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Original research article

Evaluating landowner-based beaver relocation as a tool to restore salmon habitat

V.M. Petro [a], J.D. Taylor [a,b,*], D.M. Sanchez [c]

[a] *Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97331, USA*
[b] *USDA, APHIS, Wildlife Services, National Wildlife Research Center, Corvallis, OR 97331, USA*
[c] *Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331, USA*

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ABSTRACT

Relocating American beavers (*Castor canadensis*) from unwanted sites to desirable sites (i.e., where damage exceeds stakeholder capacity) has been posited as a method to enhance in-stream habitat for salmonids in the Pacific Northwest region of the US; however, no studies have evaluated this method. From September–December 2011, we trapped and relocated 38 nuisance beavers using guidelines available to Oregon landowners. Release sites were selected from models that identified high values of beaver dam habitat suitability and where dams would increase intrinsic potential of coho salmon (*Oncorhynchus kisutch*). Mean distance moved from release sites within 16 weeks post-release was 3.3 ±0.2 (SE) stream km (max 29.2 km). Mean survival rate for relocated beavers was 0.47 ±0.12 (95% CI: 0.26–0.69) for 16 weeks post-release, while the probabilities of an individual dying to predation or disease/illness during the same period were 0.26 (95% CI: 0.09–0.43) and 0.16 (95% CI: 0.01–0.30), respectively. Dam construction was limited and ephemeral due to winter high flows, providing no in-stream habitat for coho. We conclude beaver relocation options available to landowners in Oregon may not be an effective option for stream restoration in coastal forestlands due to infrequent dam occurrence and short dam longevity.

1. Introduction

The decline of Pacific salmon populations has prompted efforts to identify factors affecting fish survival. In western Oregon, overwinter-rearing habitat was identified as the leading factor limiting recovery of coho salmon (*Oncorhynchus kisutch*; Nickelson et al., 1992a, ODFW, 2007),an anadromous fish species given federal protection under the Endangered Species Act. Overwinter stream habitat in Coastal Oregon is affected by fluctuations in stream velocities, resulting from high flow events (Nickelson et al., 1992a; Leidholt-Bruner et al., 1992). Slow moving stream micro-habitat creates shifts in macro-invertebrate abundance and community structure, providing fish foraging opportunities that are uncommon in less diverse stream sections (Pollock et al., 2004). In addition, low stream velocity allows fish to expend less energy for foraging (Pollock et al., 2003, 2004). Anthropogenic projects that place large woody debris and boulders in streams, and create

* Corresponding author at: USDA, APHIS, Wildlife Services, National Wildlife Research Center, Corvallis, OR 97331, USA.
E-mail addresses: Vanessa.Petro@oregonstate.edu (V.M. Petro), Jimmy.D.Taylor@aphis.usda.gov (J.D. Taylor), Dana.Sanchez@oregonstate.edu (D.M. Sanchez).

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channel alcoves, have been used to create pool habitat in coastal streams; however, projects are expensive (Leidholt-Bruner et al., 1992; MacCracken and Lebovitz, 2005; DeVries et al., 2012) and have had limited detectable effect on coho salmon recovery (Nickelson et al., 1992b; Solazzi et al., 2000).

In the Pacific Northwest, American beavers (*Castor canadensis*, hereafter beavers) co-exist with several anadromous salmonids, including coho. Ponds created by beaver dams create in-stream structure, resulting in greater aquatic productivity than reaches not dammed by beavers (Leidholt-Bruner et al., 1992; Snodgrass and Meffe, 1998; Collen and Gibson, 2001; Kemp et al., 2012). In general, beaver ponds are highly productive for fish as a result of high edge-to-surface ratios, presence of vegetation within and near the stream, and high abundance of prey (Collins, 1993; Pollock et al., 2004). High water retention from dams prolongs periods of low flow, providing areas of refuge for fish (Leidholt-Bruner et al., 1992). Reductions in winter habitat for coho smolts were observed at the Stillaguamish Basin in Washington, and attributed to loss of beaver ponds (Pollock et al., 2004). Similarly, overwinter survival and growth of coho smolts in the Copper River Delta of Alaska were positively correlated with the occurrence of beaver ponds (Lang et al., 2006). In coastal Oregon, coho fry were three times more abundant in beaver-created habitat than in pools created by other fluvial processes (Leidholt-Bruner et al., 1992). However, beaver dams in the Coast Range are primarily small and ephemeral, with few withstanding high water flows (Maser et al., 1981; Leidholt-Bruner et al., 1992).

Pollock et al. (2004) suggested an increase in beaver population size may increase availability of pool habitat for coho smolts. Others have recommended managing for beavers or mimicking their dam-building behavior to augment in-stream complexity (Finnegan and Marshall, 1997; DeVries et al., 2012). Recent changes in legislation of some western states now allow landowners to relocate beavers as a management tool (ODFW, 2012, RCW 77.32.585, UDWR, 2010). We used the Oregon Department of Fish and Wildlife's Guidelines for Relocation of Beaver in Oregon (ODFW, 2012), hereafter state guidelines, as a basis for this study. At the time of this study, no state or federal programs were relocating beavers in western Oregon. Thus, we assumed that if state guidelines were used, it would be a citizen-lead program.

Ours is the first study to evaluate beaver relocation as a tool for improving in-stream habitat for salmon. We use the term "relocation" defined by Fischer and Lindenmayer (2000) as "any intentional movement by humans of an animal or a population of animals from one location to another". Our objectives were to examine post-release rates of survival and cause-specific mortality, and movement of relocated beavers; and evaluate enhancement of coho rearing habitat through dam construction. Our measure of relocation success was construction and persistence of beaver dams at release sites, as dams are potentially important to coho rather than the presence of beavers alone. Although beavers chosen for relocation in this study were taken from areas of human-wildlife conflict (i.e., nuisance beavers), conflict resolution was not an objective or a measure of success.

2. Methods

2.1. Study area

We conducted this study in the Alsea River Basin of the central Oregon Coast Range (Fig. 1). The Alsea River drains into the Pacific Ocean, near the town of Waldport. The basin is approximately 1213 km^2 and consists of 4 sub-basins: North Fork Alsea River, Five Rivers/Lobster Creek, Drift Creek, and the South Fork Alsea River. Elevation ranges from sea level to 1249 m. Average annual precipitation is 203–254 cm near the coast and 203–356 cm in higher elevations (WRCC, 1990). Most precipitation occurs as rainfall during winter. Approximately 93% of the Alsea Basin is forested and ownership of forestlands includes US Forest Service (39%), Bureau of Land Management (24%), private industrial landowners (23%), private non-industrial landowners (13%), and state (<1%). The forest matrix is dominated by Douglas-fir (*Pseudotsuga menziesii*) and common co-dominant species include western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), red alder (*Alnus rubra*), and bigleaf maple (*Acer macrophyllum*). Understory vegetation is dominated by 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*). 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), although persistent beaver dams (lasting $\geq$ 1 yr) are infrequent in the Coast Range.

2.2. Release site selection

Poor habitat conditions at release sites affect survival and reduce relocation success (Armstrong and Seddon, 2008; Moorhouse et al., 2009). We mapped and characterized potential release sites in ArcGIS (version 9.3; ESRI, Redlands, California, USA) using data associated with a 10-m digital elevation model (Clarke et al., 2008) and two other models developed from data representative of our study area. These models were used to identify sites where beavers were most likely to establish dams (Suzuki and McComb, 1998) and where dams were most likely to provide high-quality in-stream habitat for coho salmon (Burnett et al., 2007). Site selection criteria and methodology are discussed in detail in Petro (2013). We surveyed for beaver activity 1 km upstream and downstream of each potential release site, which represents the minimum distance

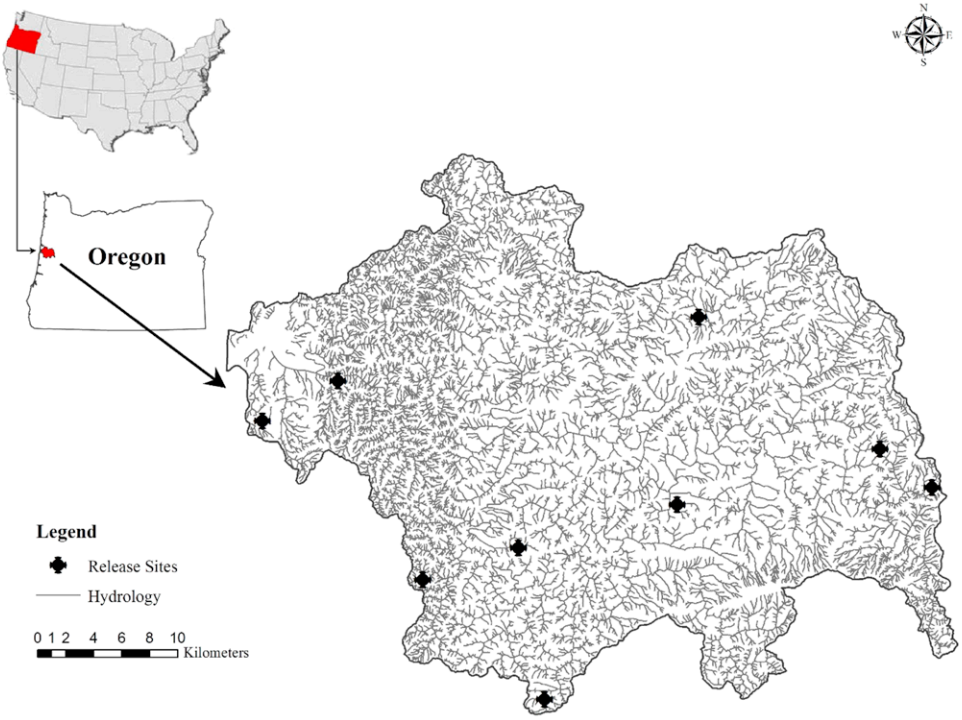

Fig. 1. Selected sites in the Alsea Basin, Oregon, USA where marked beavers were released and monitored, 2011–2012.

between two beaver colonies that will avoid territorial conflict (Boyce, 1981). We only considered streams with no neighboring colonies for release.

2.3. Capture and handling

From 01 September to 26 December 2011, we identified trap sites through close coordination with Oregon Department of Fish and Wildlife (ODFW) staff in northwestern Oregon. We selected trap sites that were outside of the study area to reduce homing behavior (Miller and Ballard, 1982; Fritts et al., 1984), and those where beaver damage exceeded stakeholder levels of acceptance. We set Hancock live traps (Hancock Trap Company, Custer, SD, USA) next to active beaver sign (e.g., slides, trails, dens, dams) and used castor-based or food-based lures to increase trapping success. We activated traps before sunset and checked traps the following morning at daybreak.

We weighed captured beavers in traps to the nearest 0.1 kg, and estimated body mass using difference in mass between a trap with and without a captured beaver. We assigned age classes based on weight; juveniles $<$ 8 kg, sub-adults 8.0–15.9 kg, and adults $\geq$ 16 kg (Breck et al., 2001). We estimated sex in the field by palpation for the os penis and presence of teats (Beer, 1955; Baker, 2006). We anesthetized sub-adults and adults with an intramuscular injection of ketamine hydrochloride (10 mg/kg) and xylazine hydrochloride (1 mg/kg) and fitted each with a 45 g tail-mount transmitter equipped with a 12 h mortality switch (Model J20500; SirTrack, Havelock North, NZ) using methods modified by Arjo et al. (2008). Sedated individuals were processed on an insulated mat and received ophthalmic ointment and a blindfold. We used a biopsy punch to collect tissue samples from the tail site used to affix the tail-mount transmitter. We submitted tissue samples for genetic analysis to confirm sex. We gave all beavers a visual health check for external signs of sickness or trauma and inserted a passive integrated transponder (PIT tag; Avid Identification Systems, Inc., Norco, CA, USA) subcutaneously along the dorsal surface and between the scapulae as a secondary marker (Bond et al., 2001; Arjo et al., 2007). We monitored body temperature rectally every 5 min while beavers were sedated.

We conducted hard-releases (Teixeira et al., 2007) for all trapped individuals to replicate relocation efforts that would be conducted by landowners following the state guidelines for relocation of beaver in Oregon (ODFW, 2012). Therefore, we did not use a holding facility and instead released beavers at their designated release site immediately after capture. Individuals were transported in medium-sized dog kennels. We provided extra protection for warmth or cooling if ambient temperatures were $\leq$0 °C or $\geq$27 °C. We trapped damage sites until no new beaver sign appeared, in order to live-capture and relocate entire colonies. All members of a colony were released at the same location. All study methods were approved by the Institutional Animal Use and Care Committee of the United States Department of Agriculture, Animal and Plant Inspection Service, Wildlife Services, National Wildlife Research Center (Protocol QA-1891), and the Oregon Department of Fish and Wildlife Scientific Taking Permit No. 136-11.

2.4. Monitoring post-release responses

We monitored radio-tagged individuals 3 times weekly for the first month, twice a week for months 2–6, and once a week thereafter. Individuals were located during daylight hours with the homing technique using a handheld Model R-1000 telemetry receiver (Communications Specialists; Orange, CA, USA) equipped with a 3-element folding yagi antenna (Model 13863; Advanced Telemetry Systems, Isanti, MN, USA). Beaver locations (<5 m) were acquired with a global positioning system (GPS; Model GPSMAP 76CSx; Garmin, Chicago, IL) and entered into ArcGIS. If homing was not possible, we obtained at least 2 bearings for each individual from known locations with an overall separation of 60–120° in $\leq$ 15 min. We estimated true locations and associated error in the program Location of a Signal (LOAS version 4.0; Ecological Software Solutions, LLC., Doral, FL, USA). We used trail cameras (Model PC800 Hyperfire; Reconyx, Inc., Holmen Wisconsin) to monitor juveniles at locations occupied by radio-tagged colony members. Trail cameras also provided ancillary locations for individuals whose transmitter failed or dropped. We checked trail cameras weekly.

To determine sources of mortality, we immediately found individuals upon detecting a mortality signal. We recorded GPS locations of carcasses and physical characteristics of mortality sites. We classified mortalities into 1 of 3 groups: (1) disease or illness, (2) human, and (3) predation. Human mortalities included legal take and poaching. Upon recovering depredated beavers, we identified the predator species based on the presence of bite marks, scat, tracks, and caching at the recovery site. We collected carcasses when the cause of mortality was unknown, and submitted them to the Oregon State University Veterinary Diagnostics Laboratory for further analysis.

All known beaver locations were surveyed for evidence of dam establishment each month. We measured 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. We monitored dam establishment for 64 weeks post-release.

2.5. Statistical analysis

We 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. We used the stream length distance measure because movement over land was highly unlikely due to topographical constraints. Movement distances were calculated to reflect weekly intervals post-release. Distances were log-transformed for normality and compared between age and sex groups using Welch two sample t-tests in program R (version 2.15; www.r-project.org, accessed 15 Mar 2013). We did not 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. We estimated weekly Kaplan–Meier survival rates (Kaplan and Meier, 1958) with known-fate modeling in Program MARK (version 6.0; White and Burnham, 1999). We estimated cause-specific mortality rates in program MICROMORT (Heisey and Fuller, 1985). We 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.

3. Results

In the Alsea Basin, we identified 7 stream km of highly suitable beaver damming habitat, and 272 stream km as high intrinsic potential for coho salmon. Intersection of these results revealed 19 non-contiguous sites that we assumed were the best release sites in the basin. These potential release sites were distributed across both private and public land. We were declined permission to relocate individuals at 4 sites. Six release sites were occupied by extant beaver colonies within 1 stream km. Therefore, we used the remaining 9 eligible sites for beaver relocation (Fig. 1). Mean (SE) values for bank full width (m) [3.9 (0.2)], channel gradient (%) [2.2 (0.2)], and valley floor width (m) [21.4 (1.5)] were consistent with the most highly suitable sites identified by Suzuki and McComb (1998), as well as other studies that quantified beaver dam habitat (Beier and Barrett, 1987; Barnes and Mallik, 1997).

We captured 38 beavers representing 12 separate colonies from September through December 2011. One colony was released into each of the 9 unoccupied release sites from September through December 2011. Three more colonies were released into 3 of the 9 sites after previous releases were unsuccessful (i.e., 100% mortality or emigration). Age distribution of captured beavers was 61% ($n = 23$) adults, 21% ($n = 8$) sub-adults, and 18% ($n = 7$) juveniles. We radio-tagged 31 ($n = 18$ F, 13 M) adult and sub-adult beavers; one of which died of capture myopathy within 48 h post-release. Mean (SD) colony size for relocated beavers was 3.1 ± 1.6. Of the 12 colonies: 6 completely separated, 2 separated into smaller family units, 2 were completely depredated, and 1 remained intact (Table 1).

All radio-tagged individuals moved from their initial release sites. The mean distance moved from release sites within 16 weeks post-release was 3.3 ± 0.2 (SE) stream km, although the longest recorded movement from a release site was 29.2 stream km. 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). 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 4 (13%) individuals conducted maximum movements within 8 weeks and the remaining 8 (26%) within 12 weeks post-release. More than half of 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 did

Table 1
Descriptors of nuisance beaver colonies 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.

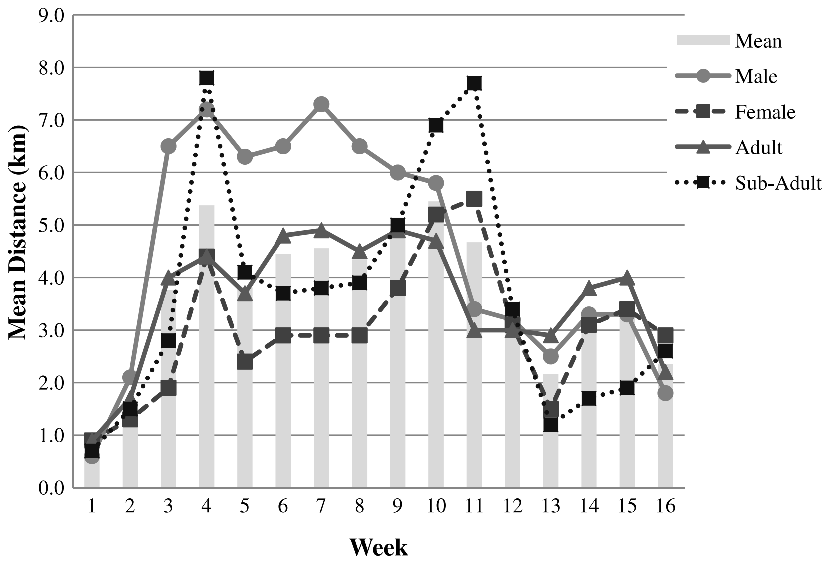

Fig. 2. Mean movement distances (stream km) from release sites within 16 weeks post-release for both age and sex groups of relocated beavers, Alsea Basin, Oregon, 2011–2012.

not differ between adults and sub-adults ($t_{298} = 0.0$, $P = 0.970$) or between males and females ($t_{361} = -1.4$, $P = 0.161$) within 16 weeks post-release.

Twelve (40%) radio-tagged individuals were right-censored in program Mark due to faulty transmitters. We were unable to examine influences of age and sex on survival due to small sample size, preventing successful testing of our global model. The Kaplan–Meier survival rate for relocated beavers was 0.47 ± 0.12 (95% CI: 0.26–0.69) for 16 weeks post-release. Cause-specific mortality rates were 0.26 (95% CI: 0.09–0.43) for predation, 0.16 (0.01–0.30) for disease or illness, and 0.03 (0.00–0.10) for human-related mortalities (Fig. 3). Of 30 radio-tagged beavers, 8 (27%) died within 30 days, and an additional 4 (13%) died within 90 days of release (Table 2). Predation was the cause of mortality for 7 individuals. Mountain lions (*Puma concolor*) were positively identified as predators for 6 beavers, and were suspected in the seventh case. However, the carcass of the seventh beaver was scavenged before we recovered it. Three beavers died from disease or illness based on necropsy results, including 1 case of tularemia (*Francisella tularensis*), an opportunistic *Bordetella bronchiseptica* infection of the upper respiratory tract, and a circulatory collapse attributed to brain damage. A fourth beaver also was categorized as disease or illness as its remains were recovered intact with no signs of predation and was not necropsied at the veterinary college. One beaver was poached out of trapping season and was the only case of human-related mortality. Trail cameras provided additional locational data for beavers, but not the necessary number of observations per sampling occasion to meet the assumptions for known-fate modeling in Program Mark (White and Burnham, 1999).

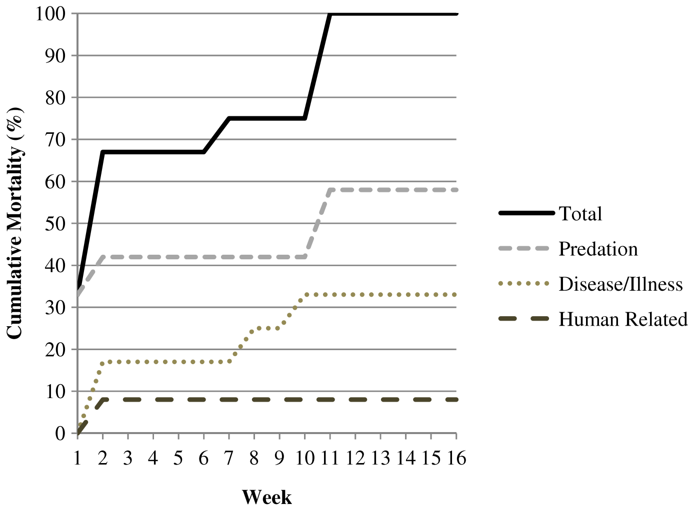

Fig. 3. Cumulative mortality rates representing the 3 fate types identified within 16 weeks post-release for beavers relocated to the Alsea Basin, Oregon, 2011–2012.

Table 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 (SD)
Predation	7	3 to 75	25 (25.6)
Disease and illness[a]	4	8 to 67	44 (32.8)
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—necropsy not possible.

The majority of predation (57%) occurred within the first week post-release (Fig. 3). We observed no mortalities after week 11; however, we were limited to tracking 8 radio-tagged individuals as a result of transmitter failures. Mortalities were located 7.7 $\pm$ 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). However, 6 (20%) individuals were still detected by trail cameras at this time. No juvenile beavers were detected by camera surveys post-release and were assumed to have been depredated very early in the study.

We observed 9 total dams constructed by relocated beavers within the 64 week post-release monitoring period. Five of these dams were built by 1 male:female pair in 2011. In 2012, only 4 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 3 dams were built by relocated individuals that separated from their colonies and established territories with resident beavers as noted in camera surveys (Table 1). All 9 dams were initiated in the late summer and early fall, and were ephemeral due to winter high flow events. These dams persisted for an average of 62 $\pm$ 39.7 days. Dams constructed were on average 4 $\pm$ 3.7 (SD) m long and 30 $\pm$ 9.7 (SD) cm tall.

4. Discussion

Animal relocation generally supports one of three primary goals: solving human-wildlife conflict, restocking game populations, or conservation (Fischer and Lindenmayer, 2000). Historically, relocation of beavers following large-scale extirpation has been considered a North American conservation success story, as have relocation efforts with *C. fiber* in Europe (Muller-Schwarze, 2011). Few efforts to re-populate beavers in areas following overharvest or habitat alteration in North America have documented distances moved by relocated beavers; however, all reported studies have shown some movement from release sites. No published studies that we found mentioned use of habitat models to select release sites, thus we assume all used expert opinion. Of 114 relocated nuisance beavers in Wyoming, 58 (51%) moved >10 km from their release sites (McKinstry and Anderson, 2002), although neither mean nor maximum distances were reported. A study in eastern Oregon observed 78% of relocated individuals moved away or disappeared from release sites (Scheffer, 1941), yet distances and beavers' fates were not recorded. Mean distance moved from release sites in our study (3.3 $\pm$ 0.2 stream km) was lower than mean distances reported in North Dakota (14.6 stream km, Hibbard, 1958), Colorado (16.7 km, Denney, 1952), northern Quebec (18 air km, Courcelles and Nault, 1983), and Wisconsin (stream-based release sites = 11.7 km, potholes and lake release sites = 5.1 km, Knudsen and Hale, 1965), suggesting our release site selection process using habitat models is an improvement over expert opinion. Our observed maximum distance moved from release sites (29.2 stream km) also was less than other beaver relocation studies in North Dakota (238 stream km, Hibbard, 1958), Wisconsin (76.2 km, Knudsen and Hale, 1965), and Colorado (48 km, Denney, 1952); however, this maximum distance is still a concern as this and other relocated beavers crossed several landowner boundaries. While our relocated beavers did not cause landowner conflict post-release, movement outside of target areas where landowner permission is granted must be considered in relocation efforts. In Oregon, state statutes allow landowners to remove damage causing beavers from their property without requesting permission or reporting take. Lack of landowner coordination and excessive movement by relocated beavers can negate relocation efforts. Relocation guidelines in Oregon (ODFW, 2012) only require monitoring 1 km upstream and downstream from release sites for a minimum of 3 times over 1 year. Our results demonstrated that most of our relocated beaver activity would not have been detected using minimum state criteria.

Goals of more recent interest in beaver relocation differ based on one's desire to give or receive beavers. Therefore, relocation may address conflict resolution and conservation simultaneously while having different measures of success. "Giving" landowners view relocation as a non-lethal option to reduce beaver damage (e.g., tree cutting, flooding, bank destabilization), while "receiving" landowners desire the positive effects of beaver dams (e.g., increased biodiversity, wetland creation, riparian improvement), not necessarily beavers themselves. Relocations to solve human-wildlife conflicts often fail due to predation at release sites (Fischer and Lindenmayer, 2000) or reinvasion of new nuisance individuals at capture (i.e., conflict) sites. Beaver relocation activities that fail to estimate survival of individuals may add to the public misperception that relocated animals "live happily ever after" (Craven et al., 1998). We documented high mortality of relocated individuals due mainly to predation by cougars and illnesses, possibly exacerbated by the stress of relocation. Although the focus of our study was not to solve human-wildlife conflict, follow-up conversations with landowners revealed that beaver damage reoccurred at 58% of capture sites soon after colonies were live-trapped and relocated. Successful reproduction in the release site (Teixeira et al., 2007; Moorhouse et al., 2009) and persistence of the established population (Griffith et al., 1989; Seddon, 1999) are common measures of success in relocation, especially when working with sensitive species. McKinstry and Anderson (2002) evaluated beaver relocation as a tool to improve riparian habitat in Wyoming, and considered releases successful in 13 of 14 sites when relocated beavers reproduced; yet, their efforts required an average of 17 beavers released at each site before young were born.

Survival and fitness alone are not appropriate measures of relocation success where habitat modification is desired. In our case, we relocated beavers well within the geographic range of healthy resident beavers. Our measure of relocation success was construction and persistence of beaver dams at release sites in stream reaches where dams did not exist or persist. Not all surviving beavers attempted to build dams, and the few dams built were washed out by high water velocity. There was no apparent link between dam-building of individuals pre- and post-release. Two previously non-damming individuals constructed dams and only two original damming individuals established dam sites post-release. One third of dams constructed by relocated beavers were done by surviving individuals that paired with resident beavers. This raises the question as to why resident beavers are unsuccessful in building stable dams in areas we identified as suitable habitat. Reasons for this remain unclear and warrant additional research.

Relocating nuisance beavers may not offer an effective solution to lethal control measures as originally perceived by the general public (Needham and Morzillo, 2011). Furthermore, releasing beavers into an unfamiliar site, combined with stress of trapping, handling, and moving, may influence their susceptibility to predators (McKinstry and Anderson, 2002). Concerns may arise around the best time to relocate beavers. Our goal was to emulate when landowners would relocate beavers in accordance with ODFW's beaver relocation guidelines (ODFW, 2012), thus we attempted to relocate beavers August through October. This period corresponds with beavers' principal dam building period (Olson and Hubert, 1994) and when beavers were less likely to disperse into other areas away from release sites (McKinstry and Anderson, 2002; DeStefano et al., 2006). Landowner complaints were few from August–October and we were only able to relocate 12 individuals during this period. October–December has the highest numbers of landowner beaver complaints in western Oregon (K. Christensen, USDA, personal communication). ODFW (2012) allows landowners to request permission to relocate outside August–October, and it was allowed under our scientific collection permit. Therefore, we continued responding to landowner complaints and relocating beavers through mid-December until we stocked all release sites at least once (3 sites were restocked due to complete mortality or emigration).

McKinstry and Anderson (2002) found no difference in predation risk between spring and fall releases in Wyoming. Their observed survival rate was 0.49 ± 0.06 (McKinstry and Anderson, 2002) and was similar to our survival rate of 0.47 ± 0.12 following fall release. In both studies, predation was the leading cause of mortality. During their initial relocation phase, beavers were depredated an average of 17 days post-release, with 35% of those mortalities occurring within six days of release (McKinstry and Anderson, 1997). Over half of our predator-related mortality (57%) occurred within the first week post-release and the probability of a relocated beaver being killed by a predator was 0.26. In a relocation study conducted by Oregon Department of Fish and Wildlife in southwestern Oregon, beavers were released between 26 May–31 July (DeWaine Jackson, ODFW, personal communication). Post-release survival was estimated between 30% and 40%, with depredation by coyote (*Canis latrans*) accounting for the greatest source of mortality (DeWaine Jackson, ODFW, unpublished data). While spring release of beavers may seem desirable because streams are at high flow stages, this could result in greater movement distances from release sites and potentially reduce the likelihood of dam construction. Relocating beavers into watersheds with resident beavers may create competition for territories as sub-adults are dispersing (Sun et al., 2000). Trapping and relocation also is risky during spring because it coincides with beaver parturition and kit-rearing. Trapping pregnant females could cause adult death or fetal mortality due to high stress. Trapping adults when kits are in dens could cause orphaning.

The size of a colony may be affected by predation, habitat quality, and population density (Novak, 1987). It remains unknown if the number of individuals in each relocated colony affects the success of relocation efforts. The colony size for our relocated beavers ranged from 2 to 7 and was consistent with the average range (3.2–8.2) reported throughout North America (Novak, 1987). However, our mean colony size for relocated beavers was 3.1. This small colony size is consistent with our observations of newly established colonies that cause human-wildlife conflict. Regardless of colony size, we released all colony members at the same release site. In some cases, all individuals were captured in the same night and released together the following morning. In other cases, capture of all individuals occurred over multiple nights (mean 2.2, SD 1.5), and releases were staggered. Beaver colonies relocated in northern Quebec typically separated post-release (Courcelles and Nault, 1983). Our relocated colonies either separated, remained in male:female pairs, or separated into smaller family units. The reason for separation of family units is unknown and warrants further investigation. We posit that stress associated with relocation and the overwhelming need to survive may have overridden social responsibilities of colonies.

Our study used a hard release approach because that is most likely how landowners will catch and relocate beavers when they utilize state guidelines (ODFW, 2012). Some proponents of beaver relocation have criticized this, saying soft release allows colonies to adjust and be released together. We caution that soft release practices require resource intensive husbandry practices including a holding facility, security, food supply, medication, and daily health and welfare checks, among other things. Animal welfare is a serious responsibility and should not be taken lightly. Soft release was not an option for this study and will likely be resource-prohibitive for landowners interested in beaver relocation. Additionally, we found no published scientific articles that described soft release practices and their benefits over hard release. We conducted an extensive literature review using keywords "beaver", "relocated", "translocated", and "transplanted" in JSTOR, Google Scholar, OneSearch, and ScienceDirect. Most articles implied or stated using hard release, or did not describe release methods.

5. Conclusions

Dams are the key component by which beavers have been recognized as ecosystem engineers (Jones et al., 1994, 1997; Wright et al., 2002, 2004) and keystone species (Naiman et al., 1986). Our results suggest that not all beavers build dams in all circumstances. Furthermore, our results correspond with previous observations that beaver dams are primarily ephemeral in the Oregon Coast Range (Maser et al., 1981; Leidholt-Bruner et al., 1992). 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. We used state relocation guidelines as a basis for our research study and our research protocol exceeded the level of involvement that landowners must follow to relocate beavers in western Oregon (ODFW, 2012). We conclude that small scale beaver relocation designed to restore salmon habitat in the Oregon Coast Range is unlikely to succeed using the state guidelines. Furthermore, new research is needed to investigate population dynamics and dam-building activities of resident beavers within the Oregon Coast Range. We recommend individuals or programs involved in beaver relocation to adopt a similar method of monitoring and to clearly establish measures of relocation success. Lastly, we encourage an increased level of outreach and education where beaver relocation is considered or utilized. 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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