the area comprises of an Evolutionarily Significant Unit for this salmonid species (ODFW 2007). Integrating beavers into public and private management policies could allow a natural engineer to potentially enhance rearing habitats, reducing the need to implement commonly used restoration practices, such as placing large logs, boulders, or gabions. These methods are costly (McComb et al. 1990, Leidholt-Bruner et al. 1992) and may negatively impact surrounding stream habitat. Exploring the use of beavers as a management tool for stream restoration has also prompted addressing additional beaver-human conflict issues. Nuisance beaver populations on private lands throughout western Oregon are primarily controlled by lethal methods that are not publicly acceptable; humane controls including live capture and relocation are supported instead (Needham and Morzillo 2011).

One challenge that may affect the success of beaver relocation efforts is the assumption that an increase in beaver populations would result in a subsequent increase in damming habitat and coho productivity (Pollock et al. 2003, Pollock et al. 2004). No data on beaver population contributions to dam construction, their survival or cause-specific mortality sources, or responses to relocation efforts exists throughout the Coast Range of Oregon. In addition, it remains unknown to what degree ecological factors such as predation, colony densities, and food availability influence selection of the dam sites.

Another challenge in designing a beaver relocation effort is to identify appropriate release sites that will maximize the probability of achieving project goals, such as beaver survival and habitat restoration. Previous attempts to identify beaver release sites in other areas have relied on expert opinion, personal experience, or are unknown in cases where the site selection process was not described (Denney 1952, McKinstry and Anderson 2002). Knowledge of beaver habitat preferences must be addressed when considering relocation of beavers as a management strategy for stream habitat restoration (Collins 1993). Conditions that predict dam establishment and longevity likely vary from one region to another due the high variability of local conditions such as geomorphology and weather (Suzuki and McComb 1998). In the Coast Range of Oregon, Suzuki and McComb (1998) developed a Habitat Suitability Index (HSI) model that predicts potential dam site locations based on geomorphic attributes. Similarly, another habitat based model was designed to identify stream reaches of high intrinsic potential to provide quality rearing habitat for Oregon coastal coho salmon by producing an index score based on the relationship of stream attribute values including mean annual stream flow, valley width, and channel gradient (Burnett et al. 2007). Therefore a combination of these models output could be used to select locations where increased beaver dams should increase coho population growth and achieve multiple project objectives.

Limited research on beaver populations within the Oregon Coast Range provided the opportunity to study them to better understand their ecology and capabilities for salmonid habitat restoration. In a review of the literature, I found my study was the first to evaluate beaver relocation as a tool to decrease human-wildlife conflict in one area and increase anadromous fish habitat specific to coho salmon in another. To inform resource managers about the potential of beavers as a stream management tool, I evaluated post-release responses of relocated nuisance beaver and examined the utility of using spatial models for predicting suitable locations for beaver dam establishment specific to coho salmon habitat improvement. In Chapter 2, I used radio-tracking data from 30 beavers to address research objectives including: 1) quantify movement of relocated nuisance beavers, 2) examine differences in movement between age and sex groups, 3) estimate beaver survival and identify cause-specific mortality sources, and 4) quantify dam construction. I concluded this chapter with management implications and further research needs.

In Chapter 3, I examined data collected at 47 stream sites to assess the use of pre-existing spatial models for identifying release sites where beaver dams would enhance coho rearing habitat. Dam sites representing relocated and extant beaver colonies located throughout the Alsea Basin were incorporated into this analysis to determine if different or additional stream habitat relationships existed beyond those described in the Suzuki and McComb (1998) HSI model. Research objectives addressed in Chapter 3 included: 1) examine the utility of the modeling approach for identifying locations where released beavers are likely to construct dams and ideally improve rearing habitat for coho salmon, and 2) explore the importance of reach and channel-unit scale habitat characteristics for dam site establishment in the Alsea Basin of the central Oregon Coast Range. Chapter 3 concludes with management implications and further research needs.

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CHAPTER 2: MOVEMENT, SURVIVAL, AND DAM CONSTRUCTION RESPONSES OF BEAVERS RELOCATED TO COASTAL OREGON

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American beavers (*Castor canadensis*, hereafter beavers) are commonly referred to as ecosystem engineers due to their role in structuring stream channels and increasing habitat heterogeneity (Wright et al. 2002, Baker 2003, Jakes et al. 2007). In recent decades, the critical role of beavers has been recognized in enhancing channel morphology from their dam building and foraging activities (Naiman et al. 1986, Jones et al. 1997, Wright et al. 2004). The positive correlation of high aquatic productivity in beaver ponds compared to that in non-impounded sections without beaver is well documented (Leidholt-Bruner et al. 1992, Snodgrass and Meffe 1998, Collen and Gibson 2001, Pollock et al. 2003, 2004, MacCracken and Lebovitz 2005). Beaver ponds are highly productive for fish as a result of increased edge-to-surface ratios, productivity of vegetation within and near the stream, and increased abundance of prey (Collins 1993, Pollock et al. 2004). Slow moving stream habitats create shifts in macro-invertebrate abundance and community structure creating fish foraging opportunities that are uncommon in non-impounded stream sections (Pollock et al. 2004). In addition, reduced stream velocity allows fish to expend less energy for foraging (Pollock et al. 2003, 2004).

In the Pacific Northwest, beavers co-exist with several anadromous salmonids, many of which are listed under the Endangered Species Act. Growth rates for juvenile salmonids were positively influenced by the productive conditions created by beaver ponds (Lang et al. 2006). In coastal Oregon, coho salmon (*Oncorhynchus kisutch*) fry were three times more abundant in beaver-created habitat than in pools created by other fluvial processes (Leidholt-Bruner et al. 1992). Reductions in winter habitat capacities for coho smolts were observed at the Stillaguamish Basin in Washington, and attributed to loss of beaver pond habitat (Pollock et al. 2004). Similarly, the overwinter survival and growth of coho salmon smolts in the Copper River Delta of Alaska were suggested to be positively correlated with the occurrence of beaver pond habitat (Lang et al. 2006).

Resource managers in the Pacific Northwest have recognized the potential influences of beaver dam construction on aquatic environments and are interested in using beavers as a management tool to augment in-stream complexity (Finnegan and Marshall 1997, DeVries et al. 2012). In western Oregon, the decline in Pacific salmon populations survival, particularly ESA-listed coho salmon (*Oncorhynchus kisutch*), was determined to be linked to the loss of overwintering habitat (ODFW 2007). Beavers may help enhance this factor limiting salmon recovery by increasing the survival, growth, and abundance of coho salmon through their damming activities (Leidholt-Bruner et al. 1992, Pollock et al. 2003, Pollock et al. 2004, ODFW 2007). It has been suggested that an increase in beaver population size may increase the availability of pool habitat for coho smolts (Pollock et al. 2004); however, the utility for restoration depends on the percentage of beavers that construct dams and will likely contribute to coho rearing habitat. In coastal Oregon, beaver dams are primarily small and ephemeral, with few withstanding high water flows (Maser et al. 1981, Leidholt-Bruner et al. 1992). Despite limited dam longevity, integration of natural engineers into stream restoration management may offer an alternative to costly restoration practices including mechanical and re-vegetation approaches. Placement of large wood structures in streams throughout southwestern Washington cost approximately $4,046 each (MacCracken and Lebovitz 2005). Additional methods such as boulder or gabion placements in streams are also expensive (McComb et al. 1990, Leidholt et al. 1992) and the machinery necessary to place them can impact surrounding stream habitat.

Using beavers for stream restoration purposes introduces a variety of issues related to the social acceptability of their activities (Conover 2002, Baker and Hill 2003). Landowners that experience economic loss from beaver damming activities view beavers as a cost, while those that experience little to no economic loss describe beavers as a benefit (Woodward et al. 1985). In addition, nuisance beaver populations in urban areas throughout western Oregon are primarily controlled by lethal methods that are not publicly acceptable by everyone; humane controls including live capture and relocation are supported instead (Needham and Morzillo 2011). Therefore, using relocated “nuisance” beavers could offer an alternative management option to resolving human-beaver conflict. Landowners in Oregon may follow beaver relocation guidelines set by the Oregon Department of Fish and Wildlife (ODFW; ODFW 2012) to move nuisance beavers to an area where damming is desired. Despite this potential, the feasibility of beaver relocation as a restoration tool for coho salmon rearing habitat depends on several factors.

Beavers have been widely studied throughout North America; however, data is unavailable regarding their basic ecology, movements, dispersal, or how naïve beavers would respond to relocation efforts throughout the Coast Range of Oregon. Previous attempts to identify beaver release sites in other areas have relied on expert opinion, personal experience, or are unknown in cases where the site selection process was not described (Denney 1952, Hibbard 1958, Kundsen and Hale 1965, Courcelles and Nault 1983, McKinstry and Anderson 2002). Conditions that predict dam establishment and longevity likely vary from one region to another due to the high variability of local conditions such as geomorphology, hydrology, and weather (Suzuki and McComb 1998). In addition, variables such as age and sex may affect the success of the relocation effort. I found no studies that evaluated beaver relocation as a tool to decrease human-beaver conflict in one area and increase anadromous fish habitat in another. Therefore, assessment of post release responses of relocated beavers in the Oregon Coast Range is needed. My objectives were to: 1) quantify movement of relocated nuisance beavers, 2) examine differences in movement between age and sex groups, 3) estimate beaver survival and identify cause-specific mortality sources, and 4) quantify dam construction.

STUDY AREA

I conducted the study in the Alsea River Basin of the central Oregon Coast Range. The Alsea River drains into the Pacific Ocean, near the town of Waldport. The Basin is approximately 1,213 km^2 and consists of four sub-Basins: North Fork

Alsea River, Five Rivers/Lobster Creek, Drift Creek, and the South Fork Alsea River. Elevation ranges from sea level to 1,249 meters. 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. Coho salmon in the Alsea River Basin are part of the Coastal Coho Salmon Evolutionarily Significant Unit, which is an ESA-listed threatened species (ODFW 2007). In Oregon, the beaver population is considered abundant and healthy (Hiller 2011). The common tree species found within the Alsea Basin 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*), indian plum (Oemleria cerasiformis), stinking currant (*Ribes bracteosm*), red huckleberry (*Vaccinium parvifolium*), vine maple (*Acer circinatum*), and sword fern (*Polystichum munitum*).

METHODS

Release Site Identification

I mapped and characterized potential release sites for relocated beavers using data associated with a 10-m digital elevation model (DEM; Clark et al. 2008) and two existing models developed from data representative of my study area. These models were used to identify sites beavers were most likely to establish dams (Suzuki and McComb 1998) and where dams were most likely to provide high-quality instream habitat for coho salmon (IP; Burnett et al. 2007). I identified highly suitable stream reaches as having: a) 3-4 m bank-full width, b) 25-30 m wide valley floor, and c) < 3% channel gradient. These criteria were based on my interpretation of the Suzuki and McComb (1998) results that depicted the geomorphic ranges containing the highest frequency of beaver dams. This approach did not incorporate their habitat suitability index score criteria for beaver dam establishment (Suzuki and McComb 1998). I selected stream reaches that had high intrinsic potential for juvenile coho salmon rearing habitat (IP > 0.75). These stream reaches consisted of low gradients, unconstrained channels, and moderate mean annual stream flows. I used ArcGIS (version 9.3; ESRI, Redlands, California, USA) to intersect the outputs from the two sets of models to identify stream reaches as potential release sites.

Releases of relocated individuals should be prevented in locations where extant colonies are established. I surveyed for beaver activity one km upstream and downstream of each potential release site to reduce the potential of colony conflict. This distance represented neutral territories between colonies (Boyce 1981). The sites were categorized with methods in Snodgrass and Meffe (1998) that identified four classes of beaver activity; stream, active pond, abandoned pond, or recovering stream. The term ‘pond’ was replaced with ‘sites’ due to my observations of prevalent bank denning behavior and the occurrence of ephemeral beaver dams throughout the Alsea Basin. I only considered streams, abandoned sites, and recovering streams with no neighboring colonies within one km for release.

Capture and Handling

For relocation efforts, I obtained nuisance beaver colonies from damage locations throughout western Oregon. I targeted nuisance beaver colonies outside of the study area to reduce homing behavior. Hancock live traps (Custer, SD) were set at night when beavers were most active and checked the following morning to reduce capture related stress. Castor-based or food-based lures were used to increase trapping success. I placed traps near waterlines and dams to allow for easy access in setting traps and prevent drowning of trapped individuals. Burlap sacks were used to minimize stress by covering individuals in traps prior to processing and in transport to release sites.

I anesthetized sub-adults and adults to attach a tail-mount transmitter to monitor post-release responses. These individuals were administered an intramuscular injection of ketamine (5mg/kg) and xylazine (0.1mg/kg) and fitted with a 45g tail-mount transmitter equipped with a 12 hr mortality switch (Model J20500; SirTrack, Havelock North, NZ). Juveniles did not receive tail-mount transmitters. Sedated individuals were processed on an insulated mat and received ophthalmic ointment and a blindfold. I cleaned the tail sites with iodine for transmitter attachment and a sterile drill bit and cordless drill was used to produce a 5mm hole (Baker 2006). A biopsy punch was used to collect tissue samples from the tail site used to affix the tail-mount transmitter. I submitted the tissue samples for genetic analysis to confirm sex.

I assessed general health, classified age groups by weight, and monitored vitals for trapped individuals prior to relocation. All beavers were given a visual health check for external signs of sickness or trauma. I inserted a Passive Integrated Transponder (PIT) behind the neck region via a large gauge needle for all individuals. The PIT would allow for future identification if the individual was physically located without a transmitter. Body temperature was monitored rectally every five minutes once the beaver was sedated. I used blankets or ice packs to counteract any noticeable change in body temperature. Individuals were weighed, and sexed (except juveniles) by palpation for the os penis and presence of teats (Beer 1955, Baker 2006). I assigned age classes based on weight; juveniles < 8 kg, sub-adults 8.0-15.9 kg, and adults ≥ 16 kg (Breck et al. 2001).

I conducted hard-releases for all trapped individuals to replicate relocation efforts that would be conducted by landowners following the ODFW guidelines for relocation of beaver in Oregon (2012). Therefore, I did not use a holding facility and instead released them at their designated release site within 24 hours of capture. Individuals were transported in medium-sized dog kennels. I covered the kennels with dry blankets to prevent hypothermia in the beaver if ambient temperatures were considered cold (0˚C), or wet blankets and flooded approximately 3 inches deep with water if ambient temperatures were considered hot (> 27˚C). All members of a nuisance colony were removed to the best of my ability and transported to the same release site as previous family unit members. Therefore, individuals remained with the family unit. All study methods were approved by the United States Department of Agriculture, Animal and Plant Inspection Service, Wildlife Service's Animal Use and Care Committee Protocol QA-1891, and the Oregon Department of Fish and Wildlife Scientific Taking Permit No. 136-11.

Monitoring Movement, Survival, and Dam Establishment

Beaver responses to relocation efforts were intensively monitored following release. I monitored radio-tagged individuals three times weekly to track post relocation responses for the first month, twice a week for months two through six, and then once a week for a year post-release. Individuals were located during daylight hours with the homing technique using a handheld Communications Specialists telemetry receiver (Model R-1000; Orange, CA) equipped with a three element folding yagi antenna (Model 13863; Advanced Telemetry Systems, Isanti, MN). I used an omni-directional antenna (Model 13861; Advanced Telemetry Systems) for locating individuals from a vehicle. If homing was not possible, I obtained at least two bearings for each individual from known locations. Beaver locations were marked with a global positioning system (Model GPSMAP 76CSx; Garmin, Chicago, IL) and entered into ArcGIS. I estimated bearings in the program Location of a Signal (version 4.0; Ecological Software Solutions, LLC., Doral, FL). I retained locations for which the angle between bearings was 60-120˚apart. I monitored juveniles with trail cameras (Model PC800 Hyperfire; Reconyx, Inc., Holmen Wisconsin) at locations occupied by radio-tagged colony members. Trail cameras were placed also at active sites for radio-tagged individuals on whom transmitters had failed. I checked trail cameras weekly.

To determine cause-specific sources of mortality, I immediately found individuals that emitted a mortality signal unless conditions prevented this. If a beaver died leaving insufficient evidence to identify the individual, the body was scanned with a hand-held device for the PIT. I recorded the location of the carcass and proximate cause of mortality using the best available evidence. I classified mortalities into one of three groups: 1) natural causes, 2) human, and 3) predation. Natural causes included disease, physiological conditions, or unknown sources. I classified human related mortalities based on trapping, poaching, or road kill incidents. In the event of a predation, I identified the predator species based on the presence of bite marks, body entry, scat, and caching at the recovery site. Carcasses were collected when the cause of mortality was unknown, and submitted to the Oregon State University Veterinary Diagnostics Laboratory for further analysis.

All known beaver locations were surveyed for evidence of dam establishment each month. I measured the length and height of each constructed dam to the nearest 10 cm. The establishment and known fate dates were recorded to estimate the longevity of dams constructed by relocated beavers. Dam establishment was monitored for 64 weeks post-release.

Statistical Analysis

Movement distances were calculated to reflect weekly intervals post-release. I analyzed beaver movement from release sites by creating a distance matrix with methods developed by Dussault and Brochu (2003) for Visual Basic Editor in ArcGIS. I used the stream length distance measure because movement over land was unlikely due to topography. Distances were log-transformed for normality and compared between age and sex groups using Welch two sample t-tests. I did not statistically analyze the influences of age and sex on movement because of the large number of censored individuals and mortalities that would likely result in a Type I error. I performed all statistical analyses of movement responses in program R (version 2.15; www.r-project.org, accessed 15 Mar 2013).

I estimated the weekly Kaplan-Meier survival rate (1958) with known-fate modeling in Program MARK (version 6.0; White and Burnham 1999). Twelve (40%) radio-tagged individuals were censored in program Mark due to transmitter failure. I was unable to examine influences of age and sex on survival due to sample size (number of radio-ragged individuals) and encounter occasion limitations, preventing successful testing of our global model. The trail cameras provided sufficient information for movement responses, but not the necessary number of observations per sampling occasion to meet the assumptions for known-fate modeling of survival in Program Mark (White and Burnham 1999). I estimated cause-specific mortality rates in program MICROMORT (Heisey and Fuller 1985).

Examination of post-release survival and movement responses across weekly time intervals did not reflect behavioral or seasonal considerations of extant beaver because I believed the relocation efforts masked these influences. I chose to analyze these responses over a pooled 16 week post-release duration because: a) radio-transmitters had short retention times (60 ± 14 (SD) days) due to equipment failures, and b) all observed mortalities occurred within 90 days of release. I excluded one animal from analysis because it died from capture myopathy post-release. The last date of live-location served as the final movement and survival data point. Statistical significance was assumed for all tests when $\alpha \leq 0.05$.

RESULTS

In the Alsea Basin, I modeled seven stream km of highly suitable dam establishment habitat, and 272 stream km as high intrinsic potential for coho salmon. Intersection of these results identified two stream km as potential release sites. Release sites were distributed across 19 stream reaches located in both private and public ownership. I was declined permission to relocate individuals at four sites. Six release sites were occupied by extant beaver colonies within the one stream km distance. Therefore, I had nine eligible sites for beaver relocation efforts (Fig. 2.1).

I relocated 38 nuisance beaver from 12 separate colonies to the nine unoccupied release sites from September through December of 2011. The average colony size for relocated beavers was 3.1 ± 1.6 (SD). Of the 12 colonies: six completely separated, two separated into smaller family units, two were completely

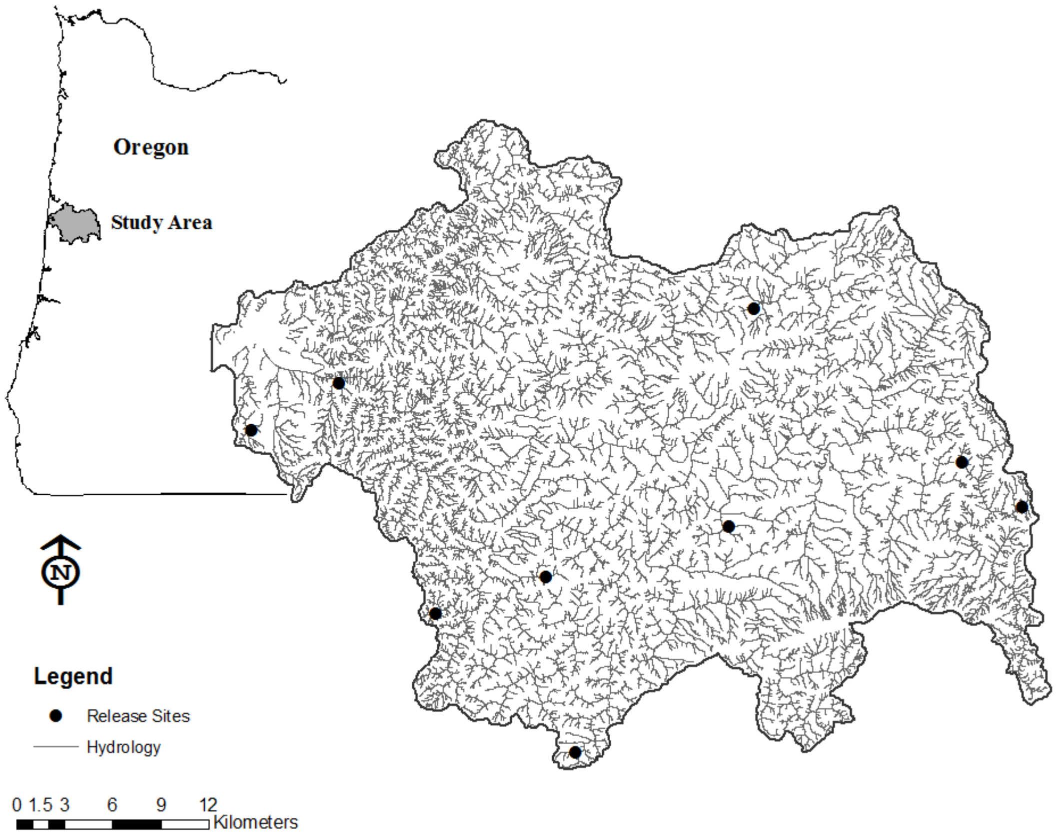

Figure 2.1 Map of modeled unoccupied release sites identified as highly suitable for beaver dam establishment and high intrinsic potential for Coho salmon, Alsea Basin, Oregon, 2011-2012

depredated, one remained intact, and one colony only had one relocated individual (Table 2.1). The age distribution was 61 % (*n* = 23) adults, 21% (*n* = 8) sub-adults, and 18% (*n* = 7) juveniles. I radio-tagged 31 (*n* = 18 F, 13 M) adult and sub-adult beavers.

All radio-tagged individuals moved from their initial release sites, but movements were variable. The mean distance moved from the release site within 16 weeks post-release was 3.3 ± 0.2 (SE) stream km. The longest recorded movement from a release site was 29.2 stream km (See appendix A.1). The minimum distance moved from a release site was 0.2 stream km. Maximum movement distance from a release site was attained within 30 days for 18 (60%) radio-tagged individuals. Females moved 2.7 ± 0.2 stream km whereas males moved 4.3 ± 0.4 stream km (Fig. 2.2). Adults moved 3.3 ± 0.2 stream km and sub-adults moved 3.6 ± 0.4 stream km within 16 weeks post-release. An additional four (13%) individuals conducted maximum movements within eight weeks and the remaining eight (26%) within 12 weeks post-release. Most individuals (57%) returned within a mean distance of 3.4 ± 1.0 stream km of release sites after conducting these exploratory movements. Total median movement distances of adults were similar to sub-adults (t_{298} = 0.0, P = 0.970) and for males and females (t_{361}= -1.4, P = 0.161) within the 16 weeks post-release. Post-release movement distances for week 16 were represented by only seven beavers.

Table 2.1 Summary of colony dynamics for nuisance beavers relocated to the Alsea Basin, Oregon, 2011-2012.

Colony	Main Damage Complaint[b]	Trap Site Description[c]	No. of Beaver Released	Relocation Outcome	
				Dam Constructed	Colony Structure[d]
Lower Peak	D	A	2	N	S
Upper Peak	D	A	2	Y	I
Racks	D	U	3	N	S
SF Salmonberry	D	T	3	N	S
Cherry	D	T	2	N	D
Cherry[a]	D	U	2	N	D
Sudan	D	U	1	N	NA
Lint	TC	A	7	N	F
Racks[a]	TC	A	4	Y	S
Sudan[a]	D	U	5	Y	F
Upper 5 Rivers	B	H	4	Y	S
Buck	D	U	3	N	S

[a] Release of new colony at site after previous colony did not survive or no longer occupied the area.
[b] (D), dam related activities including flooding and culvert blockage; (TC), tree cutting/girdling; (B), bank destabilization.
[c] (A), agricultural; (T), timber; (U), urban and sub-urban; (H), hydroelectric dam/canal
[d] (I), remained intact; (S), separated; (F), separated into smaller family units; (D), entire colony depredated; (NA), not applicable because only one beaver represented this colony.

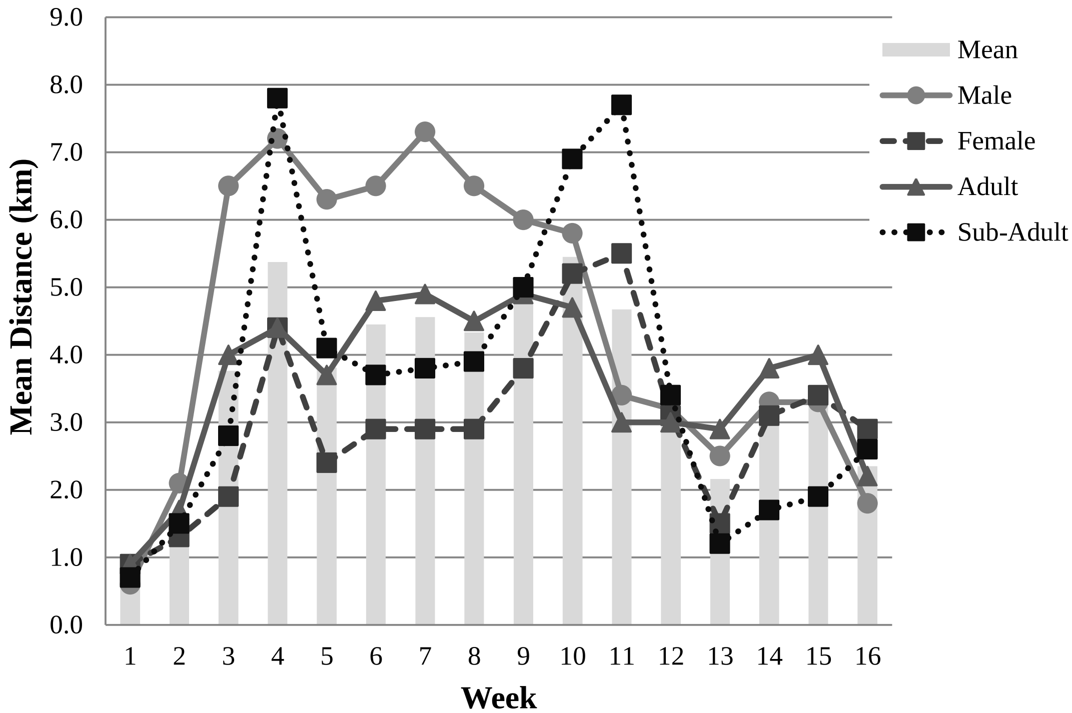

Figure 2.2 Mean movement distances (stream km) from release sites within 16 weeks post-release for both age and sex groups of relocated beavers, Alsea Basin, Oregon, 2011-2012.

Low survival was noted for relocated beavers post-release. The cumulative Kaplan-Meier survival rate for relocated beavers was 0.47 ± 0.12 (95% CI: 0.26-0.69) for 16 weeks post-release. Of the 30 radio-tagged beaver (excluding the one capture myopathy), eight (27%) died within 30 days, and an additional four (13%) died within 90 days of release (Table 2.2). Predation was the cause of mortality for seven (23%) individuals; mountain lions (*Puma concolor*) contributed to six deaths and the seventh mortality was from an unidentified predator. Three beavers (3%) died from natural causes based on necropsy results, including one case of tularemia (*Francisella tularensis*). One individual died from an unknown cause. I observed no trapping related mortalities outside of my own trapping efforts; however, one individual was potentially shot and placed as a "road kill" by hunters.

Twelve mortalities were observed within 16 weeks post-release. Cause-specific mortality source rates were 0.26 (95% CI: 0.09-0.43) for predation, 0.16 (0.01-0.30) for natural causes (e.g. disease), and 0.03 (0.00-0.10) for human related mortalities (Fig.2. 3). The majority of predation based mortalities (57 %) occurred within the first week post-release. I observed no mortalities after week 11; however, I was limited to tracking eight radio-tagged individuals as a result of transmitter failures after this time. Of the observed predation mortalities, 57% (4) were beavers trapped from timber or agricultural sites. Mortalities were located 7.7 ± 3.5 (SE) stream km away from release sites and within 30 m of waterline. No radio-tagged individuals retained their transmitters when data collection ceased (64 weeks post-release).

Table 2.2 Cause-specific mortalities observed for radio-tagged nuisance beavers relocated to the Alsea Basin, Oregon, 2011-2012.

Source	No. of Beavers	Days of Radio Contact	Average Days of Radio Contact
Predation	7	3 to 75	25
Natural Cause[a]	4	8 to 67	36
Human Related	1	10	10

[a] Two individuals diagnosed by necropsy results including: opportunistic *Bordetella bronchiseptica* infection from upper respiratory tract, and a circulatory collapse attributed to brain damage. Third individual diagnosed with tularemia (*Francisella tularensis*). Unknown cause of death was noted for the fourth individual.

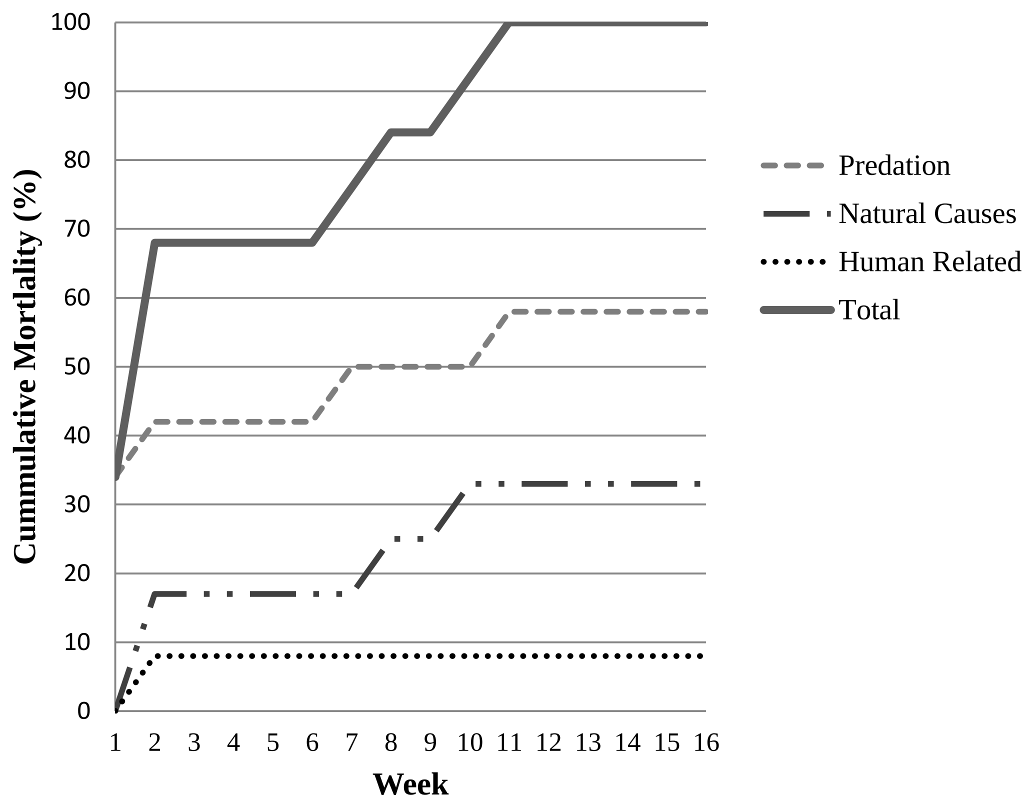

Figure 2.3 Cumulative mortality rates representing the three fate types identified within 16 weeks post-release for beavers relocated to the Alsea Basin, Oregon, 2011-2012

However, six (20%) individuals were still detected by camera surveys at this time. No juvenile beavers were detected by camera surveys post-release.

I observed nine total dams constructed by relocated beavers within the 64 week post-release monitoring period. Five of these dams were built by one male: female pair in 2011. In 2012, only four dams were built. One dam was constructed by the male: female pair from the previous year, but was located in a different tributary from the 2011 dam site. The other three dams were built by relocated individuals that separated from their colonies and established a nearby territory with a resident beaver as noted in camera surveys (Table 2.1). Overall, all dams were initiated during the late summer and early fall, and were ephemeral due to winter high flow events. These dams persisted on the landscape for an average of two months. Dams constructed by relocated beavers were on average three to four meters long and less than one meter in height.

DISCUSSION

Previous studies in North America have documented the effectiveness of relocating beavers to re-populate large areas following overharvest or habitat alteration; however, initial survival estimates were generally low, with some individuals moving long distances from release sites. Relocated beavers in North Dakota traveled an average distance of 14.6 stream km (9.1 miles), with one individual moving 238 stream km (148 miles) in seven months (Hibbard 1958). Beavers relocated in Wisconsin moved further from stream-based release sites (mean

11.7 km; max 76.2 km) than beavers moved to potholes and lakes (mean 5.1 km; max 50.8 km) (Knudsen and Hale 1965). Relocation efforts in Colorado resulted in average movement distances of 16.7 km (10.4 miles) with a maximum distance of 48 km (30 miles) (Denney 1952). The average movement for beavers relocated in northern Quebec was 18 air km (11 miles) with a maximum distance of 66 air km (41 miles) (Courcelles and Nault 1983). A study in eastern Oregon observed 78% of relocated individuals moving away or disappearing from release sites (Scheffer 1941).

Comparisons of movement responses for age and sex groups was challenging due to the limited number of relocation studies that examined movement post-release. A comparison of mean movement based on sex was only possible with the relocation effort conducted in Wisconsin (Knudsen and Hale 1965). From 1951-1957, the mean movements of relocated male beavers (5.8 stream km) was greater than that of female beavers (4.7 stream km) (Knudsen and Hale 1965). A similar pattern was noted with my relocated beavers despite statistical testing showing no significance between these groups. Age based movement responses post-release were not available with other studies. Average movement responses for beavers relocated to the Alsea basin were slightly greater for sub-adults (by 0.3 stream km) than adults. However, statistical testing found no significant differences in movement differences between these age groups.

Difficulties arise when attempting to predict movement responses of relocated individuals from established movement theories that are age and sex based (Sun et al.

2000). These theories reflect natural, seasonal movements of established colonies and are not relevant to the conditions released, intact colonies experience when placed into unfamiliar locations. These results suggest additional research is needed to address predictions for post-release movement based on these factors. I could not provide any explanation for my study subjects shorter movement distances (3.4 stream km) when compared to other studies. I did not examine variables such as predation, resource availability, and population size of extant beaver colonies, which might have influenced their movement. I suggest future relocation efforts into randomly selected or other HSI model (Suzuki and McComb 1998) based habitat suitability indices sites might be worth further exploration on this matter.

Relocating nuisance beavers may not offer an effective solution to lethal control measures as originally perceived by the general public (Needham and Morzillo 2011). Survival findings for this study were comparable to other relocation efforts. Post-release survival was 0.49 ± 0.06 over 180 days for individuals relocated in Wyoming, with predation responsible for 71% of the mortalities (McKinstry and Anderson 2002). Fifty percent of radio-tagged beavers relocated in northern Quebec died with an additional 40% that were never found (Courcelles and Nault 1983). In a pilot relocation study conducted by Oregon Department of Fish and Wildlife in southwestern Oregon, post-release survival was estimated between 30-40 %, with coyote (*Canis latrans*) predation accounting for the greatest source of mortality (DeWaine Jackson, ODFW, unpublished data).

Relocation into an unfamiliar site, in combination with reduced individual fitness from trapping related stress might influence their susceptibility to predators (McKinstry and Anderson 2002). I experienced complete depredation of two relocated colonies, and a combination of natural cause or human related mortalities coupled with extensive movement out of the release site for other colonies. These outcomes resulted in a subsequent release of a second colony to these unoccupied release sites at a later time. In addition, most predation based mortalities occurred with individuals relocated from timber or agricultural based landscapes than those removed from urban/suburban landscapes. This questions the potential assumption that beavers occupying urban environments would be more susceptible to predators as a result of limited predation pressure due to their close proximity to human establishment.

It remains unknown if the densities of nuisance beaver colonies might vary the success of relocation efforts. The average colony size for relocated beavers (3.1) was smaller than expected when compared to a literature review that determined extant colony size estimates ranged from 3.2 to 8.2 individuals throughout areas in North American (Novak 1987). The number of members occupying a colony can be influenced by several factors including predation, habitat quality, and population density (Novak 1987). I postulate my smaller relocated beaver colonies reflect recent establishment of breeding pairs into unoccupied territories. Relocation efforts in Wyoming noted an average of 17 beavers, representing different colonies, were released per site to prompt successful establishment. Beaver colonies relocated in northern Quebec typically separated post-release (Courcelles and Nault 1983). My relocated colonies either separated, remained in male: female pairs, or separated into smaller family units (Table 2.1).

Targeting nuisance colonies for relocation purposes presented temporal challenges. I attempted to relocate beavers during the principal dam building period of August through October (Olson and Hubert 1994) when they were less likely to disperse into other areas away from the release site (McKinstry and Anderson 2002, DeStefano et al. 2006). However, relocating beavers at this time of year during low flow periods may increase their susceptibility to mortality, while releasing during periods of high water in the spring may result in greater movement distances from release sites (Sun et al. 2000) and potentially reduce the likelihood of dam construction. In addition, I had to extend our trapping season beyond the principal dam building period due to the timing of human-wildlife conflicts in which beavers were targeted for removal throughout western Oregon.

Results from my study question the validity of using nuisance colonies as an alternative to stream restoration, particularity enhancement of coho salmon habitat in the Alsea Basin. Only five out of 38 total relocated beavers contributed to the construction of the nine ephemeral dams, with the assistance of extant beavers at three of the sites. This may elucidate the reality that there was no return on investment (i.e., no enhancement of coho rearing habitat) by dams due to lack of construction, short longevity, and non-establishment in model identified release sites within the Alsea Basin. Twenty-three of my relocated individuals (61%) were damming prior to relocation (Table 2.1). Interestingly, two previously non-damming individuals constructed dams and only two original damming individuals established dam sites post-release. Reasons for this remain unclear and warrant additional research.

MANAGEMENT IMPLICATIONS

Dams are the key component by which beavers have been recognized as ecosystem engineers and keystone species. My results suggest that not all beavers build dams, and correspond with previous observations that beaver dams are primarily ephemeral in the Oregon Coast Range (Maser et al. 1981, Leidholt-Bruner et al. 1991). Relocation may offer an alternative approach to managing nuisance beaver populations in some regions; however, the rationale for supporting this option other than lethal removal may not be as effective in the Alsea Basin due to the high rate of mortality noted in post-release responses. In addition, managers must recognize increasing or reintroducing beaver populations to selected areas may not always result in a return of constructed dams. My study revealed that out of 38 total beaver relocated to the Alsea Basin, only five beavers contributed to dam construction, three of which were assisted by extant individuals. The risk of relocated individuals dispersing out of target stream restoration areas and into locations where their foraging and damming activities may cause damage to another landowner's property should also be considered.

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CHAPTER 3: FACTORS INFLUENCING DAM CONSTRUCTION BY AMERICAN BEAVER IN THE ALSEA BASIN OF THE CENTRAL OREGON COAST RANGE

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American beavers (*Castor canadensis*, hereafter beavers) are considered ecosystem engineers where their dam-building creates physical state changes in abiotic and biotic communities (Jones et al. 1994, Wright et al. 2002). Dam-building beavers also are keystone species (Paine 1969, Power et al. 1996) where relatively small-scale effort (i.e., a dam) yields disproportionally large effects (Naiman et al. 1986). In many fluvial systems of the Pacific Northwest, beavers coexist with and may benefit anadromous salmonids, many of which are listed under the Endangered Species Act. Beaver impoundments increase water retention and reduce water velocity, attenuating floods and augmenting high flows (Collins 1993). Damming activities positively influence macro-invertebrate abundance and community structure, creating fish foraging opportunities that are uncommon in non-impounded streams (Pollock et al. 2004). In these productive conditions, juvenile salmonids expend less energy foraging, resulting in increased growth rates (Lang et al. 2006). In Coastal Oregon, coho salmon (*Oncorhynchus kisutch*) fry were three times more abundant in beaver created habitat than in pools created by other fluvial processes during the fall season (Leidholt-Bruner et al. 1992). Overwinter survival and growth of coho smolts was suggested to be positively correlated with the availability of beaver pond habitat in the Cooper River Delta of Alaska (Lang et al. 2006).

Given the potential to benefit salmonids, land managers are interested in the feasibility of using beavers for stream restoration. As a prime example, lack of fresh water stream complexity, specifically high-quality overwintering rearing habitat that beavers may help create has been identified as a primary limiting factor for recovery of coho salmon in western Oregon (ODFW 2007). Pollock et al. (2004) suggested that increasing beaver populations may be a simple and effective means to increase coho salmon production. This is primarily based on the assumption that beavers would construct habitats that may increase survival, growth, and abundance of salmonid fishes (Pollock et al. 2003, Pollock et al. 2004). However, no data exist on the contribution of beaver populations to dam construction in the Pacific Northwest. Furthermore, most dam-building attempts occur during low-flow stages in August through October (Olson and Hubert 1994) and most dams in western Oregon are lost during winter high-flow events (Maser et al. 1981, Leidholt-Bruner et al. 1992). Beaver impacts to stream systems are also cyclical (Baker and Hill 2003) and the rate of colonization and abandonment of sites remains unknown throughout western Oregon. Growing interest over using beaver relocation as a management tool has led to the adoption of new management practices available to landowners in some Pacific Northwest states. In Oregon, nuisance beavers may be relocated from one area to another by following Oregon Department of Fish and Wildlife's guidelines (ODFW 2012). In Washington, release of nuisance beavers is authorized in certain circumstances in accordance with state law (RCW 77.32.585).

Problems arise in designing instream habitat restoration efforts with nuisance beaver due to the lack of criteria and availability of information necessary to predict suitable release sites. Unwanted movement from release sites, mortality loss, or conflict with landowners further confounds this. Knowledge of beaver habitat requirements may help address these problems when considering beavers as a tool for stream habitat restoration (Collins 1993). Several studies have documented the importance of vegetative and reach-scale geomorphic variables associated with beaver dam locations. Percentages of hardwood vegetation and abandoned fields described locations of damming colony sites in Massachusetts (Howard and Larson 1985). In northern Ontario, high densities of shoreline woody vegetation and upstream watershed area characterized dam establishment sites (Barnes and Mallik 1990). Channel gradient and width have been noted as important determinants of damming locations (Howard and Larson 1985, Beier and Barrett 1987) as has valley floor width (Suzuki and McComb 1998).

Efforts to predict suitable beaver release sites may be aided by understanding dam habitat composition and structure at multiple spatial scales. According to the hierarchically nested habitat classification system of Frissell et al. (1986), each stream reach consists of individual channel-unit scale habitat features (e.g., pool, riffle, and glide). Unlike the reach scale, exploration of instream variables at a channel-unit or finer scale that might be important to beaver remains a novel concept. I hypothesize that beavers using small streams, such as those in the Oregon Coast Range, require sufficient pool habitat for security and foraging purposes (MacCracken and Lebovitz 2005). However, a review of sampling methods found no prior studies that characterized habitat at the channel-unit scale when examining relationships with beaver dams. Instead, one study collected pool data restricted to areas nearest to instream wood structures used for dam construction (MacCracken and Lebovitz 2005), and stream cross-sectional area (Barnes and Mallik 1997) and stream depth (Beier and Barrett 1987) were previously studied, but not at the channel-unit scale. My work on relocating nuisance beaver colonies into unoccupied sites (Petro 2013, chapter 2) created an opportunity to further explore habitat characteristics that cue dam building by incorporating both channel-unit and reach-scale features.

Identification of suitable release sites based on reach-scale geomorphic characteristics was possible for western Oregon using a beaver habitat suitability model (HSI) developed by Suzuki and McComb (1998). However, the model was constructed with field data from only one sub-basin and did not incorporate variability over a larger spatial extent. The reach-scale geomorphic predictor variables determined by Suzuki and McComb (1998) to be important for dam site establishment can be derived from inexpensive and easy to obtain digital elevation data, possibly allowing for model application over a large area when field data cannot be collected. A strategic tool may be developed for planning beaver release sites by combining the HSI (Suzuki and McComb 1998) modeled reaches with stream reaches most capable of providing high-quality rearing habitat for juvenile coho salmon in the Oregon Coast Range (Burnett et al. 2007). My objectives were to: 1) examine the utility of the modeling approach for identifying locations where released beavers are likely to construct dams and ideally improve rearing habitat for coho salmon, and 2) explore the importance of reach and channel-unit scale habitat characteristics for dam site establishment in the Alsea Basin of the central Oregon Coast Range.

STUDY AREA

I conducted the study in the Alsea River Basin of the central Oregon Coast Range. The Alsea River drains into the Pacific Ocean, near the town of Waldport. The Basin is approximately 1,213 km^2 and consists of four sub-Basins: North Fork Alsea River, Five Rivers/Lobster Creek, Drift Creek, and the South Fork Alsea River. Elevation ranges from sea level to 1,249 meters. 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. Coho salmon in the Alsea River Basin are part of the Coastal Coho Salmon Evolutionarily Significant Unit, which is an ESA-listed threatened species (ODFW 2007). In Oregon, the beaver population is considered abundant and healthy (Hiller 2011). The common tree species found within the Alsea Basin 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*), indian plum (*Oemleria cerasiformis*), stinking currant *(Ribes bracteosm*), red huckleberry (*Vaccinium parvifolium*), vine maple (*Acer circinatum*), and sword fern (*Polystichum munitum*).

METHODS

Site Classes

Beaver dam habitat composition and structure were examined within the Alsea Basin by classifying study sites into two groups: 1) model and 2) dam sites (Fig. 3.1). I identified "model sites" (Group 1) as those that were highly suitable for beaver dam establishment (Suzuki and McComb 1998) and where beaver dams were most likely to provide high-quality instream habitat for coho salmon (Burnett et al. 2007). I used a stream network developed from a 10-m digital elevation model (DEM; Clarke et al. 2008) in ArcGIS (version 9.3; ESRI, Redlands, California, USA) to choose model parameters. I interpreted Suzuki and McComb's (1998) HSI results to determine the best of the best sites for dam establishment, not the full range of possible dam sites. Thus, I defined highly suitable stream reaches as having: a) 3-4 m wide bank-full width, b) 25-30 m wide valley floor, and c) $\leq$ 3% channel gradient. I intersected those stream reaches with streams possessing high ($\geq$ 0.75) intrinsic potential (IP) for juvenile coho salmon (Burnett et al. 2007). Intrinsic potential values were derived from reach-scale variables of channel gradient, valley constraint, and mean annual flow. The intersection of the two sets of stream reaches served as potential release sites for a beaver relocation project in the Alsea Basin (Petro 2013, chapter 2). I included additional randomly selected model sites with locations that met my criteria for highly suitable beaver dam establishment, but were not used as release sites.

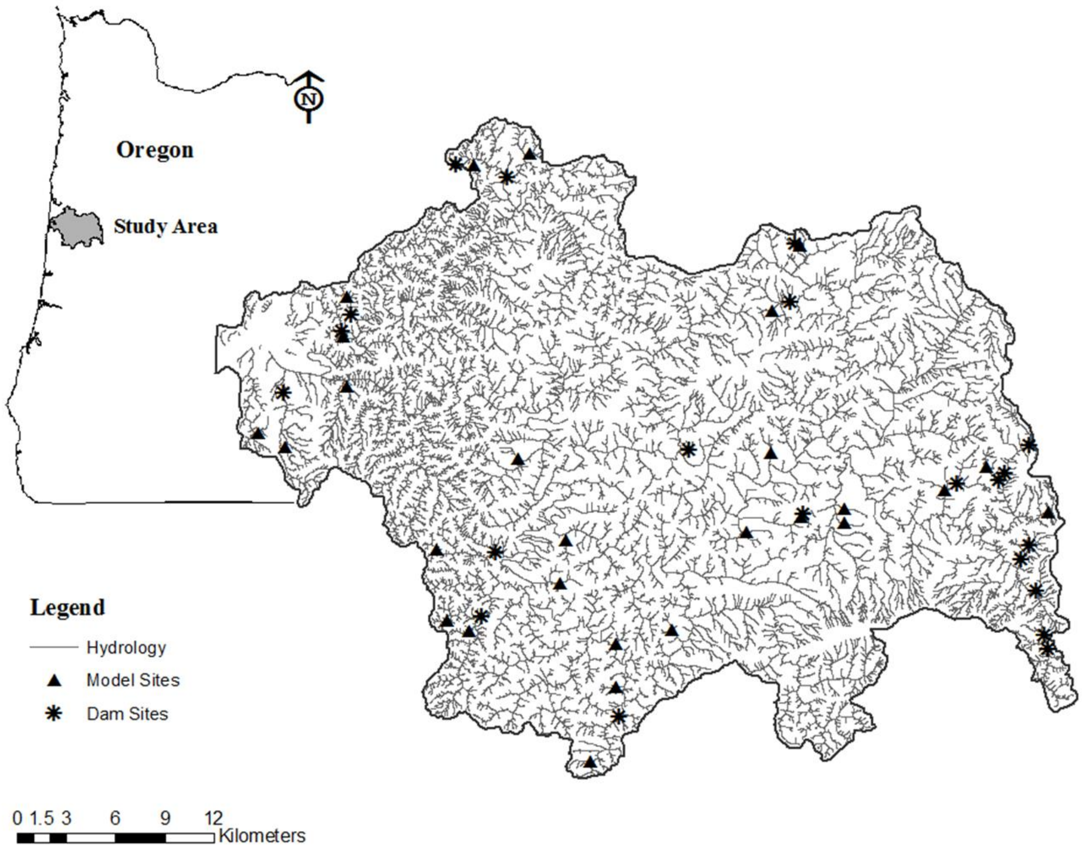


Figure 3.1 Distribution of stream sites sampled for beaver dam habitat composition and structure, Alsea Basin, Oregon, 2011-2012

“Dam sites” (Group 2) were extant colonies identified through aerial photos and local knowledge, and also included sites where relocated nuisance beavers constructed dams (Petro 2013, chapter 2). Both study site groups were considered mutually exclusive because all model sites were unoccupied by beaver.

Field Data Collection

All sites were surveyed using methods similar to Barnes and Mallik (1997). Two 100-m X 30-m plots were placed at each site. I determined plot dimensions by using the average length of delineated potential release sites (100 m) and the average distance beavers have been documented to use vegetative habitat from shoreline (Jenkins 1980). I randomly selected the streamside location for one plot and then placed the other plot on the opposite side. For model sites, I centrally placed a point within the site to separate the upstream and downstream plots (Fig. 3.2). For dam sites, I located a point at the stream center immediately up- and down-stream of any influence from the colony activities (Fig. 3.2). I assumed this arrangement would restrict sampling to areas unaltered from current beaver damming and foraging activities. Plot and transect sampling methods were the same for both groups.

I randomly selected four locations in each plot to collect vegetation data and extended a 1-m X 30-m belt transect from the stream bank, oriented perpendicularly to

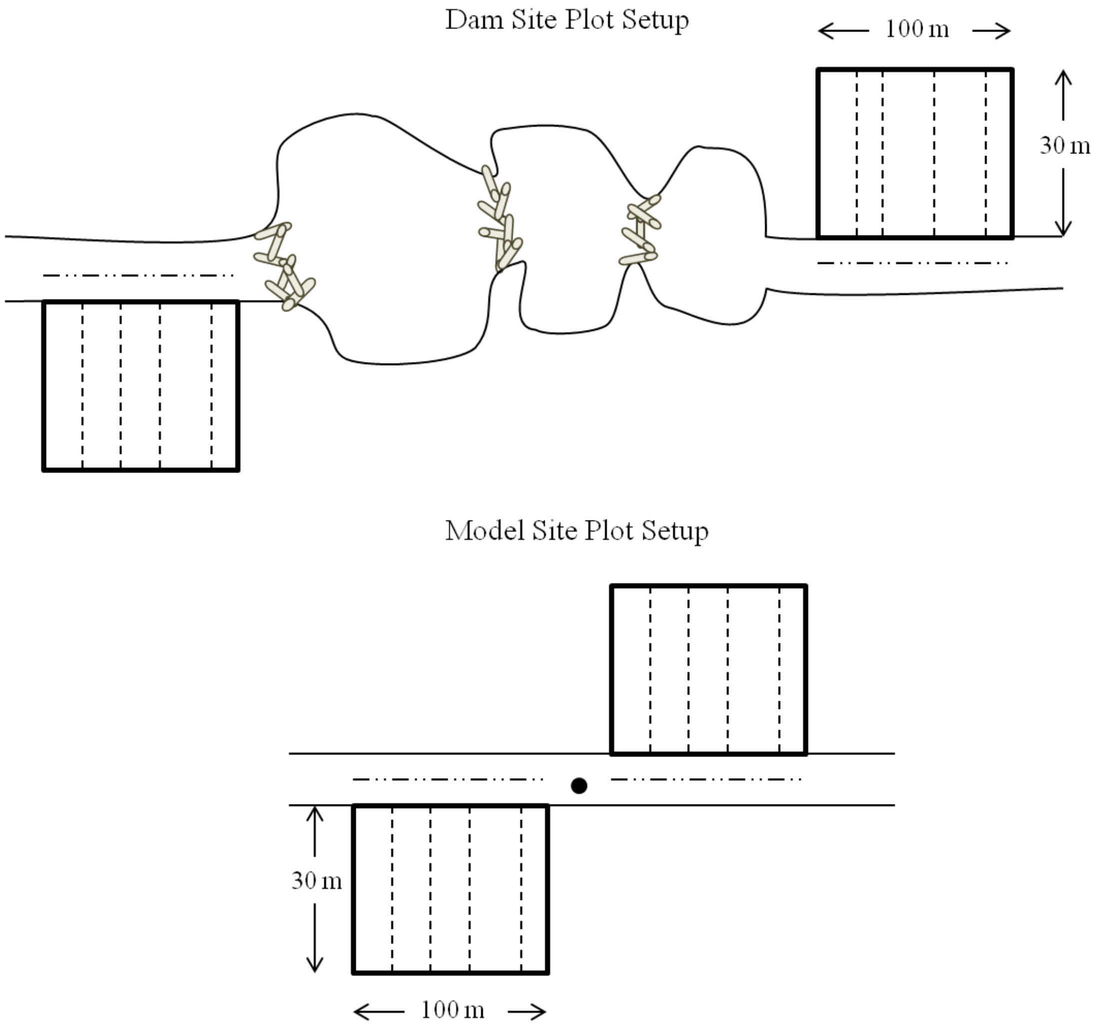


Figure 3.2 Illustration of plot layouts used at study sites to collect geomorphic and vegetative habitat variables, Alsea Basin, Oregon, 2011-2012.

the valley aspect (Fig. 3.2). I measured and recorded woody stem species ≥1 cm in diameter at stump height (30 cm above ground; Johnson and Naiman 1990). Percent overstory canopy cover was recorded at 0, 15, and 30 m along each transect using a spherical densiometer.

I delineated the stream into primary and secondary habitat units throughout each 100-m plot to collect channel-unit scale data. Habitat units were identified looking upstream 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. The maximum depth and pool tail crests (deepest point water exits a pool) were measured to the nearest 1cm with a meter stick.

Bank-full width was determined by evidence of scouring from the 1.5-year return flood interval and measured to the nearest 10 cm with a meter tape at 20-m intervals perpendicular to the thalweg throughout each plot (5/plot). The valley floor width was measured 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/plot). I measured percent channel gradient and hillside slope with a hand held clinometer at the 25-m and 75-m plot distances. Channel gradient was measured over 20-m in each direction (up and downstream) of the plot distances. Hillside slope was recorded within 20 m of the active channel. I surveyed the number of large wood pieces and jams in the bank-full channel of each 100-m plot. Large wood length and width dimensions were measured with a meter tape to the nearest 10 cm. I only measured pieces that contributed as a potential anchoring location for dam establishment or aided in pool creation. I visually recorded the number of jams that occurred within the 100-m plot that contained ≥ 2 pieces of large wood, defined as ≥ 10 cm in diameter and ≥ 1 m in length.

I combined geomorphic and vegetative measurements across both plots for each sampled study site (Table 3.1). Due to the large amount of woody vegetative species sampled, only species frequently observed in beaver foraging and damming activities were retained for analysis. Willow species were rare, occurring in fewer than three study sites, and were subsequently eliminated from analysis. I removed one suitable site (Lyndon Creek 3 sample unit) before analysis because the stream was dry.

Statistical Analysis

Tests for normality and homogeneity of variance were conducted using the R statistical software program (version 2.15; www.r-project.org, accessed 15 Mar 2013). Log and square root transformations were applied to variables with non-normal distributions. Non-parametric tests were used when applicable to analyze data that could not be transformed to a normal distribution.

I used paired t-tests to examine differences between DEM-derived and field-derived estimates of dam sites to determine if the DEM based stream network (Clarke

Table 3.1 Vegetative and geomorphic variables sampled for beaver dam habitat composition and structure, Alsea Basin,Oregon, 2011-2012.

Habitat Variable	Description
Vegetative	
Vine maple	Percent stem density recorded
Red alder	Percent stem density recorded
Salmonberry	Percent stem density recorded
Willow species	Percent stem density recorded
Canopy cover	Average percent overstory canopy cover
Reach-scale 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 percent gradient measured within bank-full
Hillside slope	Average percent gradient measured outside of bank-full
Channel-unit scale geomorphic	
Residual pool depth	Average difference between pool max depth and pool tail crest depth for all primary and secondary pools sampled (cm)
Percent pool habitat	Percent of primary pool habitat recorded along the channel thalweg
Number of pools	Total number of primary and secondary pools sampled (cm)
Max depth	Average max depth of all primary and secondary pools (cm)

et al. 2008) was a reasonable data source to apply HSI (Suzuki and McComb 1998) model site selection criteria (bank-full width, valley floor width, and channel gradient). In addition, I used a Wilcoxon rank sum test to compare the DEM (Clarke et al. 2008) derived HSI (Suzuki and McComb 1998) scores for my sampled dam sites and an equal number of random sites generated with ArcGIS. This provided an assessment of the utility for the HSI model (Suzuki and McComb 1998) to provide coarse filter selection for dam sites within the Alsea Basin. I used Welch two sample t-tests to compare field-derived estimates of the HSI model input variables (bank-full width, valley floor width, and channel gradient) for dam sites sampled by Suzuki and McComb (1998) and for my field sampled dam sites to explore potential temporal changes in dam site establishment. I compared stream habitat variables between model and dam sites with Welch two sample t-tests or Wilcoxon rank sum tests for non-normal variables. This step would determine if selecting locations that were highly suitable for dam site establishment was reasonable based on the narrow range of values for vegetative and reach-scale geomorphic variables. In addition, it would also elucidate if channel-unit geomorphic variables were important in dam habitat composition and structure.

I examined dam habitat associations with stepwise discriminant analysis (DA) in SPSS (version 19.0; SPSS, Inc., 2002) to determine the vegetative and geomorphic variables that best predicted the model and damming groups. Discriminant analysis is an eigenanalysis technique that maximizes separation of pre-defined groups through linear analysis of among group variation (McCune and Grace 2002). Partial F-tests were set to the defaults of 3.0 to enter and 2.5 to remove stream habitat variables. I assessed variation among groups with Wilks' Lambda. Prior probabilities were based on group size. The discriminant function classifications were evaluated with cross validations or "jack-knife" classification. I used a confusion matrix to assess the classification accuracy. Statistical significance was assumed when $\alpha \leq 0.05$ for all tests.

A univariate outlier analysis conducted with SPSS 19.0 (SPSS, Inc., 2002) using a Mahalanobis distance measure indicated no outliers existed ($F_{14} = 36.1$, *P*-value < 0.001). The stream habitat data matrix used for the DA did not meet the multivariate normality assumption required 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). I visually assessed the linearity of all variables among both groups with a scatterplot matrix using the "lattice" package in R (Sarkar 2008). The dataset met the linearity assumption for discriminant analysis due to strong linear relationships observed within channel-unit scale variables.

RESULTS

Field data were collected from 47 study sites during low-flow periods in 2011 and 2012. In the Alsea Basin, 272 stream km were modeled that had an IP value ≥

0.75 and seven stream km of highly suitable habitat for beaver dam establishment out of 3,761 total stream km. Overlay of these model selected sites identified two stream km of habitat as potential release sites. Channel gradient, valley floor width and bank-full width estimates did not differ between DEM-derived and field-derived estimates at dam sites in 2011-2012 ($t_{20} = -1.8$, $P = 0.083$; $t_{20} = 1.5$, $P = 0.140$; and $t_{20} = 1.3$, $P = 0.221$ respectively; Table 3.2). The DEM-derived HSI scores (mean = 0.60) for dam sites sampled in 2011-2012 were higher than the DEM-derived HSI scores (mean = 0.10) for random locations found within the Alsea Basin ($W = 403$, $P < 0.001$). The mean values for channel gradient, valley floor width, and bank-full width were similar between dam sites sampled by Suzuki and McComb (1998) and those sampled for this study in 2011-2012 ($t_{49} = -0.9$, $P = 0.348$; $t_{38} = 0.4$, $P = 0.658$; and $t_{29} = 0.6$, $P = 0.548$ respectively; Table 3.3). Channel-unit and reach-scale geomorphic variables including valley floor width and hillside slope differed between model and dam sites (Table 3.4). Dam sites were distinguished by wider valley floors, lower percent hillside slopes, and fewer but larger and deeper pools (Table 3.4). Vegetative variables, number of jams, amount of wood, bank-full width, and channel gradient did not differ between model and dam sites ($P > 0.05$).

The discriminant function analysis revealed overall variation among dam and model sites (Wilks Lambda = 0.464, $P < 0.001$) and the significant discriminant function explained 54% of between group variability. Increases of percent primary

Table 3.2 Comparison of DEM and field-derived habitat variable mean (SE) estimates at sampled dam sites, Alsea Basin, Oregon, 2011-2012.

	Dam Sites			
Variable	DEM	Field	*P*-value	Trans[a]
Channel gradient (%)	1.0 (1.1)	2.0 (0.2)	0.083	none
Valley floor width (m)	54.8 (32.8)	38.9 (4.1)	0.140	$\log_{10}$
Bank-full width (m)	5.7 (2.5)	4.8 (0.6)	0.221	$\log_{10}$

[a] Transformation based on normal probability plots.

Table 3.3 Comparison of field-derived habitat values at dam sites sampled by Petro et al. (2013) and Suzuki and McComb (1998), Alsea Basin, Oregon, 2011-2012.

	Dam Sites			
Variable	2011-2012 (n = 21)	1988-1989 (n = 40)	*P*-value	Trans[c]
Bank-full width (m)	4.8 (0.6)	4.1 (0.1)	0.548	$\log_{10}$
Valley floor width (m)	38.9 (4.1)	32.8 (2.0)	0.658	$\log_{10}$
Channel gradient (%)	2.0 (0.2)	2.2 (0.2)	0.349	$\log_{10}$

[a] Transformation based on normal probability plots.

Table 3.4 Habitat mean values (SE) for model and beaver dam sites in the Alsea Basin, Oregon, 2011-2012.

Variables	Model (n = 26)	Dam (n = 21)	*P*-value	Trans [b]
Vegetative				
Vine maple (%)	10.3 (2.4)	11.3 (2.8)	0.722	sq rt
Red alder (%)	2.4 (0.6)	3.2 (0.6)	0.120	sq rt
Salmonberry (%)	65.8 (4.3)	62.0 (4.4)	0.549	none
Canopy cover (%)	93.7 (1.3)	90.5 (2.5)	0.483[a]	sq rt
Reach-scale geomorphic				
Valley floor width (m)	21.4 (1.5)	38.9 (4.1)	0.001	$\log_{10}$
Wood jams	3.5 (0.8)	4.1 (0.5)	0.271	sq rt
Large wood	3.6 (0.8)	4.1 (1.0)	0.949	sq rt
Bank-full width (m)	3.9 (0.2)	4.8 (0.6)	0.445	$\log_{10}$
Channel gradient (%)	2.2 (0.2)	2.0 (0.2)	0.392[a]	$\log_{10}$
Hillside slope (%)	36.6 (2.9)	28.0 (3.6)	0.001	sq rt
Channel-unit scale geomorphic				
Residual pool depth (cm)	22.1 (1.0)	33.5 (2.9)	0.052	$\log_{10}$
Percent pool habitat (%)	47.6 (3.0)	73.7 (3.2)	0.001	none
Number of pools[a]	39.0 (1.5)	32.2 (3.3)	0.035	sq rt
Max depth (cm)	20.8 (0.6)	82.7 (6.4)	0.001	$\log_{10}$

[a] *P*-values were based on Wilcoxon rank sum tests.

[b] Transformations based on normal probability plots.

pool habitat and of valley floor width were positively associated with dam sites (Fig. 3.3). The discriminant scores separated more effectively for both original groups than the discriminant scores for predicted group membership (Fig. 3.4). Classification results indicated 85% of the stream sites were correctly classified into both original groups while 81% of cross-validated sites were correctly classified. Model sites were classified with better accuracy (88%) than dam sites (71%) (Table 3.5).

DISCUSSION

Incorporation of locally developed models that rely on reach-scale geomorphic characteristics may offer a strategic tool for basin-wide identification of release sites in beaver relocation projects. This is supported by similarities I found between values measured in the field and estimated from the DEM-derived stream network (Clarke et al. 2008) for geomorphic inputs to the HSI model (Suzuki and McComb 1998). Furthermore, based on the DEM-estimated reach-scale geomorphic variables, the beaver HSI model (Suzuki and McComb 1998) successfully distinguished dam sites from random sites in the Alsea Basin. These findings are consistent with several studies that noted strong correlations of geomorphic variables to dam site locations including watershed area, stream cross-sectional area, stream gradient (Barnes and Mallik 1997), and both stream width and depth (Beier and Barrett 1987). Despite the utility of reach-scale geomorphic characteristics, my analyses also suggested the importance of considering fine-scale habitat criteria for identifying dam site locations suitable for future release sites.

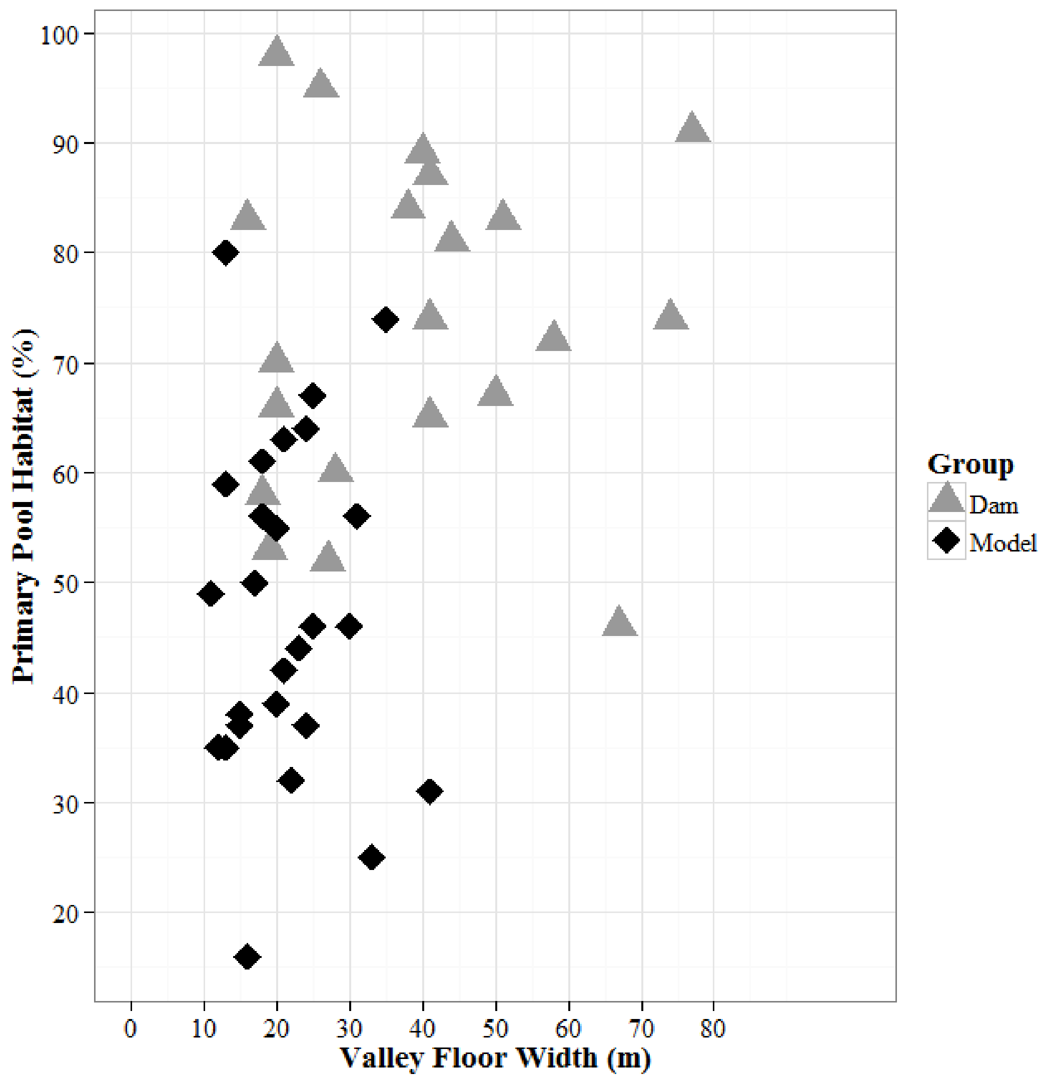
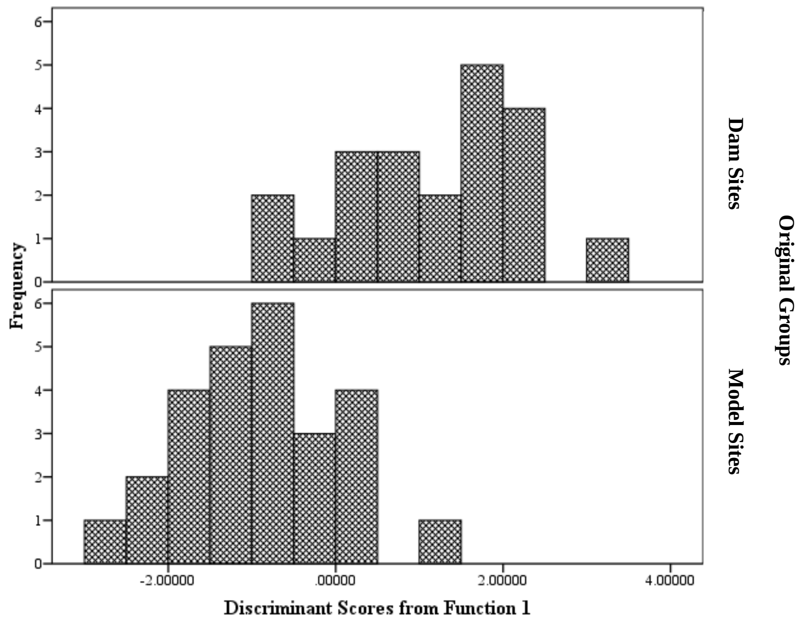


Figure 3.3 Scatterplot illustrating the relationship of percent primary pool habitat and valley floor width between model and beaver dam sites, Alsea Basin, Oregon, 2011-2012.



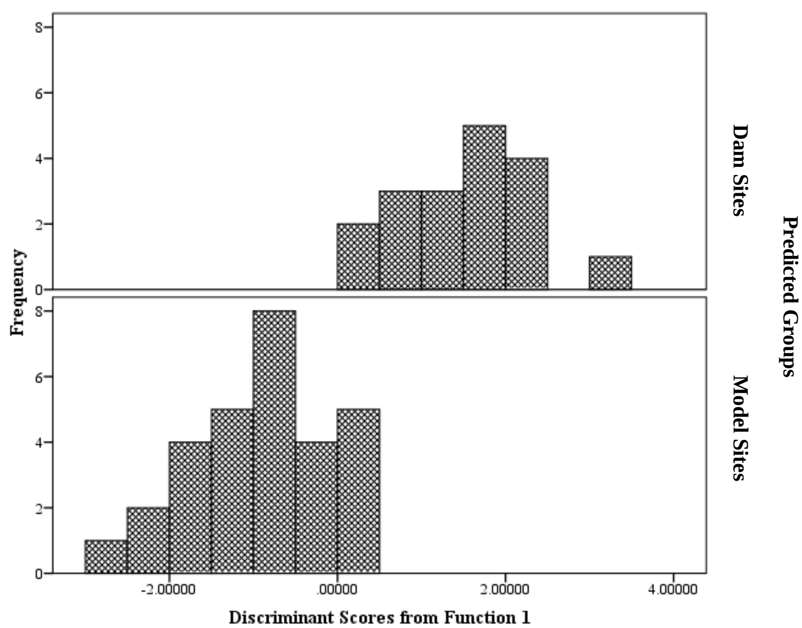


Figure 3.4 Histograms illustrating the distribution of discriminant scores for model and beaver dam sites, Alsea Basin, Oregon, 2011-2012.

Table 3.5 Confusion matrix of classifications for original and predicted groups sampled for beaver dam habitat structure and composition, Alsea Basin, Oregon, 2011-2012.

		Group	Predicted Group Membership: Dam Site	Predicted Group Membership: Model	Total
Original	Count	Dam Site	16	5	21
		Model	2	24	26
	%	Dam Site	76	24	100
		Model	8	92	100
Cross-validated[a]	Count	Dam Site	15	6	21
		Model	3	23	26
	%	Dam Site	71	29	100
		Model	12	88	100

a. In cross validation, each site is classified by the functions derived from all sites other than that site.

My multivariate analysis identified percent primary pool habitat as the strongest predictor of dam site locations within the Alsea Basin. This result supports my hypothesis that beavers require sufficient pool habitat for escape cover and food resource accessibility (MacCracken and Lebovitz 2005). Similarly, beavers were observed using instream wood structures that were in close proximity to deep pools in southwestern Washington (MacCracken and Lebovitz 2005). Reaches in the Truckee River Basin had higher frequencies of beaver use in deeper tributaries (Beier and Barrett 1987), while beaver dam establishment in the Swanson River Basin was highly correlated with reduced stream cross-sectional area that eases dam construction (Barnes and Mallik 1997).

My analyses revealed that vegetative variables had no explanatory power for identifying dam site locations in the Alsea 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 sites (Suzuki and McComb 1998).

Dam site establishment may be influenced by other factors beyond stream habitat characteristics within the Alsea Basin. For example, the lack of strong separation in discriminant scores for the original model and dam sites groups illustrated in Fig. 3.4 suggests the function did not discriminate well. The multivariate analysis did not include variables such as intra and inter-specific competition, predation, and disease, which remain unknown to what degree these factors might influence dam site establishment. In addition, my results may be influenced by spatial and temporal limitations at sampled dam sites. Firstly, dam sites surveyed for the purposes of this study reflect only one basin within the Coast Range of Oregon. Secondly, beaver dam establishment was examined for less than two years. However, mean values of channel gradient, valley floor width, and bank-full width as HSI model input variables were similar when sampled at dam sites from 1988-1989 and from 2011-2012. Expanding the scope of dam site locations used for analysis and extending the monitoring period may elucidate additional factors that affect dam longevity and number in this area.

Targeting highly suitable dam sites based on the HSI model (Suzuki and McComb 1998) criteria to narrow the scope of potential release sites for relocation efforts seemed a useful approach. However, expanding the criteria to include valley floors wider than 30 m seems warranted in future beaver relocation efforts given I found that valley floor widths were significantly wider in dam sites than model sites and that this variable was important in the discriminant model. Although more of the Suzuki and McComb (1998) dam sites were contained in the 25-30 m class than any other single valley floor width class, approximately 75 % of all dams occurred in valleys wider than 25 m. The importance of valley floor width as a predictor variable may be explained by dams that are established in wide valley floors are potentially less susceptible to high water flows than those located in narrower valleys (Suzuki and McComb 1998). Considering alternative criteria could further limit the number of areas identified as potential release sites. For example, interested managers could use my release site selection methodology as a coarse scale filter to identify suitable dam locations and then incorporate a fine scale assessment of primary pool habitat at those sites. This approach may reduce the amount of stream reaches identified for stream restoration by beavers when managers are limited by monetary resources.

MANAGEMENT IMPLICATIONS

Using "nuisance" 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). Baker and Hill (2003) acknowledged the rationale of relocation programs should be addressed prior to implementing management actions by answering questions such as: 1) what is the purpose and feasibility of the relocation effort, 2) why are beavers not currently established at the site, 3) why are beavers important to the site, 4) is natural dispersal a more feasible option for re-establishment than relocation, 5) and how will beavers respond in regards to movement and potential conflict with adjacent landowners and resources? Decisions regarding beaver relocation should be made with the best available knowledge and may include modeling efforts when data is absent (Baker and Hill 2003).

My approach for identifying highly suitable damming locations may be useful to other projects interested in using available spatial models for relocation. The accessibility of digital data or a DEM derived GIS layer offers an alternative approach to modeling release sites when the parameters that describe dam locations are available and on the ground field assessments are unrealistic due to resource constraints. Yet, spatial models should reflect similar geographical regions of target relocation areas due to variation in geomorphic and vegetative characteristics across the landscape.

In the Alsea Basin, results from this study may aid in identifying locations for coho salmon conservation with beaver dam establishment by providing two separate, nested habitat scales for a search radius. Management actions that encourage dam establishment through plantings of forage species may prove to be unsuccessful due to the limitation of vegetation predicting dam site locations. Despite the potential for nuisance beavers to be a stream management tool, the factors that influence dam and colony longevity remain unstudied in complex forest landscapes such as the Oregon Coast Range. In addition, further research is needed to examine the influences of predation, disease, and other variables that may affect dam site establishment beyond stream habitat variables.

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CHAPTER 4: GENERAL CONCLUSION

Understanding how beavers (*Castor canadensis*) respond to relocation is critical in assessing the efficacy of a beaver relocation project. Results from this thesis provide a foundation for understanding beaver ecology within the central Oregon Coast Range, despite limitations with radio telemetry. Chapter 2 documents how relocated beavers moved in relation to release sites that were predicted to be highly suitable for dam construction, and where dams would provide coho (*Oncorhynchus kisutch*) rearing habitat. In many cases, beavers moved across property ownership boundaries and movement from release sites was similar between age and sex groups. The documented low survival rate suggests that live-trapping and relocating beavers have animal welfare concerns that many may not consider when promoting relocation over lethal control. Depredation loss to cougar (*Felis concolor*) was the greatest single source of mortality and most events occurred within a week of release. This was likely affected by the lack of adequate escape cover (i.e., existing pools) in close proximity to release sites, complicated by the inherent stress of being moved to an unfamiliar area. Despite my best efforts to release colonies together, colonies did not remain intact post-release. While this study was not designed to test within colony behavior, one may theorize that individual instinct to survive overrode social responsibilities in this case. Ultimately, the planned measure of success of this study was to evaluate the response of coho to dams built by relocated beavers. Six relocated beavers were detected by trail cameras at the end of the study (64 weeks). Despite, targeting relocation efforts during the principal dam building period, only nine dams were constructed by relocated individuals, with three of those dams receiving construction assistance from extant individuals based on camera surveys. Given that the number of dams constructed by my relocated individuals was low and those dams were ephemeral, I was not able to measure any benefit from beaver relocation.

Chapter 3 demonstrates that using pre-existing models to predict suitable release sites for relocation and stream habitat restoration may be an adequate approach to identifying potential release sites; however, limitations may exist due to inadequacies in representing highly suitable dam sites accurately. Furthermore, the identification of primary pool habitat and valley floor width as strong predictors of dam sites in the Alsea Basin elucidates the need to consider basic needs of the beaver beyond forage availability (e.g., availability of escape cover in pools). The modeling approach for predicting release sites suggested usage of the 10-m digital elevation model (Clarke et al. 2008) was a feasible and accurate tool for site selection within the Alsea Basin. The utility of the beaver HSI model (Suzuki and McComb 1998) developed with data collected within the Drift Creek sub-Basin of the Alsea Basin was adequate for predicting current suitable damming locations in this area. Yet, further analysis revealed the need to consider additional criteria for dam site establishment. The determination of primary pool habitat and valley floor width as indicators of beaver dam sites may provide managers an improved ability to predict beaver dam establishment sites that incorporate high intrinsic potential for coho salmon for stream restoration purposes.

Collectively, results from this thesis suggest using relocated nuisance beavers as a management tool for restoration may not be feasible based on my radio-tagged individuals low survival rates, establishment outside of model predicted release sites, and lack of dam construction. In addition, the assumption that increasing beaver populations would result in a subsequent increase of damming habitat was not supported by my study. My data suggests live capture may not be an effective solution to lethal control measures due to high mortality rates of relocated individuals. Although my scope of inference was limited to the Alsea Basin, my dam habitat association results may provide a baseline comparison for watersheds with similar geomorphologic and vegetative traits throughout the Coast Range of Oregon.

INCIDENTAL FINDINGS

Routine monitoring of relocation responses for Chapters 2 and 3 provided the opportunity to observe seasonal beaver foraging behavior. Selective harvest of salmonberry (*Rubus spectabilis*), vine maple (*Acer circinatum*), and red alder (*Alnus rubus*) were detected on camera and on-site surveys for dam construction. This finding is contrary to observations describing beaver foraging preferences for willow species (*Salix* spp.) in several areas across the western United States (Collen and Gibson 2001, Baker and Hill 2003). Willow species were found near beaver establishment areas, but they appeared to be harvested less frequently. I observed similar foraging patterns for extant damming and non-damming colonies located within the Alsea Basin. Dam habitat surveys conducted by Suzuki and McComb (1998) also documented selective foraging on salmonberry and red alder within the Drift Creek Sub-Basin of the Alsea Catchment. Findings like these support the need for additional research that examines food selection and preferences among Coast Range beaver species. Such results would be useful to local watershed councils and special interest groups interested in “enhancing beaver habitat” through riparian planting projects.

This research study attracted a great deal of interest as the general consensus among the local public was there were very few beavers in the Alsea Basin. Suspected causes range from changes in forestry operations to over-trapping to predation and disease. Concerns of reduced beaver dam and colony persistence across the Coast Range also are a concern among some fisheries biologists with Oregon Department of Fish and Wildlife, who monitor trends in number of dams encountered during fish surveys (Chris Lorion, Oregon Department of Fish and Wildlife, personal communication). During the spring of 2012, I attempted to re-trap relocated individuals who experienced equipment failures of the tail-mount transmitters and replace them with a new unit. Within 45 days of trapping, I trapped 27 extant beavers near relocated beaver sites while the previously radio-tagged, relocated individuals continued to be detected on the trail cameras. These extant beavers were not previously in the area and were assumed to be dispersing from the lower river, as this period corresponded with spring dispersal seen in other beaver populations (Leege 1968, Baker and Hill 2003, DeStefano et al. 2006). In addition, I frequently observed non-damming colonies located throughout first through fourth order tributaries in the Alsea Basin while monitoring relocation responses in Chapters 2 and 3. My random observations of beavers dispersing, not damming, and living in bank dens present an interesting perspective on human perception of local beaver population in the Alsea Basin. From my observations, I postulate that the assumed reduction in beaver populations is attributed to lack of experience or knowledge in the proper identification of beaver activity. In short, it appears there may be more beaver colonies established within the Basin than originally perceived, yet they go largely unnoticed because they do not build dams or lodges, leaving only subtle clues to their existence. Future research should attempt to estimate effective population size of beavers in Coast Range watersheds where dams are desired.

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APPENDIX

Table A.1 Summary of post-release movement and survival responses of nuisance beavers relocated to the Alsea Basin, Oregon, September 2011-December 2012.

Beaver No.	Gender	Age Class	Relocation Site	Days of Contact	No. of Observations	Mortality Agent	Days Until Max Movement	Max Movement Distance from Release Site (km)	Final Movement Distance from Release Site (km)
2	M	Adult	Lower Peak	155	45	Censored[d]	98	4.8	0.7
3[a]	UNKN	Juvenile	Upper Peak	0	0	Unknown	0	0.0	0.0
4	M	Adult	Upper Peak	460	59	Survived	271	2.5	1.9
5	F	Adult	Upper Peak	459	45	Survived	330	2.4	1.9
6	M	Adult	Racks	67	27	Natural Cause	62	20.5	20.4
7[a]	UNKN	Juvenile	Racks	0	0	Unknown	0	0.0	0.0
8	F	Adult	Racks	10	3	Human Related	10	1.3	1.3
9	F	Adult	SF Salmonberry	78	32	Censored[d]	9	0.9	0.9
10	M	Adult	SF Salmonberry	11	6	Natural Cause	9	0.9	0.9
11	M	Adult	SF Salmonberry	60	22	Censored[d]	34	3.6	2.4
14	F	Adult	Cherry	10	5	Predation	6	2.2	2.1
15[a]	UNKN	Juvenile	Cherry	0	0	Unknown	0	0.0	0.0
16	M	Adult	Cherry[c]	3	1	Predation	3	0.2	0.2
17	F	Adult	Cherry[c]	3	1	Predation	3	0.2	0.2
18	F	Adult	Sudan	47	19	Censored[d]	47	11.9	11.9
19	F	Adult	Lint	9	2	Censored[d]	9	6.2	6.2
20	F	Adult	Lint	71	21	Predation	67	6.8	6.8

Beaver No.	Gender	Age Class	Relocation Site	Days of Contact	No. of Observations	Mortality Agent	Days Until Max Movement	Max Movement Distance from Release Site (km)	Final Movement Distance from Release Site (km)
21	M	Sub-Adult	Lint	7	4	Predation	2	0.4	0.1
22	M	Adult	Lint	8	4	Nautral Cause	8	6.1	6.1
23	F	Sub-Adult	Lint	75	20	Predation	57	6.5	1.3
24[a]	UNKN	Juvenile	Lint	0	0	Unknown	0	0.0	0.0
25	F	Adult	Lint	53	13	Censored[d]	17	6.2	3.9
26	F	Adult	Racks[c]	321	43	Survived	92	5.5	5.4
27	M	Sub-Adult	Racks[c]	347	54	Survived	233	1.5	1.5
28[a]	UNKN	Juvenile	Racks[c]	0	0	Unknown	0	0.0	0.0
29	F	Adult	Racks[c]	70	16	Censored[d]	2	1.2	0.5
30	F	Sub-Adult	Sudan[c]	56	23	Natural Cause	19	4.3	0.6
31	M	Adult	Sudan[c]	377	70	Survived	241	5.8	5.1
32[a]	UNKN	Juvenile	Sudan[c]	0	0	Unknown	0	0.0	0.0
33	F	Sub-Adult	Sudan[c]	22	4	Censored[d]	17	5.3	2.1
34	F	Sub-Adult	Sudan[c]	112	34	Censored[d]	24	5.1	3.2
35[b]	M	Adult	Upper 5 Rivers	0	0	Capture Myopathy	0	0.0	0.0
36	F	Adult	Upper 5 Rivers	11	4	Censored[d]	3	0.7	0.1
37	M	Adult	Upper 5 Rivers	357	51	Survived	11	4.4	4.1
38	F	Sub-Adult	Upper 5 Rivers	27	9	Censored[d]	22	29.2	10.6

Beaver No.	Gender	Age Class	Relocation Site	Days of Contact	No. of Observations	Mortality Agent	Days Until Max Movement	Max Movement Distance from Release Site (km)	Final Movement Distance from Release Site (km)
39	F	Sub-Adult	Buck	81	21	Censored[d]	51	17.4	16.4
40	M	Adult	Buck	6	3	Predation	4	5.0	2.5
41[a]	UNKN	Juvenile	Buck	0	0	Unknown	0	0.0	0.0

[a] Individual did not receive tail-mounted radio transmitter.

[b] Only radio-tagged individual that was not included in movement analysis.

[c] Second release of new colony at site after previous released colony did not survive or no longer occupied the area.

[d] Only transmitter was recovered and no evidence was found indicating a mortality.