Crop Protection 28 (2009) 703–709

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Short-term evaluation of two integrated pest management programs for mountain beaver (*Aplodontia rufa*) control

Wendy M. Arjo [a], Stephanie Shwiff [b,*], Katy Kirkpatrick [b]

[a] United States Department of Agriculture/Animal and Plant Health Inspection Service/Wildlife Services/National Wildlife Research Center, Olympia Field Station, 9730-B Lathrop Industrial Dr. SW, Olympia, WA 98512, USA

[b] United States Department of Agriculture/Animal and Plant Health Inspection Service/Wildlife Services/National Wildlife Research Center, 4101 LaPorte Ave., Fort Collins, CO 80521, USA

ARTICLE INFO

Article history:
Received 26 November 2008
Received in revised form
8 April 2009
Accepted 9 April 2009

Keywords:
Chlorophacinone
Cost effectiveness analysis
Damage
Douglas-fir seedlings
Mountain beaver
Pacific Northwest
Seedlings

ABSTRACT

In the Pacific Northwest, mountain beavers (*Aplodontia rufa*) are an impediment to reforestation efforts due to the damage they cause to seedlings. Trapping is currently the most effective method of reducing mountain beaver populations and seedling damage; however, mountain beavers can quickly reinvade harvested units, negating trapping efforts. Seedlings are most vulnerable to damage the first 3–4 months after planting, prior to emergence of forbs within timber harvest units. The integration of an additional tool to supplement trapping, such as baiting with a chlorophacinone rodenticide bait, may allow for additional seedling protection between trapping and forage green-up. Two integrated pest management (IPM) systems were tested in western Washington: treatment 1, baiting followed by trapping; and treatment 2, trapping followed by baiting. Using a cost effectiveness analysis we compared the costs of two different methods of mountain beaver management. In treatment 1, the units were baited and later trapped to remove remaining animals for a per acre cost of $42.47. In treatment 2, traps were placed in the units to remove mountain beaver, and then baits were placed in active areas for a per acre cost of $49.69. This indicates that the cost minimizing or efficient method of mountain beaver management was treatment 1. We found that seedling damage did not differ ($P = 0.61$) between the treatments; however, overall activity based on fern monitoring demonstrated a greater overall reduction in activity on the treatment 2 plots. Retrapping efforts the year following planting demonstrated the ability of the species to reinvade units quickly. Treatment 1 units averaged 0.75–1.36 beavers/ha and treatment 2 units 0.36–1.14 beavers/ha. Damage after 1 year remained similar between the treatments. Although higher in costs, fewer baits were placed on treatment 2 plots, since the population was reduced initially, than on treatment 1 plots. Treatment 2 may, therefore, be more socially acceptable because fewer baits are available in the environment with this treatment since the population is first reduced through trapping.

Published by Elsevier Ltd.

1. Introduction

The Pacific Northwest is the leading production area for United States forest products. Privately owned forest lands account for more than 70% of the timber harvested in Washington (WFPA, 2008) and 76% in Oregon (ODF, 2008). Since artificial regeneration efforts began in the early 1900s, animal damage has been recognized as an impediment to forest regeneration (Black and Lawrence, 1992). Mountain beavers (*Aplodontia rufa*) occur in the productive Douglas-fir forest (*Pseudotsuga menziesii*) region of western Washington and Oregon where they have long been recognized as a problem to reforestation efforts (Borrecco and Anderson, 1980; Black and Lawrence, 1992; Cafferata, 1992; Arjo and Nolte, 2006). Damage to newly planted seedlings is most pronounced, often with entire seedlings being removed.

Managers have implemented both non-lethal and lethal methods to control mountain beaver populations and reduce seedling damage. Fencing is both cost prohibitive and ineffective unless wire is buried at least 1.5 m underground, and even then, some mountain beavers have been known to have deeper burrow systems (Arjo, unpublished data). Installation of individual tree barriers can be labor intensive because tubes are placed on the seedlings prior to planting or with an additional crew after planting, and maintenance of the tubes is required to insure integrity. Borrecco and Anderson (1980) documented a decrease in damage of seedlings averaging 3% with the application of tree

* Corresponding author. Tel.: +1 970 266 6150; fax: +1 970 266 6157.
E-mail address: stephanie.a.shwiff@aphis.usda.gov (S. Shwiff).

0261-2194/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.cropro.2009.04.004

barriers; however, even with barriers, damage to seedlings occurred. Tubes can be penetrated by mountain beavers, especially those tubes with perforations or seams that allow the mountain beaver to hold onto the plastic (Runde et al., 2008). Mountain beavers have also been documented to climb larger tree tubes in order to clip individual seedlings inside the tubes, as well as undermining the tubes (Cafferata, 1992). Lethal trapping is the preferred method used to control mountain beaver populations, and occurs from October through February in both Oregon and Washington prior to seedling planting. Although trapping can effectively reduce mountain beaver populations for the short-term, mountain beavers can reinvade recently trapped units in less than a few weeks (Arjo and Nolte, 2006; Arjo et al., 2007), often negating prior control measures. Although mountain beavers may damage and even kill older trees (10–15 years old), seedlings are most often affected. Seedlings are most vulnerable to damage the first 3–4 months after planting, prior to emergence of forbs within the units; therefore, protecting seedlings during this window of time would be most beneficial to regeneration efforts. Chlorophacinone baits were found to be an effective tool for mountain beaver control (Arjo and Nolte, 2004; Arjo et al. 2004a) but were never intended to act as a single tool or to replace trapping. Using an integrated pest management (IPM) system of trapping and baiting may allow for additional seedling protection between trapping and forage green-up. We developed this study to test cost efficiency and damage mitigation efficacy of an IPM program for mountain beavers of trapping and baiting with chlorophacinone rodenticide pellets (Lipha Tech – EPA reg. no. 7173-151) to prevent seedling damage in western Washington.

2. Methods and materials

2.1. Study sites

Four recent harvest units, <50 acres in size, in Grays Harbor County of western Washington were used for the treatment portion of this study (Fig. 1). Units were chosen from recently harvested areas (≤1 year old) with similar site preparation (i.e., herbicide treatment, brush piling, burning). All the harvest units were influenced by the marine-type climate due to their windward coastal location. Temperatures during the study were mild with average maximum temperatures over the study period around 11 (SE = 0.3) °C and minimum temperatures of 2.5 (SE = 0.37) °C. February was a dry and cold month, and the winter precipitation was generally reduced for the area (0.9 × 0.1 cm).

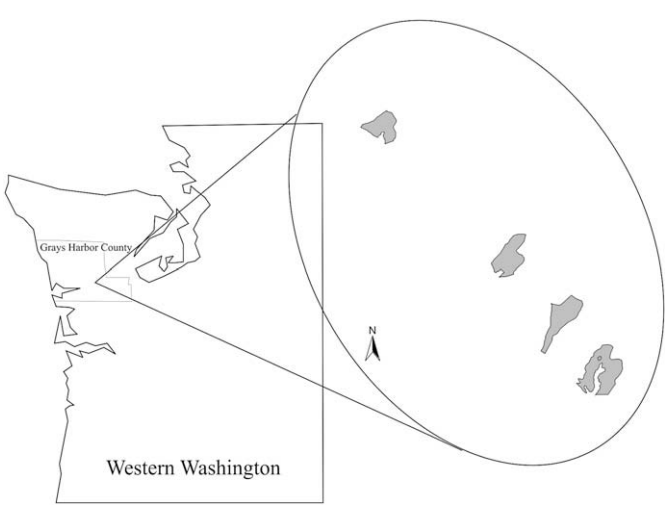

Fig. 1. Map of harvest units used in two integrated pest management (IPM) programs for mountain beaver control in western Washington.

The Satsop and Canyon unit comprised treatment 1 plots in the study. The Satsop unit (14.6 ha at 116 m in elevation) was harvested in late October 2004 and consisted of several main drainages and a few side drainages. A riparian management zone (RMZ) bordered the south and southwest portion of the unit and older regenerating timber (≥17 years) the east and northeast portion. Regenerating forest (≥8 years) bordered the west and northwest portion of the unit, with a small patch of older trees comprised of hemlock at the extreme northern end of the unit. The most northern unit, 5.8 km from Satsop, was the 11 ha Canyon unit. This unit, 131 m in elevation, contained two main north–south drainages and three side drainages. Canyon was harvested in November 2004 and contained no RMZ. This unit was surrounded by regenerating forest (≥15 years old).

Treatment 2 units consisted of the D-line and West Satsop unit. The D-line unit, originally a 22.3 ha unit, was divided into a smaller 12 ha unit for the study. A RMZ traversed the middle of the unit, dividing the unit into two halves. This unit, 85 m in elevation, was buffered on the east side by regrowth alder (≥13 years), on the northwest and south by regenerating Douglas-fir forests (≥17 years), and on the west by the RMZ and other portions of the unit. Younger regenerating forest (≥8 years) bordered the north-east portion of the unit. Several small drainages comprised this unit. The D-line unit was logged in April 2005. Approximately 0.81 km northwest of the D-line unit was the 15.8 ha West Satsop unit. This long, thin unit was 87 m in elevation and was also harvested in April 2005. A RMZ paralleled the western border of the unit, whereas young regenerating forests (≥8 years) surrounded the rest of the unit. The West Satsop unit contained one main drainage through the center of the unit with a few side drainages.

2.2. Subjects

Mountain beavers were live-trapped in Tomahawk traps (15 × 15 × 60 cm; Tomahawk Live Trap Company, Tomahawk, WI) placed in active runway systems between October and November 2005 for the purpose of radio collaring animals in all units. We enlarged active runways to accommodate the placement of the double-ended trap directly into the runway. Traps were baited with half an apple threaded on a stick directly over the trap pan. In addition, we suspended a small bag of netting containing 5–6 pieces of Purina Mills Inc. rat diet (Animal Specialties, Hubbard, OR) from the top of the trap. We placed sword fern on top of the trap and then covered it with black plastic to simulate a tunnel system. Traps were checked every morning and removed after an animal within the system was captured. We removed animals from the trap by coaxing them into burlap sacks. Animals were aged, weighed, sexed, measured, and ear tagged in both ears with Monel #1005-1 tags (National Band and Tag Co., Newport, KY). Animals weighing over 500 g were fitted with a mortality-sensing radio transmitter (Advanced Telemetry Systems, Isanti, MN). Attempts were made to capture and radio collar 10–20 animals, both subadult and adult males and females, in the Satsop and Canyon units as well as 2–4 animals at the edge of the units (referred to as buffer area). At the West Satsop and D-line units, attempts were made to capture and collar 5–6 animals in the buffer area only. Mountain beavers have been documented reinvading trapped units quickly. We collared animals in the buffer zones around the units to determine the efficacy of the treatments to reinvasions. Since no animals were radio-collared on the units initially trapped (West Satsop and D-line because animals were all removed), we collared more animals in the buffer zone to track potential movements due to treatment effects. Animals were released at point of capture.

After release, we allowed at least a 5-day acclimation period prior to rodenticide baiting to insure animals did not succumb to capture myopathy.

2.3. Treatments

Two integrated pest management programs were tested. The first program (treatment 1) consisted of baiting followed by trapping on the Satsop and Canyon units. The second program (treatment 2) consisted of trapping animals followed by baiting on the D-line and West Satsop units. After completion of treatments, all four units were planted in accordance with normal forest planting operations for the industrial timber company. Douglas-fir seedlings were planted approximately 1074 trees/ha (425 trees/acre in a 9×9 configuration) throughout the units in late January and early February.

The Canyon and Satsop unit were treated with 0.005% chlorophacinone baits (LiphaTech – EPA Reg. #7173-151) approximately 1 week after radio collaring animals. Active mountain beaver systems were determined based on fresh feeder holes and pushed dirt as well as the location of radio-collared animals. We placed one individual packaged plastic bait bag (336 g manufacturer issued) consisting of pellet baits just inside ($\sim$40 cm) each of two feeder holes or active runways for each mountain beaver system. Holes used for baiting were marked with numbered flags. We color-coded each group of bags (the two bags placed in an individual system) to determine where bags were obtained by each mountain beaver. Mountain beavers exhibit caching behavior and are likely to move the bait bags into their burrow system. Unopened bait bags have been shown in previous studies to remain viable to at least 5 months (Arjo, unpublished data). Baits were not placed in the buffer zones around the units. We monitored bait acceptance approximately every 3–4 days, barring severe and hazardous weather conditions, by checking for the disappearance of the bags from the burrow entrance. We monitored baits for approximately 3 months (November 2005–January 2006). Any remaining animals that did not succumb to the bait were trapped and removed prior to seedling planting. Padded foot-hold traps (#1) were set 2–3 per burrow system and checked daily. Traps were reset in the same holes following a capture and removed after 5 days.

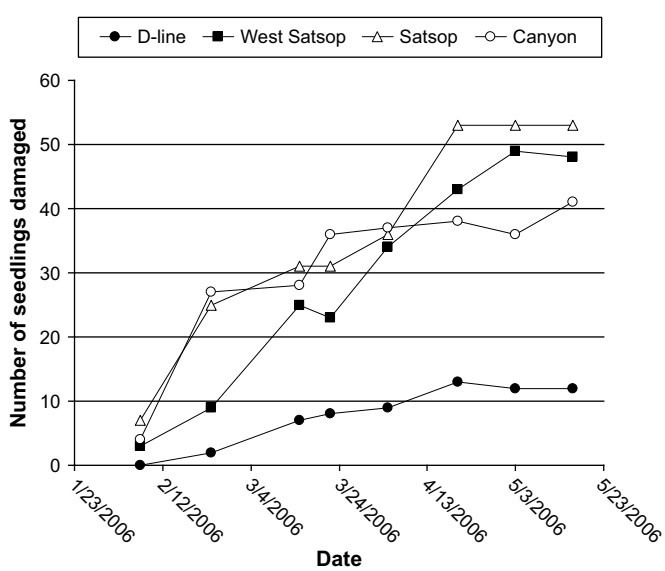

Fig. 2. Total seedling damage on the four units in western Washington planted around 23 January 2006. Deer and rabbit damage occurred as well as mountain beaver damage.

The D-line and West Satsop units (treatment 2) were trapped the end of October into November 2005. We set padded foot-hold traps (#1) 2–3 per burrow system and checked daily. In addition, traps were reset in the same holes following a capture. After 5 days, we removed the traps and baits (color-coded for each system) were placed in systems that still appeared to be active (based on pushed dirt or fresh clipped forage).

2.4. Monitoring activity and survivorship

We monitored telemetered animals every 2–3 days for 3 months to determine survival on all the treated units and buffer zones. We attempted to locate all mortalities and collect carcasses to determine cause of mortality. After approximately 3 months of monitoring, remaining animals on the treatment 1 units were removed from the unit but not the buffer area. All units were planted approximately 1 week after trapping and we continued to monitor movements of the peripheral animals for approximately 4 months. One year after we initiated the study, the landowner returned to each of the treated units to capture any reinvading animals.

In addition to monitoring telemetered animals, a second activity index was used to monitor burrow activity. Sword fern (*Polystichum munitum*) are a preferred vegetation forage species by mountain beavers, and bundles of sword fern at burrow entrances are good indicators of mountain beaver presence. Following Engeman et al. (1991), sword fern packets consisting of three sword fern fronds tied with plastic flagging, were placed at active burrows (for radio-collared or uncollared individuals if the area appeared active) within a mountain beaver system. Two bundles were placed 6–8 days prior to baiting or trapping at two separate feeder holes or active burrow systems per animal in each of the four units. Fern absence or presence was checked after 5–7 days and removed. For treatment 1, 6 weeks after baiting we conducted a second fern activity indicator test. In addition, sword fern bundles were placed the last week of January 5–7 days prior to trapping. For treatment 2, additional sword fern monitoring occurred approximately 2 weeks after trapping and baiting and approximately the third week in December (6 weeks after baiting). Each time ferns were checked 5–7 days after placement and removed.

2.5. Identifying damage to seedlings

Douglas-fir seedlings were hand-planted in late January and early February 2006 by the timber company. Number of trees per hectare averaged 1074 (425 trees/acre). Tree damage was measured using 0.04 ha plots, similar to methods used by timber companies to establish seedling survival. Ten plots on each unit were randomly chosen from fern placement data (areas that showed activity) for the four treatment units. Immediately after planting, seedlings were marked with numbered flags on the four test units and the center point of the plot was permanently marked with painted rebar. Seedling damage was assessed every 2 weeks after planting from January through May and 1 year after planting on the four treatment units. Seedling damage was noted as clipped, removed, or browsed and the species that caused the damage was noted.

2.6. Economic analyses

The economic analysis sought to answer two questions: first, was there a statistically important difference in seedling damage between treatment 1 and 2; and secondly, what were the cost differences between the two treatment groups? If there was no difference between treatment1 and 2, then the lower cost method

should be the program of choice. If there was a difference, then secondarily the cost of each treatment needed to be examined to determine the overall preferable program.

To determine whether there was a difference in seedling damage, the data analysis consisted of two units in each of the treatments and numerous plots within each unit. Data consisted of the percent of seedlings damaged by mountain beavers per plot under each treatment type by year. A two-factor repeated measures analysis of variance (ANOVA) was used to analyze the data, where units were nested in treatment, and year was the repeated factor. The data were analyzed in a mixed linear model framework (McLean et al., 1991; Wolfinger et al., 1991) using SAS PROC MIXED with restricted maximum likelihood estimation (REML) (Littell et al., 1996; SAS Institute, 2004).

The next step was to analyze additional data regarding baiting and trapping hours to determine which treatment was the more cost effective (least costly) method. Labor hours were separated by the type of management action, baiting hours versus trapping hours, because the treatment type affected the labor time required for each. We evaluated the costs associated with treatments 1 and 2 and determined which treatment minimized costs using a cost effectiveness analysis (CEA). The costs of mountain beaver management were associated with the number of baits, baiting labor hours and trapping labor hours required for each of the two treatments. The costs of traps were not included in this analysis. The costs for each variable were determined on a per acre level, averaging the number of labor hours and baits used across the units for each treatment.

3. Results

3.1. Treatment 1

We captured 25 mountain beavers (17 adults and eight subadults) in the Satsop unit and buffer area. Twenty animals (15 males and five females) were radio collared in the unit and two additional animals were radio collared in the buffer area (one male and one female). We baited 18 systems of the original 20 radio-collared animals on 7 November 2005. Two systems were not baited due to the close proximity of the tunnels in the capture area to a permanent water source. Baits were placed, however, in a few systems near this capture location for other animals. An additional 35 active systems were also baited in the Satsop unit for a total of 53 systems baited. At least one bait bag was removed from 10 of the radio-collared animal systems. Twenty-nine additional unit systems had at least one bait bag missing and 18 had both bags missing.

Fern activity (measured as at least one bundle removed per system) pre-treatment was low for both the radio-collared animals (39%) and the additional 16 unit animals (36%) and may not correspond with all systems baited. Six weeks after baiting fern activity decreased to 39 and 27% for the radio-collared and unit animals, respectively. Prior to trapping the remaining animals in January, fern activity was 33 and 23% for the radio-collared and unit animals, respectively. Nine unit animals died from the chlorophacinone treatment (41%) and all were recovered below ground. A radio-collared male was found in the tunnel entrance to the nest and was scavenged upon. It is unknown whether he succumbed to the bait or was killed by a mustelid so he was not included in the efficacy calculation. One of the radio-collared buffer animals was found above ground most likely killed by a coyote. The other buffer animal was recovered in the unit in March, near baited areas. Six of the remaining seven radio-collared animals were trapped prior to planting, along with an additional 28 adults (18 males, 10 females) the last week of January 2006.

Twenty-one mountain beavers were captured and radio-collared on the Canyon unit and three additional animals in the buffer area (13 males, 11 females). A few capture myophathies occurred during the cold rainy weather while trapping, in addition to predation events, leaving two buffer area animals and 15 unit animals alive prior to baiting on 7 November 2005. We baited the original 21 radio-collared animal systems as well as 26 additional unit animals. Bait acceptance of at least one bait bag was 86% for radio-collared animals and 88% for unit animals.

Fern activity for the radio-collared animals did not change from pre-treatment to post-treatment (33%). A decrease in fern activity was observed for other unit animals from pre-treatment (40%) to post-treatment (27%). Predation accounted for a significant proportion (54%) of mortalities on the Canyon unit. Two animals died from chlorophacinone baiting, and an additional two unit animals may also have died from baiting, but the carcasses were scavenged in the nest by a mustelid. A female's collar indicated mortality 2 December 2005, but we were unable to recover a carcass. We tracked the signal to the nest and excavated the nest containing one bait bag, but the signal moved away from the area. This animal was likely still alive and the collar malfunctioning. At the end of January 2006, we trapped the remaining five radio-collared animals as well as 21 additional animals in the unit (eight females, 11 males, and two unknowns).

Average seedling density on the Satsop unit was 1142 trees/ha (457 trees/acre). Damage to seedlings in the Satsop unit occurred from mountain beavers, rabbits (*Sylvilagus* spp.), and deer (*Odocoileus hemionus*, Table 1). Mountain beaver damage accounted for 6.5% ($n = 25$) of the damage received to the 399 trees in the 10 plots. One plot sustained heavy damage from rabbits (64%) as well as from mountain beavers. A combination of damage and adverse weather conditions (1 week of cold wind and frost) immediately following planting resulted in 5.7% mortality of seedlings in the plots. Seedlings were distributed on the Canyon plot at 1075 trees/ha (430 trees/acre). Only two seedling plots received extensive damage in the Canyon unit; one to rabbits and one to mountain beavers. Sixty percent of the seedlings on plot A were damaged by rabbits. Plot J sustained 32% damage from a radio-collared mountain beaver. Although we did not originally capture nor track this male in the plot J area, during the course of breeding season (January–February), this animal moved >200 m up the draw into a new territory containing the seedling plot. Overall total damage on the plots was 3%. Seedling mortality was 7.6%.

Damage on the Satsop unit after 1 year remained relatively similar to that observed 3 months after planting (Fig. 2). Three plots were damaged for a total of 29 seedlings. Mountain beaver reinvasion was 0.75/ha ($n = 11$ animals captured on the unit). The Canyon unit experienced a drastic increase in damage after 1 year, most likely due to the large reinvasion ($n = 15$ animals, 1.36 beaver/ha). Three new plots sustained damage, increasing the total number of trees damaged from 13 in 2006 to 30 in 2007.

Table 1
Seedling damage by herbivores on timber harvest units in western Washington, 2006.

	Mountain beaver	Rabbit	Deer	Dead	Total trees planted
Treatment 1					
Satsop	25	34	2	23	399
Canyon	13	27	2	30	395
Treatment 2					
D-line	11	1	7	16	365
West Satsop	34	17	2	31	351

3.2. Treatment 2

Unlike the treatment 1 units, we conducted minimal trapping for radio collaring mountain beavers on the treatment 2 units. We captured and radio-collared five mountain beavers (four males, one female) in the buffer area surrounding the D-line unit. The five radio-collared buffer animals were monitored through 16 May 2006. We trapped and removed mountain beavers from the unit starting on 31 October 2005. Forty-one animals were captured; 28 the first night. After four nights, we removed traps and placed baits in 36 burrow systems that still appeared active (1 November 2005). Sixteen systems had at least one bait bag removed through the course of the study.

Fern activity pre-treatment (trapping) was 57%. After trapping, activity decreased to 12% on the unit. In January a contract trapper caught 41 animals on the remaining harvested portion of the unit not used in the study. Although we flagged areas around our unit to prevent trapping, two of the radio-collared buffer animals were removed during this trapping effort. In addition, a male was killed by a mustelid in May 2006. No buffer animals moved into the unit.

We captured and radio-collared four buffer animals (two males, two females) on the West Satsop unit and monitored them through 16 May 2006. Thirty-two animals were trapped and removed starting 1 November 2005 from the unit. Seventy-five percent of the captures occurred on the first night. Traps were removed and remaining activity burrow systems ($n = 25$) baited on 5 November 2005. Of the baited systems, 40% had at least one bait bag removed.

Prior to removal trapping, fern activity was 40%. Three weeks after trapping and baiting, fern activity was 12%. After 2 months, fern activity had decreased to 5%. None of the radio-collared animals in the buffer area moved into the unit. A radio-collared female was found dead in the tunnel adjacent to her nest and was likely predated upon by a mustelid.

Seedlings were planted on the D-line unit at 1100 trees/ha (440 trees/acre). Four seedling plots received mountain beaver damage; only one seedling on two plots each were damaged. Two plots received 7 and 15% damage from mountain beavers and overall damage was 3%. Deer and rabbit damage also occurred on the plots, but not to any great extent. Seedling mortality was 4.4% for the D-line unit.

Density of seedlings on the West Satsop unit averaged 1110 trees/ha (444 trees/acre). Minimal deer damage was noted on the unit, and only four plots received some rabbit damage. The seedling plots sustained mountain beaver damage: two plots received considerable damage (44%). Total mountain beaver damage on the unit was 9.7%. Seedling mortality was 8.8% on the West Satsop unit.

One year after planting, 42 seedlings were damaged by mountain beavers on the sample plots on D-line unit. Damage occurred on five new plots not damaged the previous year and eight new animals were trapped (0.36 beaver/ha). Only two new damaged seedlings, both on a new plot, were recorded on the West Satsop unit 1 year after planting. Eighteen animals were trapped here in 2007 at 1.14 beaver/ha.

3.3. Economic analyses

Differences in seedlings damaged both directly after planting and when evaluated 1 year later, were not detected ($F_{7,79} = 0.74$, $P = 0.64$). Therefore, seedling damage does not notably vary between treatments and cannot be used as a determining factor of treatment efficiency. The next step was to examine the data for baiting and trapping hours.

The average baiting labor hours per person was 3 h for treatment 1 and 2.69 h for treatment 2. The data indicate that the average (mean) number of hours required to trap an area in treatment 1 (4.83 h) was lower than treatment 2 (8.73 h). The average number of labor hours per acre for treatment 1 was 12 (baiting) and 29 (trapping), and for treatment 2 was 10.75 (baiting) and 49 (trapping). The labor cost per hour was $25 and the total labor cost for each treatment was determined by multiplying the average total labor hours by this value (Table 2). The total labor cost per acre for treatment 1 and 2 was $22.47 and $36.39, respectively. The average number of baits used per acre in treatment 1 and 2 was multiplied by the cost per bait ($3.00) to determine the bait cost per acre for each treatment, $10.14 and $5.41, respectively. In order to perform the CEA, the total cost of application was calculated using these values.

Table 2
Comparison of total treatment cost of application per acre for mountain beaver control in western Washington.

	Bait cost/ acre ($)	Trap labor cost/ acre ($)	Bait labor cost/ acre ($)	Total cost/ acre ($)
Treatment 1				
Satsop	8.76	21.24	10.19	36.82
Canyon	9.84	23.71	10.09	48.12
Average	9.30	22.47	10.14	42.47
Treatment 2				
D-line	9.84	48.80	7.09	65.73
West Satsop	5.92	23.98	3.74	33.64
Average	7.88	36.39	5.41	49.69

The CEA compared the costs of two different methods of mountain beaver management. In treatment 1, the units were baited and later trapped to remove remaining animals for a per acre cost of $42.47. In treatment 2, traps were placed in the units to remove mountain beaver, and then baits were placed in active areas for a per acre cost of $49.69. This indicates that the cost minimizing or efficient method of mountain beaver management is treatment 1.

4. Discussion

Although mountain beavers damage sapling-aged stands through girdling, seedling damage is the most common form of damage in the Pacific Northwest. For the most part, when mountain beavers damage seedlings, the seedlings are clipped off at the base, no greenery remains, and the seedlings die. If any lateral branches remain, the tree has some chance of growth; however, the trees are usually deformed and commercially unacceptable. Seedling damage did not statistically differ between the two integrated pest management strategies, even though the remaining animals from the treatment 1 units were removed just prior to planting. We documented the majority of seedling damage occurred within the first 3 months after planting under both types of treatment.

Treatment 1 IPM strategy was based on the assumption that resident animals would remove bait bags from their system and cache and/or consume them. These baits would then be available below ground for reinvading animals. We were able to demonstrate this concept on the Satsop unit where one of the buffer animals moved into the unit, and an unoccupied territory, in March 2006 and succumbed to the baits. On both the Satsop and Canyon units, we captured the same number or more mountain beaver after baiting than were previously radio-collared, with a majority of the animals occurring in the areas originally containing radio-collared animals. In January, the captures often consisted of a male/female combination or a high number of double animals in the area. Dispersal, as well as the breeding season, occurs during seedling planting which increases mountain beaver movements and numbers within a unit. Reinvasion is also likely affected by

surrounding habitat and source populations. Both treatment 1 units were surrounded by early to mid-aged regenerating forests (8–17 years). In older-aged forest stands, densities of mountain beaver seldom exceed four per hectare (Borrecco and Anderson, 1980; Arjo, unpublished data). After harvest, populations can expand rapidly from reinvading animals depending upon available surrounding habitat, yet only average 2–3 mountain beavers per hectare (Lovejoy and Black, 1979; Neal and Borrecco, 1981; Arjo et al., 2007). Bait efficacy was not considered high ($\geq$70%) on either of the treatment 1 units, although predation may have biased the observed bait efficacy. In addition, bait consumption may have been affected by bait hoarding of resident animals which is known to occur in mountain beavers. Even though trapping occurred immediately preceding seedling plantation, damage was sustained and at a level comparable to treatment 2.

Mountain beaver trapping usually occurs from October to January; anywhere from a few weeks to months prior to planting. The treatment 2 IPM strategy used trapping to initially reduce the mountain beaver population prior to baiting. This population reduction may decrease potential bait hoarding in that remaining mountain beavers (and therefore baits) are patchily distributed throughout the unit increasing travel distance to remove bait bags. Even after trapping, fern activity and bait disappearance substantiated the fact that some animals remained on the unit. Fern activity 2 months after trapping and then baiting remained the same on the D-line unit, but lower than pre-treatment activity, yet activity at West Satsop decreased after the integration of the baiting. Even with the best overall control as determined from fern activity, two plots on the West Satsop, (with probably only one mountain beaver in each), sustained heavy seedling damage. Studies have documented that a single mountain beaver is capable of damaging a significant portion of seedlings in the field (up to 81%) within a 1/10 acre plot in less than 3 months (Arjo, unpublished data). This is further substantiated under pen conditions where up to 44 seedlings in a week were damaged (Arjo et al., 2004b). This, in contrast to the D-line which sustained lighter damage, shows the overall variability in damage even with mountain beaver present (i.e., some animals do not destroy seedlings or that forage availability and preference may differ). Lower seedling damage is also likely attributed to lower reinvasion into the D-line unit when compared to West Satsop.

Determination of the most cost effective application method involves consideration of the monetary benefits and costs of the management action. Traditionally, a benefit–cost analysis is performed to evaluate program efficiency, requiring the quantification of benefits and costs. A project or management action is chosen because it maximizes benefits. The benefits and costs associated with managing mountain beaver damage to seedlings are relatively well defined. Benefits include the reduction in seedling damage by employing treatment 1 versus treatment 2. The determination of these benefits involves estimating the amount of seedlings saved under each treatment. The more mountain beaver damage avoided or prevented, the greater the benefit of the management action. However, due to the fact that seedling damage did not differ statistically between the two integrated pest management strategies, a standard benefit–cost analysis would not be informative.

While the within group variance accounted for the between group variance, it is still interesting to note that consistently treatment 1 (bait then trap) on average yielded lower seedling damage per acre values than treatment 2 (trap then bait), in both the initial phases of the study and 1 year later. In the first damage assessment, the estimated cost to replace damaged seedlings in treatment 1 was \$12.64/acre, while treatment 2 was \$17.63/acre. After 1 year, the cost to replace seedlings damaged in treatment 1 was again less than treatment 2, \$20.85/acre versus \$30.90/acre, respectively.

Mountain beaver densities were similar across units when both trapping for radio-collaring and post-treatment trapping were considered for the treatment 1 units. All units with the exception of the West Satsop unit ranged from 3.4 to 3.8 beavers/ha. The West Satsop unit was slightly lower at 2.0 beavers/ha, yet overall costs for treatment 2 were higher than treatment 1. Although fewer mountain beavers were on one unit, each unit was relatively similar in size. Initially, trapping labor efforts are heavily concentrated on scouting the units for active systems to place traps. So, although West Satsop had few beaver per hectare due to a portion of the unit being shale (i.e., not digging habitat for mountain beavers), trappers still spent time covering the area. Therefore, labor costs for trapping on the D-line were greater than on the West Satsop due to terrain (increasing the time trappers spent searching for burrows) and the number of active mountain beaver burrows requiring placements of traps. This variation is common in the field between units and is what drives the costs of trapping when contractors bid on a per acre basis. Although differences in labor costs occurred between the treatment 2 units, we feel they represent actual efforts and differences in efforts that occur in the field. When comparing overall costs the two units were averaged. Although treatment 2 trapping labor hours increased the overall cost of the treatment, fewer bait bags were placed in the environment due to the reduction of the population immediately following trapping. Seedling damage after 1 year increased in one plot on one unit in each of the treatments. Mountain beaver captures were similar a year after planting between treatment units ($n = 26$), although average densities were greater on the treatment 2 units ($\bar{x} = 1.1$ beavers/ha) than the treatment 1 units ($\bar{x} = 0.75$ beavers/ha). Behavioral elements suggest that treatment 2 may be more cost effective long-term, because baits left in tunnels provide some level of reinvasion prevention into the future. Additionally, treatment 2 may be a more socially acceptable method since fewer baits are placed in the environment with this treatment. Managers must therefore take into consideration not only cost of the IPM strategy they employ, but also socially acceptable methods. Baiting may have an advantage over trapping in some instances such as areas that are hard to access (e.g., slash piles), and can allow managers another tool for reducing mountain beaver damage.

Acknowledgments

We thank the Animal Damage Committees of the Washington Forest Protection Association and Oregon Forestry Industries Council for their financial support. Additional support from J. Todd and Brittlind Company was greatly appreciated. Without the field efforts of J. Duvall, J. Harper, E. Meister, K. Perry, and R. Roberts this project would not have been successful and their assistance was invaluable. We appreciate the review comments of J. Taylor, D. Stalman and two anonymous reviewers whose comments greatly improved this manuscript.

References

Arjo, W.M., Nolte, D.L., 2004. Assessing the efficacy of registered underground baiting products on mountain beaver (*Aplodontia rufa*) control. Crop Prot 23, 425–430.

Arjo, W.M., Nolte, D.L. 2006. Boomer or bust: managing a Pacific Northwest pest species, in: Timm, R.M., O'Brien, J.M. (Eds.), Proceedings of the 22nd Vertebrate Pest Conference 6–9 March 2006, Vol. 22. Berkeley, CA, pp. 181–186.

Arjo, W.M., Nolte, D.L., Primus, T.M., Kohler, D.J., 2004a. Assessing the efficacy of chlorophacinone for mountain beaver (Aplodont*ia rufa*) control, in: Timm, R.M., Gorenzel, W.P. (Eds.), Proceedings of the 21st Vertebrate Pest Conference, 1–4 March 2004, Vol. 21. Visalia, CA, pp. 158–162.

Arjo, W.M., Nolte, D.L., Harper, J., Kimball, B., 2004b. The effects of lactation on seedling damage by mountain beaver, in: Timm, R.M., Gorenzel, W.P. (Eds.), Proceedings of the 21st Vertebrate Pest Conference, 1–4 March 2004, Vol. 21. Visalia, CA, pp. 163–168.

Arjo, W.M., Huenefeld, R.E., Nolte, D.L., 2007. Mountain beaver home ranges, habitat use, and population dynamics in recently harvested units. Can. J. Zool 858, 328–337.

1900-1990 Black, H.C., Lawrence, W.H., 1992. Animal damage management in Pacific Northwest forest. In: Black, H.C. (Ed.), Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests. USDA Forest Service Pacific Northwest Research Station Tech Rep., Portland, OR., pp. 23–55. PNW-GTR-287.

Borrecco, J.E., Anderson, R.J., 1980. Mountain beaver problems in the forests of California, Oregon, and Washington., in: Clark, J.P. (Ed.), Proceedings of the 10th Vertebrate Pest Conference, 4–6 March 1980, Vol. 9. Fresno, CA, pp. 135–142.

Cafferata, S., 1992. Silvicultural methods in relation to selected wildlife species. In: Black, H.G. (Ed.), Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests. USDA Forest Service Pacific Northwest Research Station Tech, pp. 231–251. Rep. PNW-GTR-287.

Engeman, R.M., Campbell, D.L., Evans, J., 1991. An evaluation of 2 activity indicators for use in mountain beaver burrow systems. Wildl. Soc. Bull. 19, 413–416.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., 1996. SAS System for Mixed Models. SAS Institute, Cary, NC.

Lovejoy, B.P., Black, H.C., 1979. Population analysis of the mountain beaver *Aplodontia rufa pacifica*, in western Oregon. Northwest Sci. 53, 82–89.

McLean, R.A., Sanders, W.L., Stroup, W.W., 1991. A unified approach to mixed linear models. Amer. Statistician 45, 54–64.

Neal, F.D., Borrecco, J.E., 1981. Distribution and relationship of mountain beaver to openings in sapling stands. Northwest Sci. 55, 79–86.

Oregon Department of Forestry (ODF), 2008. 2007 timber harvest reports. Corvallis, OR. http://egov.oregon.gov/odf/state_forests/frp/2006menu.shtml (accessed 19 September 2008).

Runde, D.E., Nolte, D.L., Arjo, W.M., Pitt, W.C., 2008. Efficacy of individual barriers to prevent damage to Douglas-fir seedlings by captive mountain beavers. West. J. Appl. For 23 99-105.

SAS Institute, 2004. SAS/STAT User's Guide 9.1. SAS Institute, Carey, NC.

Washington Forest Protection Association (WFPA), 2008. Forest facts and figures. Olympia, WA. http://www.wfpa.org/pdf/brochure/07%20Forest%20Facts%20And%20Figures.pdf (accessed 19 September 2008).

Wolfinger, R.D., Tobias, R.D., Sall, J., 1991. Mixed models: a future direction. Proceedings of the 16th SAS Users Group Conference, 17–20 February 1991, New Orleans, LA. SAS Institute, Carey, NC, pp. 1380–1388.