USDA FOREST SERVICE REGION 2

MONITORING PROTOCOL FOR AMERICAN BEAVER (*Castor canadensis*):

EXAMPLES FROM THE BIGHORN AND BLACK HILLS NATIONAL FORESTS

(Photo from Nature of New England Website – http://www.nenature.com/Beaver.htm)

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I. INTRODUCTION

In this document we present a draft monitoring protocol for American beaver (*Castor canadensis*) on the Black Hills and Bighorn National Forests. The document begins with natural history and background to consider when monitoring beaver. We then present sections on objectives and sampling design for monitoring abundance and distribution of beaver on the Bighorn and Black Hills National Forests. We describe monitoring structured around a stratified random sample of 6^{th} level Hydrologic Unit Codes (HUC). Hydrologic Unit Codes are stratified by a combination of vegetation and physical characteristics important to American beaver (hereafter beaver). Within the context of the stratification we describe separate monitoring approaches to examine trend in abundance and trend in distribution. Within these sections we detail the methods one could follow to conduct a monitoring survey. We then provide information on the value of a pilot study to assess adequate sample sizes to conduct monitoring. A results section lists findings from our modeling efforts to designate suitable stratum for monitoring beaver on the Bighorn and Black Hills National Forests.

In this protocol, both abundance and geographic distribution are sampled to achieve inference to forest-wide patterns. Evaluating abundance provides information on changes in the size of a beaver population, while evaluating change in distribution provides understandings of expansion or contraction of beaver and the environments they are influencing. Our approach examines trends in an index to abundance of beaver sampled every 3 years while trend in geographic distribution (or range) is examined through sampling every 6 years. To be most efficient, trends in abundance and geographic distribution can be monitored simultaneously during field sampling flights. Although much of this document includes information specific to the Bighorn and Black Hills National Forests, the underlying purpose is to provide pertinent information for those wishing to implement a beaver monitoring program on other forests and grasslands of Region 2.

1.0. Natural History and Habitat Characteristics

Certain characteristics of beaver, their distribution, and behavior, influence the design of monitoring; in this section we review these characteristics. Beaver occur in aquatic systems throughout much of the Rocky Mountain Region where they serve as important ecological "engineers" by creating and maintaining dams, which in turn raise water tables, providing habitat for fish and wildlife, and promoting establishment of woody riparian vegetation. Beaver live in family groups of 3.2 to 8.2 individuals (Novak 1987). The largest groups in North America occur in the midportions of their range (Novak 1987). Beavers are monogamous with reproduction typically focused on one female in family groups (Jenkins and Busher 1979). Across North America, reported densities of beaver family groups/km of streams range from 0.35 to 1.25 (Novak 1987).

Food caches are created by beaver in fall to provide a source of food under the cover of ice in winter. The presence of food caches marks the location of family groups (Jenkins and Busher 1979) because only one cache is found per group (Hay 1958). Onset of construction of food caches begins with the first heavy frost and caches are most visible following leaf fall (Novak 1987). Food caches are placed near lodges in deeper water to facilitate access under ice in winter (Grasse and Putnam 1955).

When building a food cache, beaver often form a "raft" of inedible material such as mud, peeled sticks, or conifer branches and logs. This "raft" or "cap" eventually becomes waterlogged; submerging edible foods such as aspen (*Populus tremuloides*) and willow (*Salix* spp.) placed under the raft below the level of winter ice (Slough 1978). Branches and logs forming the consumable portion of a food cache are eaten throughout winter; however, beaver will continue to cut fresh trees as long as they can break through the ice at the edges of ponds (Jenkins and Busher 1979). The composition of food caches shifts from fall to spring to higher proportions of less preferred forage species such as alder (*Alnus* spp.; Slough 1978).

Due to an association between relative abundance of beaver and their food caches (Novak 1987), monitoring the density and distribution of food caches can be used to determine beaver population abundance and distribution. Effective aerial monitoring of food caches in late October and early November occurs at a time when food caches are most visible. In contrast, monitoring food caches after ice freezing is difficult if not impossible, because only a few sticks may remain above ice (Olson and Hubert 1994). Therefore, it is critical that counts be conducted after caches have been constructed and are most visible in late October or early November. Conflicts with counting include early ice formation in late fall and disturbance to hunters (via aircraft noise) during early to mid-fall hunting seasons. Thus surveys should be planned to maximize counts while minimizing conflicts.

We evaluated beaver habitat suitability on the Bighorn and Black Hills National Forests to provide information to stratify watersheds according to predicted abundance of beaver. These stratifications provide a way to monitor beaver within homogeneous sampling units, resulting in more precise estimates and savings in time and money. We conducted a literature review on beaver habitat suitability to provide a list of important habitat features to use in a GIS to evaluate beaver habitat suitability and relative quality. Quite a few papers are available on this topic. Although this was not an exhaustive search, several of the same parameters including food availability, water conditions, and topography were identified as important factors in many of the studies we reviewed (Table 1). It is important to recognize potential geographic variation in beaver habitat associations as beavers inhabit a wide-range of aquatic systems including lakes, ponds, creeks, swamps, and rivers across North America (Jenkins and Busher 1979, Novak 1987). Robel et al. (1993) reported poor correlations between beaver colonies/km in Kansas with habitat suitability index values computed from the model presented by Allen (1983). This finding suggests it is crucial to evaluate important predictors of habitat suitability relative to habitat components available on a respective forest. In other words, context is important and we should not expect the same criteria to function in cottonwood (*Populus* spp.) gallery forests of the national grasslands as in high elevation glaciated streams in a conifer landscape on national forests. For instance, Suzuki and McComb (1998) conducted a discriminant function analysis (DFA) to identify habitat components important in discriminating between beaver dam sites and unoccupied sites in a watershed dominated by red alder (*Alnus rubra*) and Douglas fir (*Pseudotsuga menziesii*) in western Oregon. They extended their analysis by using those variables detected in their DFA (stream width, gradient, and valley floor width) to develop a new habitat suitability index model for beaver in that watershed. A similar analysis could be used to identify related habitat conditions that correspond to levels of beaver density, or could be simplified by constructing a checklist of criteria that are indicative of high, medium, low, or no beaver activity on a given national forest or grassland, other land area, or watershed.

Clearly the most fundamental consideration for suitable beaver habitat is a source of perennial water (Novak 1987). Beaver depend on woody foods during winter in the northerly areas of their distribution (Jenkins and Busher 1979, Allen 1983, Novak 1987). Consequently, availability of winter foods may limit beaver populations (Allen 1983). Beaver eat leaves, twigs, and bark of most woody species found in riparian areas, but demonstrate a preference for salicaceous trees and shrubs such as aspen, willow, and cottonwood. In addition to providing food, these woody species are also used to construct dams and lodges (Jenkins and Busher 1979, Novak 1987). Thus, relative availability of important shrubs and trees in riparian areas is an important component in selecting areas most suitable for beaver. In addition, beaver select habitats with low gradients (0–15%; Retzer et al. 1956) and wide valley bottoms to provide suitable locations for dams. Narrow canyons with little or no riparian vegetation and steep channels are not suitable for beaver; flat floodplains allow beavers to construct lateral canals to access food supplies (Olson and Hubert 1994). At the minimum, any analysis to delineate areas of high beaver density should consider water availability, gradient of stream or river, and availability of preferred woody species. Based on our review it seems that, a classification process should include identifying: (1) sites with perennial water sources, (2) gradient of lotic systems, (3) width of valley bottoms around lotic systems, and (4) composition of woody riparian vegetation especially hardwoods.

1.1. Background

American beaver have been selected as a management indicator species on the Bighorn and Black Hills National Forests. Other forests or grasslands may be interested in monitoring populations of beaver to evaluate certain aspects of riparian and stream restoration or management. However, a rigorous, complete monitoring protocol has not been developed for individual forests or grasslands within Forest Service Region 2. This document, which represents a protocol for monitoring beaver on the Bighorn and Black Hills National Forests, provides a template for use by other forests or grasslands in the region wishing to design a program to monitor trends in the abundance and distribution of beaver populations.

Monitoring design depends on the goals and objectives for monitoring. Therefore, the sampling design may differ among forests to meet the goals and objectives of the monitoring program. Critical choices in designing the monitoring program include defining sampling units, determining what parameter(s) to measure on each sampling unit, and establishing a process for selecting sampling units. Sampling units for broad-scale monitoring of beaver may be defined in a variety of ways. For instance, stream segments, whole stream courses, watershed units, or blocks of land not conforming to watershed units could be established.

To develop an efficient sampling scheme, streams or watersheds (the sampling units for beaver food caches), with similar densities of beaver could be grouped into strata. Doing so provides the foundation for a "stratified sampling scheme," which, if the stratification is successful, will lead to reduced variance in the estimate of beaver abundance. Reducing variance results in a more efficient estimate (reduced cost per unit information) and improves the ability to detect trend over time (Thompson et al. 1998). Defining effective strata requires identifying selection criteria based on environmental factors associated with beaver density. Identifying a small number of categories (2 or 3 strata) should provide the best estimates of beaver food cache abundance considering the low numbers of streams available as well as the sampling cost.

The parameter of interest in each sampling unit could also be established in a variety of ways. Because of their behavior, beaver are difficult to count and therefore estimating abundance is difficult. The literature strongly suggests recording the density of beaver food caches as the preferred observation on sampling units (Novak 1987). Food caches, then, represent an indirect index of the abundance of family groups. Aerial monitoring of food caches in late October and early November provides the best index of abundance because one to several lodges may be used by each family group, whereas only one winter food cache is established annually by each family group (Hay 1958).

Recent discussions in the wildlife literature point to the problems and pitfalls in using indices to evaluate relative abundances of wildlife (Anderson 2001, 2003; Engeman 2003). Nevertheless, given the challenge of meeting assumptions for direct measures of abundance for some species, indices of abundance, such as counts of beaver food caches per length of streams, provide measures of relative population size and are useful to track year to year changes in single populations (Caughley and Sinclair 1994:215, Hayward et al. 2002). The fundamental concern with indices is this—when used to represent relative abundance, index values are suspect because they assume equal detection probabilities across time, habitat types, and observers (Anderson 2001, 2003). It seems reasonable that beaver food caches would have high detection probabilities given that counts are conducted from air where food caches that tend to be distributed in open water should be highly visible. Indeed, mean accuracy of locating caches with helicopters was about 89% on 2 prairie rivers in Montana (Swenson et al. 1983). However, detection probabilities can be compromised by timing of aerial flights, obstructing ice or vegetation, and observer bias (Payne 1981). In addition, counting food caches may not be a feasible means to monitor abundance of beaver in low elevation areas because beaver may not construct food caches in areas where ice does not form in winter (Collins 1976, Olson and Hubert 1994). Efforts to evaluate detection probabilities should be implemented to improve the reliability of the food cache index to monitor relative abundance of beaver.

1.2. Objectives

The Bighorn and Black Hills National Forests seek to monitor trends in abundance and geographic range of beaver at the scale of the National Forest sufficient to identify a 5% annual decline in beaver abundance and a 10% change (increase or decrease) in range. The Forests seek to achieve 80% power to detect a population decline with alpha at 0.2 over a 9 year period. If sampling suggests that the distribution of beaver declines by 10% over a 12 year period, or suggests that population abundance declines annually by 5% over a 9 year period, the Forest will evaluate potential drivers for the change and develop management to address the decline. Our selection of a 5% annual decline is based on balancing conservation with variability in beaver abundance in Rocky Mountain systems as well as identifying a level of decline that is detectable given the number of sampling units and duration of the monitoring period. There is no evidence that beaver populations are cyclic (Novak 1987); therefore, we assume that increases and decreases in beaver abundance occur at relatively constant rates that are not interrupted by periodic oscillations.

The monitoring objective is designed specifically to examine potential declines in abundance of beaver at the scale of the National Forest, and to examine either increases or decreases in range of beaver. Therefore, one-tailed tests will be used to evaluate change in abundance, while two-tailed tests will be used to evaluate increases or decreases in geographic range. Although the design focuses in detecting declines, graphical analyses and descriptive statistics can be employed to examine the monitoring results to identify increases in abundance.

1.3. Sampling Design

Monitoring American beaver on the Bighorn and Black Hills National Forests will be accomplished by monitoring change in the density of food caches per stream segment in a stratified sample of watersheds on each Forest. Food cache density represents an index of beaver family group use of watersheds. By monitoring change in density of food caches on streams, both change in abundance and distribution will be monitored. Details of the sampling design are presented below.

Establishing a sampling design requires attention to the definition of sampling units, definition of the population of interest, and important decisions regarding selection of elements from the population (e.g., simple random, stratified, etc.; Thompson et al. 1998). The sampling design to collect observations and estimate abundance of beaver food caches on the Bighorn and Black Hills National Forests includes *sampling elements*, which are defined as beaver food caches; *sampling units*, which are 6th level HUC watersheds with suitable beaver habitat; the s*ampling frame* is the list of all 6th level HUC watersheds with suitable beaver habitat that could be sampled on each Forest; the *sample* is the actual list of randomly selected sampling units (6th level HUCs) on each Forest to be sampled for beaver food caches; the *sampled population* is beaver food caches in the sampling frame of 6th level HUC watersheds on each Forest; and, the *target population* for each Forest are all 6th level HUC watersheds with suitable habitat in late October or early November following aspen and willow leaf drop. Using an index of beaver food caches, abundance can be monitored on any national forest in Region 2. As mentioned, monitoring beaver on grasslands with a food cache index may be problematic, and likely requires other techniques to evaluate abundance. As an example, we used 6th level hydrologic code unit code (HUC) watersheds on the Bighorn and Black Hills National Forests as sampling units.

1.4. Selection Criteria to Delineate Suitable Beaver Habitat

Developing an efficient beaver monitoring scheme on any forest or grassland will require classification of beaver habitat suitability and potentially classifying relative habitat quality. Thus, in this protocol, we review current knowledge of beaver habitat associations in the western United States. A fundamental objective of our protocol, therefore, is to establish a habitat classification procedure to identify homogenous sampling units for use in evaluating trends in a beaver food cache index.

A useful first step in identifying criteria to classify habitat for beaver would be to evaluate habitat components on stream reaches on the forest where densities of beaver are known to be high, moderate, or low, as well as evaluating components on those reaches without beaver. This information could then be used to select strata representing those streams with the most similar traits, and hence representative of beaver habitat suitability. This is the process we used on the Bighorn and Black Hills National Forests.

II. METHODS – TRIGGER POINTS AND EVALUATION

Effective monitoring provides managers with information to evaluate Forest Plans, which leads to improved decision-making and management. Monitoring beaver, when they have been designated as a management indicator species or other designation, requires managers to obtain and evaluate data related to habitats and populations. Consequently, adjustments to forest plan goals may need to be made if habitat or population objectives are not met.

Disease, disturbance or forest succession changing cover of preferred woody species, changes in predator communities, intensity of trapping or control efforts, reintroductions, drought or high water years are all potential factors that may lead to changes in the abundance or geographic range of beaver. We suggest an approach where monitoring an index to abundance of beaver occurs every 3 years and monitoring geographic distribution (or range) is examined every 6 years. To be most efficient, trends in abundance and geographic distribution can be monitored simultaneously during every other 3-year survey for abundance. A decline of 5% in annual abundance (over 9 years) or 10% in distribution (over 12 years) are the trigger points we suggest to motivate changes in management response.

Monitoring changes in habitat alone would be a very poor, unsupportable estimate of the change in beaver populations. The reason for this is because there are many places on national forests or grasslands where suitable beaver habitat exists, but beaver are not present. The habitat models we created for the Bighorn and Black Hills National Forests predict relative abundance of beaver based on habitat components; however, we use that information to stratify the landscape into high, medium, low, and non beaver habitat watersheds where beaver can be monitored. In addition, it is likely that beaver populations on many Forest Service system lands occur at levels lower than they did historically (Emme and Jellison 2004). Analyses may be furthered by comparing current estimates of abundance and distribution to historical levels; however, monitoring efforts should be based on current population levels to provide detection of declines relative to current management activities.

Estimated food cache index values are evaluated to assess the population trend of beaver on each forest or grassland. Likewise, estimated proportions of sampling units occupied by beavers are evaluated to assess distribution of beaver populations on each forest or grassland. Trend is examined using regression methods by estimating the slope of a regression over the specified time period and determining whether the estimated value exceeds some specified level. We suggest a critical value of 5% annual decline for abundance and 10% per 6 years for changes in distribution. The slope is tested with a one-tailed *t*-test under the null hypothesis that the population trend of beaver (abundance or distribution) has decreased ($\beta_1<0.05$ or $\beta_1<0.10$; Gerrodette 1987).

By clarification, when setting up monitoring protocols, one is modeling rates of decline from one unit of time to the next. In the case of beaver, after the end of the monitoring period one will evaluate if the slope of a regression between abundance (beaver food caches/linear length of perennial water) or distribution and years has declined at a 3-year or 6-year rate of 5% annually or 10%, respectively. One is <u>not</u> simply testing to see if there has been a 5% decline in the abundance index or a 10% decline in the proportion of occupied sampling units from year 1 to the final year of the monitoring period. The decline is exponential, meaning that for each successive time period the decline is proportional to the current population size (Thompson et al. 1998). In comparison, a linear decline would be a decline at a constant amount between the time periods of interest. When one conducts a regression to obtain the slope coefficient to test, they simply natural log transform the estimates of the beaver food cache index or proportion of occupied sampling units to linearize the data prior to conducting the linear regression or more complex model (based on the underlying stratification). As an example, trend analyses for beaver abundance could be conducted to provide over 80% power to detect a 5% annual decline over 9 years in the beaver food cache index with a 20% chance of Type I Errors ($\alpha = 0.20$). This same example is also applicable to trend analysis for beaver distribution to provide over 80% power to detect a 10%, 6-year decline in the proportion of sampling units occupied by beavers with a 20% chance of Type I Errors ($\alpha = 0.20$). However, management context should determine the values used for each forest.

III. METHODS – TRENDS IN ABUNDANCE

3.0. Background – Process for Selecting a Stratified Random Sample

When initiating the monitoring protocol for the Bighorn and Black Hills National Forests, we used existing information to base sampling units and sample sizes. Our approach in using modeling to define strata is detailed in Appendix A. We explain how we verified our best model explaining suitable beaver habitat in Appendix B. Modeling provided a way to stratify 6^{th} level HUC watersheds into sampling units of low, moderate, or high quality. We were able to cast our sample to evaluate abundance with the beaver food cache index based on these sampling units.

A rather common question that has been raised is whether one changes the designation of a stratum as habitat conditions change over time (e.g., willow and aspen regenerate in watersheds or streams lacking substantial woody riparian cover at the beginning of the monitoring period). The unequivocal answer is no because changing stratum designation would not allow for the ability to evaluate changes in the beaver food cache index over time as related to management activities. Managers need to strictly adhere to strata designation throughout monitoring programs for beaver food caches. If desired, future modeling and monitoring of sampling strata could be implemented to compliment habitat restoration efforts.

3.1. Definition of Sample Elements

The sampling elements to monitor trend in abundance of beaver are defined as food caches. The number of food caches counted per sampling unit is used to compute an index of food caches per km as:

$$\text{Index} = \frac{\text{number of food caches}}{\text{total length (km) of perennial water in sampling unit}}.$$

These index values are then incorporated into a stratified random estimator to estimate the mean index for the entire area of suitable beaver habitat on each forest (Thompson et al. 1998).

3.2. Sample Size Calculation

By definition, the non habitat stratum consists of sampling units that should not be sampled. Until more information is available relative to sample sizes needed to monitor trends in beaver food caches across various forest or grassland types in the region, we suggest sampling 15 moderate quality sampling units and 15 high quality sampling units during the first year of monitoring (Figures 1 and 2). After delineating strata on the Bighorn and Black Hills National Forests, we numbered each 6th level HUC and then randomly selected 15 HUCs within both the moderate and high quality habitat strata to yield a total of 30 sampling units for each forest (Tables 6 and 7; Figures 1 and 2). Our choice of 30 samples is based on the Central Limit Theorem; however, the efficacy of this sample will be evaluated after 2 monitoring sessions (6 years) to determine whether the sample is adequate or if it exceeds the necessary sample.

As more data become available through pilot studies, sample size (*n)* can be approximated for the mean estimator for a stratified random sample as:

$$n = \frac{\sum_{i=1}^{L} N_i^2 \sigma_i^2 / w_i}{N^2 D + \sum_{i=1}^{L} N_i \sigma_i^2}$$

Where N is number of sampling units, L is the total number of strata, w_i is the fraction of observations allocated to stratum i, σ_i^2 is the population variance for stratum i, and $D = \frac{B^2}{4}$ where B is the bound on the error of estimation (Schaeffer et al. 1996:137). The bound on the error of estimation is typically represented as a proportion of the estimated parameter that one is willing to accept as error. Other sample size estimators are available that include allocating sample size given costs (Schaeffer et al. 1996); facilitating consideration of budget constraints to improve the efficiency of sample size estimators.

When working with pilot data, sequential sampling is a useful procedure to assess sample sizes. Moving averages of mean index values and standard deviations of mean index values from pilot data are plotted (y axis) against sample sizes (x axis) to evaluate the number of sample sizes where bias is evaluated through change in the point estimate (mean index values) and precision evaluated through change in the standard deviation (Elzinga et al. 1998). Sampling beyond the number of sampling units where the plots smooth out indicates a negligible amount of improvement in accuracy per unit effort. In general, we recommend consultation with a statistician when a forest reaches the stage in planning and implementation of a monitoring protocol where sample sizes are considered.

3.3. Field Methods

When monitoring declines in abundance of beaver, a helicopter survey searches the entire length of perennial streams, rivers, and water bodies in each randomly selected HUC. Each time a new beaver food cache is located in each sampling unit, it is recorded. Additional data that should be recorded include the date of the survey flight, time each food cache was located, and Universal Transverse Mercator (UTM) coordinates for each food cache (Appendix C).

Helicopters and fixed wing aircraft have been used successfully to monitor beaver food caches (Payne 1981, Swenson et al. 1983, Smith 1999). However, Payne (1981) indicated that while Super Cub fixed wing aircraft were less expensive, they were only about half as efficient in censusing beaver food caches as were helicopters in Newfoundland. In Yellowstone National Park, Smith (1999) counted beaver food caches at an altitude of 152.4 m (500 ft) above ground at a speed of 88.5 to 104.6 km per hour (55 to 65 mph) from a Super Cub fixed wing aircraft. Beaver food caches were counted from helicopter and fixed wing aircraft at 90–150 m (295.3–

492.1 ft) altitude above ground in Newfoundland. Beaver food caches were surveyed on prairie rivers in Montana in Super Cub (150 hp) fixed wing aircraft at an altitude of 100–200 m (328.1–656.2 ft) above ground level at a speed of 100 km per hour (62.1 mph; Swenson et al. 1983). It should be noted that Forest Service aircraft safety requirements preclude use of Super Cub aircraft by Forest Service personnel, but helicopters are considered to be sufficiently safe for use (J. Warder, personal communication, Bighorn National Forest, Sheridan, Wyoming, USA, 2005).

3.4. Assessing Population Trends over Time

Beaver food cache monitoring will not require annual surveys because of the persistence of beaver family groups. Consequently, food cache surveys in moderate and high quality strata could be conducted every 2 or 3 years. In this protocol we suggest 3 year intervals, however, Forests may decide to survey more frequently if management goals or suspected changes in beaver abundance suggest the need to survey more frequently.

As mentioned, the number of food caches counted per sampling unit is used to compute an index of food caches per km. These index values are then incorporated into a stratified random estimator to estimate the mean index for the entire area of suitable beaver habitat on each forest (Thompson et al. 1998). Following notation in Schaeffer et al. (1996), the estimator for the population mean (μ) for a stratified random sample is:

$$\overline{y_{st}} = \frac{1}{N}\sum_{i=1}^{L} N_i \overline{y}_i$$

Where, $\overline{y_{st}}$ is the mean estimator for a stratified random sample, N is the number of sampling units, L is the total number of strata, and, $\overline{y}_i$ is the mean for stratum i computed as a simple random sample:

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$$

The variance estimator for $\bar{y}_{st}$ is (Schaeffer et al. 1996):

$$\hat{V}(\bar{y}_{st}) = \frac{1}{N^2} \sum_{i=1}^{L} N_i^2 \left(\frac{N_i - n_i}{N_i} \right) \left(\frac{s_i^2}{n_i} \right)$$

Where, N is the total number of sampling units, N_i is the number of sampling units in stratum i, n_i the number of sampling units in stratum i, and s_i^2 is the sample variance for stratum i computed as a simple random sample:

$$\hat{V}(\bar{y}) = \frac{s^2}{n} \left(\frac{N - n}{N} \right), \text{ where}$$

$$s^2 = \frac{\sum_{i=1}^{n} y_i^2 - n\bar{y}^2}{n-1}$$

IV. METHODS – TRENDS IN DISTRIBUTION

4.0. Background

Forest-wide distribution of beaver is not expected to change rapidly unless the species experiences a significant stressor (e.g., epidemic disease). Therefore we recommend monitoring distribution through surveys every 4 to 6 years. In this protocol we develop an approach for surveying changes in distribution every 6 years to compliment the 3-year surveys for abundance monitoring.

4.1. Definition of Sample Elements

The sampling elements to monitor trend in distribution of beaver are defined as the proportion of sampling units that are occupied by beaver as assessed through the presence or absence of food caches.

4.2. Sample Size Calculation

To select a sample of sampling units to monitor every 6 years we recommend the following steps. First, all sampling units that potentially can be occupied by beaver (i.e., low, moderate, and high quality strata) are identified and numbered excluding sampling units that were originally selected for abundance monitoring. Next, a random sample will be drawn of sampling units in each stratum with no consideration for sampling units where beaver were found during earlier sampling. The estimator for this sample will not be stratified because we are interested in obtaining an estimate for beaver distribution irrespective of habitat quality. Because monitoring sampling units for presence of beaver (rather than counting all beaver in the watershed) could be relatively fast, it may be feasible to monitor a larger number of sampling units than when monitoring abundance. When pilot data are available, one may estimate an adequate number of samples with the following sample size estimator for the population proportion (p) of a simple random sample (Schaeffer et al. 1996:99):

$$n = \frac{Npq}{(N-1)D + pq}$$

Where, n is the number of samples, N is the total number of sampling units in the sampling frame, $q = 1 - p$, and $D = \frac{B^2}{4}$

4.3. Field Methods

To evaluate changes in distribution of beaver, a helicopter survey would begin searching the length of perennial streams, rivers, and water bodies in each randomly selected sampling unit. In this case, monitoring would cease as soon as 1 food cache was located in each sampling unit because active beaver presence in that sampling unit has been confirmed. On the other hand, if no cache is observed, the search would not cease until the entire sampling unit had been surveyed. Data from the presence/absence survey to document distribution would be combined with data from the abundance survey to determine distribution every 6 years.

4.4. Assessing Trends in Distribution over Time

Changes in distribution of beaver populations through presence or absence of food caches need not be an annual activity due to the persistence of beaver colonies. Monitoring to evaluate expansion and contraction of populations could be conducted every 6 years. The parameter of interest in this case is the proportion of sampling units that are monitored that are occupied by beaver (Thompson et al. 1998). Following notation in Schaeffer et al. (1996), the estimator for the population proportion (p) for a simple random sample is:

$$\hat{p} = \frac{\sum_{i=1}^{n} y_i}{n}$$

Where, $\hat{p}$ is the estimator for a population proportion (p) for a simple random sample, y_i is presence of beaver in sampling unit i, and, n is the total number of sampling units monitored.

The variance estimator for $\hat{p}$ is (Schaeffer et al. 1996):

$$\hat{V}(\hat{p}) = \frac{\hat{p}\hat{q}}{n-1}\left(\frac{N-n}{N}\right)$$

Where, $\hat{q} = 1 - \hat{p}$

To place a bound on the error of estimation:

$$2\sqrt{\hat{V}(\hat{p})} = 2\sqrt{\frac{\hat{p}\hat{q}}{n-1}\left(\frac{N-n}{N}\right)}$$

Where, N is the total number of sampling units in the sampling frame, and n is the number of sampling units in the sample.

V. PILOT STUDY TO DETERMINE SAMPLE SIZE

Currently we have insufficient information to evaluate sample size to monitor trend in beaver abundance or trend in distribution on the Bighorn or Black Hills National Forests. Pilot studies provide a means to obtain essential information relative to time and financial costs to monitor beaver food caches. To conduct a pilot study it may be more feasible to sample fewer sampling units than would be monitored in a typical year. For example, 5 or 10 sampling units in moderate and high quality strata would be randomly selected from the 15 sampling units randomly selected for monitoring. A helicopter survey would then be carried out to search the entire length of perennial streams, rivers, and water bodies in each randomly selected HUC. The index value from the set of sample HUCs could then be used to estimate variance and a power analysis completed to evaluate sample sizes needed to detect an annual decline of 5% in the index value over the time period of interest.

Costs are a very important consideration when conducting monitoring programs. Helicopter flights during September 2004 on the Black Hills National Forest indicated that 8 hours of helicopter surveys occurred at a speed of 118.5 km per hour (73.6 miles per hour). The cost for 8 hours of operation was $4,441.80 for the contract helicopter and a ground support vehicle (K. Burns, personal communication, Black Hills National Forest, Custer, South Dakota, USA, 2005). The maximum length of perennial stream or river in any 6th level HUC on the Black Hills National Forest is 26.7 km (43.0 mi). A helicopter moving at a speed of 73.6 miles per hour could survey these streams in 35 minutes at a cost of $323.88. However, much time during the 2004 flight was spent in the air traveling between beaver lodges (K. Burns, personal communication, Black Hills National Forest, Custer, South Dakota, USA, 2005). Therefore, it is anticipated that intensive survey work in sampling units will result in slower speeds, and thus higher helicopter costs. Pilot studies will assist in better understanding costs to monitor beaver abundance in various sampling units on forests or grasslands engaging in beaver monitoring.

When pilot data are available, a statistician employed by the Forest Service could use these preliminary results to evaluate how many samples are needed to evaluate power over time in a monitoring context (the probability of making a correct decision that a change has occurred when, in fact it has). For instance, pilot data could be entered into a statistical program such as Program Monitor (Gibbs 1995) to evaluate the number of samples needed to achieve a desired level of power to detect declines in beaver abundance and distribution. Program Monitor requires inputs including mean values, temporal and spatial variation, years of monitoring, alpha, and rate of decline to assess power for a sample of monitoring data (Gibbs 1995). Power results are very useful to assist biologists in determining sample sizes needed to detect trend within the bounds of their objectives.

VI. DATA RECORDING AND ARCHIVING

A data form containing the basic information to record when conducting beaver food cache surveys to monitor abundance is provided in Appendix C and a data form to use when monitoring beaver distribution is provided in Appendix D. Recording UTM coordinates at food cache locations will facilitate entry of these data points in NRIS Fauna or other wildlife databases. Further details for counting beaver food caches are found on pages 19–21 of the British Columbia Ministry of Environment, Lands and Parks publication "Inventory Methods for Beaver and Muskrat" (http://srmwww.gov.bc.ca/risc/pubs/tebiodiv/bemu/index.htm).

VII. RESULTS – BIGHORN AND BLACK HILLS NATIONAL FORESTS

Beaver locations in the Bighorn National Forest were closer to suitable vegetation and a perennial water source, situated at lower elevations and slopes, and in areas with lower topographic complexity than at random (Table 2). The same patterns were observed for beaver locations on the Black Hills National Forest with the exception that topographic complexity and slope did not differ between beaver and random locations (Table 3). We reason that these differences are related to the fact that topography is more rolling and less abrupt on the Black Hills than on the Bighorn National Forest.

The best model identifying suitable beaver habitat on the Bighorn and Black Hills National Forests was the model with predictor variables including percent slope, distance to water, distance to aspen and/or willow, and elevation deviation (Tables 4 and 5). On the Bighorn

National Forest, relative importance of the predictor variables in the best model were slope (1.00), distance to aspen and/or willow (1.00), distance to water (1.00), and elevation deviation (0.69). On the Black Hills National Forest, relative importance of the predictor variables in the best model were slope (1.00), distance to aspen and/or willow (1.00), distance to water (1.00), and elevation deviation (0.92). Our cross validation analyses indicated the best model was a strong, positive predictor of beaver habitat suitability on the Bighorn ($r_s = 0.82$, $P = 0.004$, $n = 10$) and Black Hills National Forests ($r_s = 0.94$, $P < 0.001$, $n = 10$).

In Tables 6 and 7, each 6th level HUC sampling unit is categorized into a stratum based on the proportion of suitable beaver habitat, and a random sample of sampling units selected for moderate and high quality habitat strata are tabulated. A summary of the distribution of 6th level HUC sampling units for each forest is tabulated in Table 8.

VIII. LITERATURE CITED

ALLEN, A. W. 1983. Habitat suitability index models: beaver. U.S. Fish and Wildlife Service FWS/OBS–82/10.30 Revised.

ANDERSON, D. R. 2001. The need to get the basics right in wildlife field studies. Wildlife Society Bulletin 29:1284–1297.

ANDERSON, D. R. 2003. Response to Engeman: Index values rarely constitute reliable information. Wildlife Society Bulletin 31:288–291.

BEIER, P., AND R. G. BARRETT. 1987. Beaver habitat use and impact in Truckee River basin, California. Journal of Wildlife Management 51:794–799.

BOYCE, M. S., P. R. VERNIER, S. E. NIELSEN, AND F. K. A. SCHMIEGELOW. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.

BURNHAM, K. P., AND D. R. ANDERSON. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd ed. Springer-Verlag New York, New York, New York, USA.

CAUGHLEY, G., AND A.R.E. SINCLAIR. 1994. Wildlife ecology and management. Blackwell Science, Cambridge, Massachusetts, USA.

COLLINS, T. C. 1976. Population characteristics and habitat relationships of beavers, Castor canadensis, in northwest Wyoming. Doctoral Dissertation, University of Wyoming, Laramie, Wyoming, USA.

ELZINGA, C. L., SALZER, D. W., AND J. W. WILLOUGHBY. 1998. Measuring and monitoring plant populations. U.S. Department of the Interior, Bureau of Land Management. BLM Technical Reference BLM Technical Reference 1730-1. Denver, Colorado.

ENGEMAN, R. M. 2003. More on the need to get the basics right: population indices. Wildlife Society Bulletin 31:286–287.

FRYXELL, J. M. 2001. Habitat suitability and source–sink dynamics in beavers. Journal of Animal Ecology 70:310–316.

GERRODETTE, T. 1987. A power analysis for detecting trends. Ecology 68:1364–1372.

GIBBS, J. P. 1995. Monitor version 6.2 users manual. Exeter Software, Setauket, New York, USA.

GRASSE, J. E., AND E. F. PUTNAM. 1955. Beaver management and ecology in Wyoming. Federal Aid to Wildlife Restoration Project, Bulletin Number 6. Wyoming Game and Fish Commission, Cheyenne, Wyoming, USA.

HAY, K. G. 1958. Beaver census methods in the Rocky Mountain region. Journal of Wildlife Management 22:395–402.

HAYWARD, G. D., D. G. MIQUELLE, E. N. SMIRNOV, AND C. NATIONS. 2002. Monitoring Amur tiger populations: characteristics of track surveys in snow. Wildlife Society Bulletin 30:1150–1159.

HOWARD, R. J., AND J. S. LARSON. 1985. A stream classification system for beaver. Journal of Wildlife Management 49:19–25.

JENKINS, S. H., AND P.E. BUSHER. 1979. *Castor canadensis*. Mammalian Species No. 120. American Society of Mammalogists, Shippensburg, Pennsylvania, USA.

MCCOMB, W. C., J. R. SEDELL, AND T. D. BUCHHOLZ. 1990. Dam-site selection by beavers in an eastern Oregon Basin. Great Basin Naturalist 50:273–281.

NOVAK, M. 1987. Beaver. Pages 283–312 in M. Novak, J. A. Baker, M. E. Obbard, and B. Malloch, editors. Wild Furbearer Management and Conservation in North America. Ministry Natural Resources, Toronto, Ontario, Canada.

OLSON, R., AND W. A. HUBERT. 1994. Beaver: water resources and riparian habitat manager. University of Wyoming, Laramie, Wyoming, USA.

PAYNE, N. F. 1981. Accuracy of aerial censusing for beaver colonies in Newfoundland. Journal of Wildlife Management 45:1014–1016.

RETZER, J. L., H. M. SWOPE, J. D. REMINGTON, AND W. H. RUTHERFORD. 1956. Suitability of physical factors for beaver management in the Rocky Mountains of Colorado. Colorado Department of Game and Fish, Technical Bulletin 2.

ROBEL, R. J., L. B. FOX, AND K. E. KEMP. 1993. Relationship between habitat suitability index values and ground counts of beaver colonies in Kansas. Wildlife Society Bulletin 21:415–421.

SATTERTHWAITE, F. E. 1946. An approximate distribution of estimates of variance components. Biometrics Bulletin 2:110-114.

SCHEAFFER, R. L., W. MENDENHALL III, AND R. L. OTT. 1996. Elementary survey sampling, 5th ed. Duxbury Press, Boston, MA.

SLOUGH, B. G. 1978. Beaver food cache structure and utilization. Journal of Wildlife Management 42:644–646.

SLOUGH, B. G., AND R. M. F. S. SADLEIR. 1977. A land capability classification system for beaver (*Castor canadensis* Kuhl). Canadian Journal of Zoology 55:1324–1335.

SMITH, D. W. 1999. Beaver survey: Yellowstone National Park 1998. Yellowstone Center for Resources (YCR-NR-99-3), Yellowstone National Park, Wyoming, USA.

SUZUKI, N., AND W. C. MCCOMB. 1998. Habitat classification models for beaver (*Castor canadensis*) in the streams of the central Oregon Coast Range. Northwest Science 72:102–110.

SWENSON, J. E., S. J. KNAPP, P. R. MARTIN, AND T. C. HINZ. 1983. Reliability of aerial cache surveys to monitor beaver population trends on prairie rivers in Montana. Journal of Wildlife Management 47:697–703.

THOMPSON, W. L., G. C. WHITE, AND C. GOWAN. 1998. Monitoring vertebrate populations. Academic Press, San Diego, California, USA.

Table 1. Literature review of important predictors of beaver habitat suitability.

Reference	Location	Important predictors of beaver habitat suitability
Retzer et al. (1956)	Colorado	Excellent habitat was characterized by valley grades of ≤6%; valley width of >46 m; and, rock types of glacial till, schist, or granite. Unsuitable habitat had a valley grade of >15%, and a valley width that was not much wider than the stream itself.
Slough and Sadleir (1976)	British Columbia	Beaver occupancy along lakes and streams was most related to food availability (aspen along lakes and cottonwood along streams).
Beier and Barrett (1985)	eastern California and western Nevada	Increasing stream width and depth and decreasing stream gradient were most influential in beaver habitat use. Food availability added little explanatory power.
Howard and Larson (1985)	Massachusetts	Watershed size (ha) above the colony site, stream width (m) below the final dam, stream gradient, soil drainage class, % hardwood vegetation within 100m of the site center, percentage hardwood vegetation within 200 m of the site center, and percentage abandoned fields within 100 m of the site center all affected beaver colony site longevity
McComb et al. (1990)	Eastern Oregon	Stream reaches with beaver dams were shallower and had a lower gradient than unoccupied reaches. Beaver did not build dams at sites with a rocky substrate. Bank slopes at occupied reaches were not as steep as those at unoccupied reaches. Occupied streams had greater tree canopy cover, especially of thinleaf alder
Suzuki and McComb (1998)	Western Oregon	Beaver built dams in areas with wide valley-floors, low gradient streams, high graminoid cover, low red alder cover, and low shrub cover.
Fryxell (2001)	Ontario, Canada	Beaver abundance was related to food availability.

Table 2. Mean (± SE) habitat characteristics at 154 beaver and 500 random location pixels, Bighorn National Forest, Wyoming, 2003. Independent sample *t*-tests evaluated differences between beaver and random locations.

Habitat variables	Beaver	Random	*t*	*Df*	*P*
Distance (m) to vegetation[a]	754 ± 93	1,940 ± 67	–10.38	327	<0.001
Distance (m) to water[b]	167 ± 9	319 ± 10	–11.15	496	<0.001
Elevation (m)	2,539 ± 13	2,607 ± 17	–3.23	592	0.001
Elevation deviation (m)	3.6 ± 0.2	6.6 ± 0.2	–9.34	525	<0.001
Slope (%)	13.8 ± 0.9	25.6 ± 1.0	–9.18	519	<0.001

[a]Distance (m) to nearest aspen and/or willow.

[b]Distance (m) to nearest stream or water body.

Table 3. Mean (± SE) habitat characteristics at 85 beaver and 400 random location pixels, Black Hills National Forest, South Dakota and Wyoming, 2004. Independent sample t-tests evaluated differences between beaver and random locations.

Habitat variables	Beaver	Random	*t*	*df*	*P*
Distance (m) to vegetation[a]	593 ± 66	4,510 ± 380	–10.15	422	<0.001
Distance (m) to water[b]	35 ± 4	289 ± 10	–23.00	467	<0.001
Elevation (m)	1,546 ± 19	1,651 ± 13	–4.65	170	<0.001
Elevation deviation (m)	5.0 ± 0.3	4.8 ± 0.2	0.43	483	0.671
Slope (%)	18.0 ± 1.4	18.3 ± 0.6	–0.21	483	0.833

[a]Distance (m) to nearest aspen and/or willow.

[b]Distance (m) to nearest stream or water body.

Table 4. Model selection results for suitable beaver habitat (n = 654), on the Bighorn National Forest, Wyoming, 2003. Models are based on 154 beaver location pixels and 500 random pixels and are listed according to the model that best fits the data and ranked by ΔAIC_c, the difference between the model with the lowest Akaike's information criterion for small samples (AIC_c) and the AIC_c for the current model. The strength of evidence for each model is assessed with Akaike weights (w_i). Model fit is described with the value of the maximized log-likelihood function (log[L]) and the number of parameters (K).

Model[a]	Log(L)	K	AIC_c	ΔAIC_c	w_i
Slope + Veg + Stream + ED	–257.43	5	524.951	0.000	0.689
Slope + Veg + Stream	–259.24	4	526.539	1.588	0.311
Stream	–305.75	2	615.520	90.570	0.000
Veg	–320.01	2	644.040	119.090	0.000
ED	–323.24	2	650.495	125.545	0.000
Slope	–324.40	2	652.825	127.875	0.000
Elevation	–354.53	2	713.078	188.128	0.000
Null	–356.96	1	715.921	190.970	0.000

[a]Explanatory variables used are percentage slope (Slope), distance (m) to nearest aspen and/or willow (Veg), distance (m) to nearest stream or water body (Stream), elevation deviation (ED), and elevation (m) at each beaver or random pixel.

Table 5. Model selection results for suitable beaver habitat (n = 485), on the Black Hills National Forest, South Dakota and Wyoming, 2004. Models are based on 85 beaver location pixels and 400 random pixels and are listed according to the model that best fit the data and ranked by ΔAIC_c, the difference between the model with the lowest Akaike's information criterion for small samples (AIC_c) and the AIC_c for the current model. The strength of evidence for each model is assessed with Akaike weights (w_i). Model fit is described with the value of the maximized log-likelihood function (log[L]) and the number of parameters (K).

Model[a]	Log(L)	K	AIC_c	ΔAIC_c	w_i
Slope + Veg + Stream + ED	–98.17	5	206.458	0.000	0.916
Slope + Veg + Stream	–101.57	4	211.227	4.769	0.084
Stream	–122.36	2	248.744	42.286	0.000
Veg	–190.02	2	384.064	177.606	0.000
Elevation	–218.44	2	440.907	234.449	0.000
Null	–225.10	1	452.210	245.752	0.000
ED	–225.01	2	454.048	247.590	0.000
Slope	–225.08	2	454.182	247.724	0.000

[a]Explanatory variables used are percentage slope (Slope), distance (m) to nearest aspen and/or willow (Veg), distance (m) to nearest stream or water body (Stream), elevation deviation (ED), and elevation (m) at each beaver or random pixel.

Table 6. Sampling units identified for monitoring beaver through a food cache index on the Bighorn National Forest, Wyoming. Sampling units are 6th level hydrologic unit code (HUC) watersheds with suitable beaver habitat and are stratified according to probabilities of beaver habitat suitability. A random sample of 15 moderate and 15 high quality sampling units is identified in the strata column. Hydrologic unit code 12 codes and names for are provided because they represent 6th level HUC information.

HUC 12 Code	HUC 12 Name	Strata
100800100402	Bighorn River-Willow Creek	Non habitat
100800080502	Brockenback Creek	Non habitat
100800160108	East Pass Creek	Non habitat
100901010209	Goose Creek	Non habitat
100800100107	Horse Creek-Shell Creek	Non habitat
100901010205	Lower Big Goose Creek	Non habitat
100800080406	Lower Canyon Creek	Non habitat
100901010110	Lower Quartz Creek	Non habitat
100800100602	Middle Porcupine Creek	Non habitat
100902060303	North Piney Creek	Non habitat
100800100307	Salt Creek	Non habitat
100800160104	West Fork Little Bighorn River	Non habitat
100800100103	Cedar Creek	Low sample
100800160102	Dry Fork Little Bighorn River	Low sample
100902060302	Kearny Creek	Low sample
100800080403	Lower Tensleep Creek	Low sample
100901010207	Middle Goose Creek	Low sample
100902060305	North Prong Shell Creek	Low sample
100800100104	Shell Creek-Cottonwood Creek	Low sample
100901010106	Tongue River-Columbus Creek	Low sample
100800100106	Trapper Creek-Shell Creek	Low sample
100901010206	Upper Little Goose Creek	Low sample
100901010203	West Fork Big Goose Creek	Low sample
100800100105	White Creek	Low sample
100800080402	East Tensleep Creek	Moderate sample
100800100401	Five Springs Creek	Moderate sample
100800080404	Leigh Creek	Moderate sample
100800080602	Long Park Creek	Moderate sample
100800100204	Lower Beaver Creek-Shell Creek	Moderate sample
100901010101	North Tongue River	Moderate sample
100800100101	Shell Creek-Willett Creek	Moderate sample
100800100604	Trout Creek	Moderate sample
100800100305	Upper Bear Creek	Moderate sample
100800100203	Upper Beaver Creek	Moderate sample

Table 6. Continued.

HUC 12 Code	HUC 12 Name	Strata
100901010204	Upper Big Goose Creek	Moderate sample
100901010201	Upper East Fork Big Goose Creek	Moderate sample
100902050106	Upper Middle Fork Crazy Women Creek	Moderate sample
100901010109	Upper Quartz Creek	Moderate sample
100800160107	West Pass Creek	Moderate sample
100800100603	Deer Creek	Moderate - no sample
100800160103	Little Bighorn River-Red Canyon Creek	Moderate - no sample
100800160101	Little Bighorn River-Wagon Box Creek	Moderate - no sample
100901010107	Little Tongue River	Moderate - no sample
100800160301	Lodge Grass Creek-Line Creek	Moderate - no sample
100901010202	Lower East Fork Big Goose Creek	Moderate - no sample
100800080601	Paint Rock Creek-Trout Creek	Moderate - no sample
100902060301	South Piney Creek	Moderate - no sample
100800160109	Twin Creek	Moderate - no sample
100902060304	Upper Piney Creek	Moderate - no sample
100902060104	Clear Creek-Grommund Creek	High sample
100800100309	Crystal Creek	High sample
100800080606	Lower Medicine Lodge Creek	High sample
100901010104	Lower South Tongue River	High sample
100902060102	Middle Clear Creek	High sample
100902050103	Muddy Creek	High sample
100800080604	Paint Rock Creek-Luman Draw	High sample
100902050107	Poison Creek	High sample
100902060202	Rock Creek-Clear Creek	High sample
100800080605	Upper Medicine Lodge Creek	High sample
100902050101	Upper North Fork Crazy Women Creek	High sample
100902010301	Upper North Fork Powder River	High sample
100800100601	Upper Porcupine Creek	High sample
100800080401	Upper Tensleep Creek	High sample
100901010103	Upper Tongue River	High sample
100901010102	Fool Creek	High - no sample
100902060106	French Creek	High - no sample
100902050102	Middle North Fork Crazy Women Creek	High - no sample
100902060201	North Rock Creek	High - no sample
100800080603	Paint Rock Creek-South Paint Rock Creek	High - no sample
100902060103	Seven Brothers Creek	High - no sample
100800100102	Shell Creek-Granite Creek	High - no sample
100902060101	South Clear Creek	High - no sample
100901010105	Tongue River-Sheep Creek	High - no sample
100800080405	Upper Canyon Creek-Tensleep Creek	High - no sample

Table 7. Sampling units identified for monitoring beaver through a food cache index on the Black Hills National Forest, South Dakota and Wyoming. Sampling units are 6th level hydrological unit code (HUC) watersheds with suitable beaver habitat and are stratified according to probabilities of beaver habitat suitability. A random sample of 15 moderate and 15 high quality sampling units is identified in the strata column.

HUC 6 Code	HUC 6 Name	Strata
101201060201	Cheyenne Rvr-Moss Agate Ck	Non habitat
101201060203	--	Non habitat
101201060204	Cheyenne Rvr-Sheep Canyon	Non habitat
101201060206	Chilson Canyon	Non habitat
101201060207	Cheyenne Rvr-Little Tepee Ck	Non habitat
101201060208	Cheyenne Rvr-Tepee Ck	Non habitat
101201060403	--	Non habitat
101201060404	--	Non habitat
101201060405	--	Non habitat
101201060406	--	Non habitat
101201070203	Upper Oil Ck	Non habitat
101201070307	Beaver Ck-Hay Ck	Non habitat
101201070308	Line Ck	Non habitat
101201070402	Beaver Ck-Rats Valley Ck	Non habitat
101201070407	Beaver Ck-Rock Canyon	Non habitat
101201070502	Middle Pass Ck	Non habitat
101201070503	Teepe Canyon	Non habitat
101201070504	Lower Pass Ck	Non habitat
101201070505	Pass Ck-East Pass Ck	Non habitat
101201090101	--	Non habitat
101201090102	--	Non habitat
101201090103	--	Non habitat
101202010701	--	Non habitat
101202010802	--	Non habitat
101202010803	--	Non habitat
101202010804	--	Non habitat
101202010805	--	Non habitat
101202010901	--	Non habitat
101202020602	--	Non habitat
101201060402	--	Low sample
101201090203	--	Low sample
101201110203	--	Low sample
101202010705	--	Low sample
101202020102	Belle Fourche Rvr-Deep Ck	Low sample
101202020104	Belle Fourche Rvr-Spring Ck	Low sample
101202030401	Redwater Ck	Low sample
101201070401	Beaver Ck-Bear Run	Moderate sample

Table 7. Continued.

HUC 6 Code	HUC 6 Name	Strata
101201070404	Beaver Ck-Whoopup Ck	Moderate sample
101201070405	Whoopup Ck	Moderate sample
101201090201	--	Moderate sample
101201090502	--	Moderate sample
101201100103	--	Moderate sample
101201100106	--	Moderate sample
101201110102	--	Moderate sample
101201110201	--	Moderate sample
101201110202	--	Moderate sample
101202020101	Deer Ck	Moderate sample
101202020103	Belle Fourche Rvr-Medicine Ck	Moderate sample
101202020201	Beller Fourche Rvr-Crooked Oak Ck	Moderate sample
101202030103	Sundance Ck	Moderate sample
101202030204	Red Canyon Ck	Moderate sample
101201060401	--	Moderate - no sample
101201070501	Upper Pass Ck	Moderate - no sample
101201090503	--	Moderate - no sample
101201090604	--	Moderate - no sample
101201100102	--	Moderate - no sample
101201100104	--	Moderate - no sample
101201100202	--	Moderate - no sample
101201110101	--	Moderate - no sample
101201110103	--	Moderate - no sample
101202010801	--	Moderate - no sample
101202020601	--	Moderate - no sample
101202020701	--	Moderate - no sample
101202030101	Upper Redwater Ck	Moderate - no sample
101202030201	Cold Springs Ck	Moderate - no sample
101201090301	--	High sample
101201090302	--	High sample
101201090602	--	High sample
101201100101	--	High sample
101202010806	--	High sample
101202010903	--	High sample
101202010906	--	High sample
101202030102	South Redwater Ck	High sample
101202030202	Grand Canyon	High sample
101202030205	Bear Gulch	High sample
101202030303	Little Spearfish Ck	High sample
101202030304	Lower Spearfish Ck	High sample
101202030402	Upper False Bottom Ck	High sample
101202030403	Polo Ck	High sample
101202030404	Lower False Bottom Ck	High sample
101201090202	--	High - no sample
101201090204	--	High - no sample

Table 7. Continued.

HUC 6 Code	HUC 6 Name	Strata
101201090501	--	High - no sample
101201090601	--	High - no sample
101201090603	--	High - no sample
101201100105	--	High - no sample
101201100107	--	High - no sample
101201100108	--	High - no sample
101201100201	--	High - no sample
101202010707	--	High - no sample
101202010907	--	High - no sample
101202030105	Crow Ck	High - no sample
101202030203	Sand Ck	High - no sample
101202030301	Upper Spearfish Ck	High - no sample
101202030302	Middle Spearfish Ck	High - no sample

Table 8. Number of beaver sampling units by sampling strata on the Bighorn and Black Hills National Forests, South Dakota and Wyoming. Sampling units are 6th level hydrologic unit code watersheds.

Strata	Number of sampling units	
	Bighorn	Black Hills
Low – sample (presence/absence)	12	7
Moderate – sample	15	15
High – sample	15	15
Moderate – no sample	10	14
High – no sample	10	15
Non habitat	12	29
Total	74	95

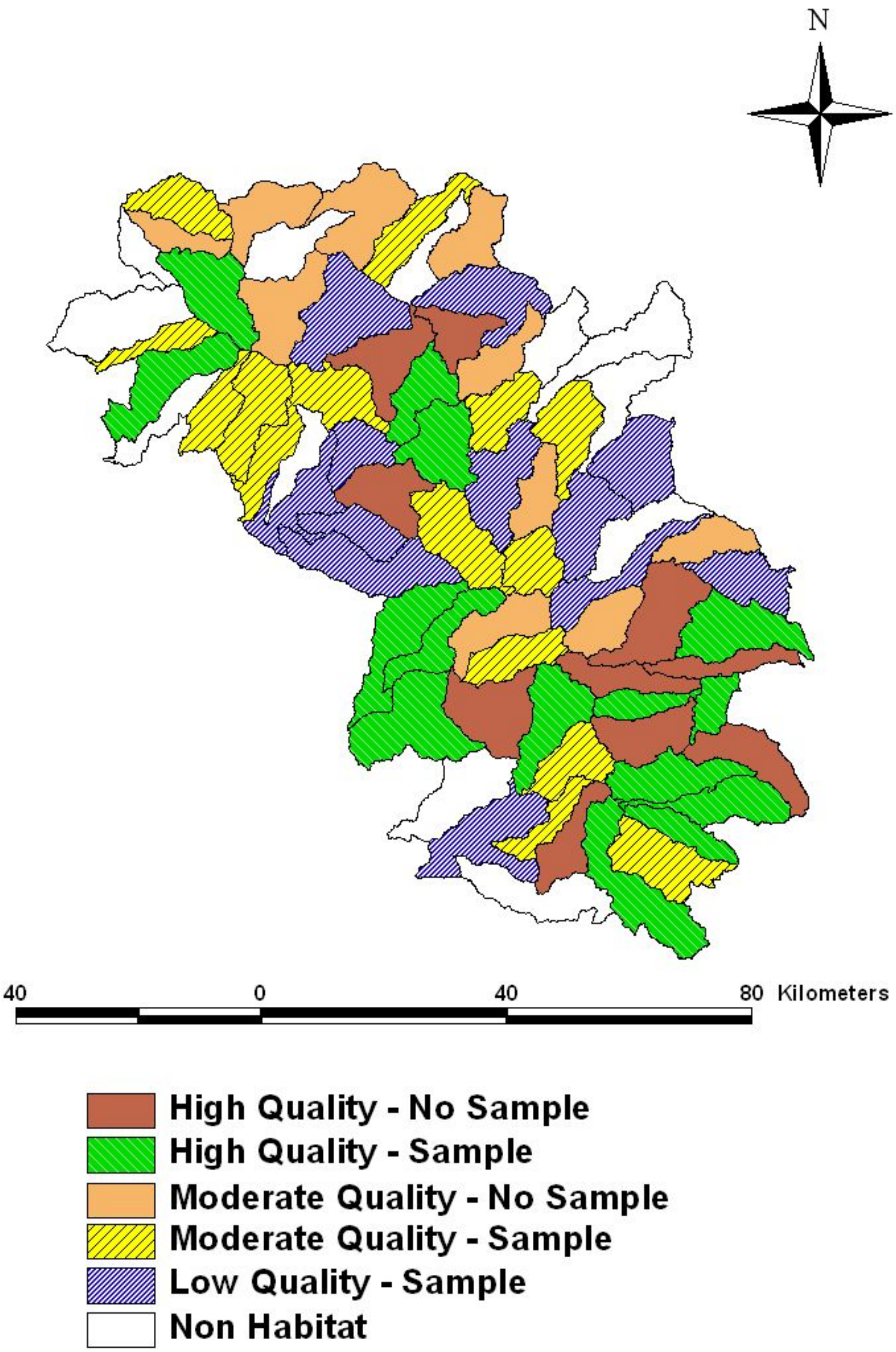

Figure 1. Proposed sampling units to monitor abundance of beaver with a food cache index on the Bighorn National Forest, Wyoming. Sampling units are 6th level hydrologic unit codes that have been designated as strata.

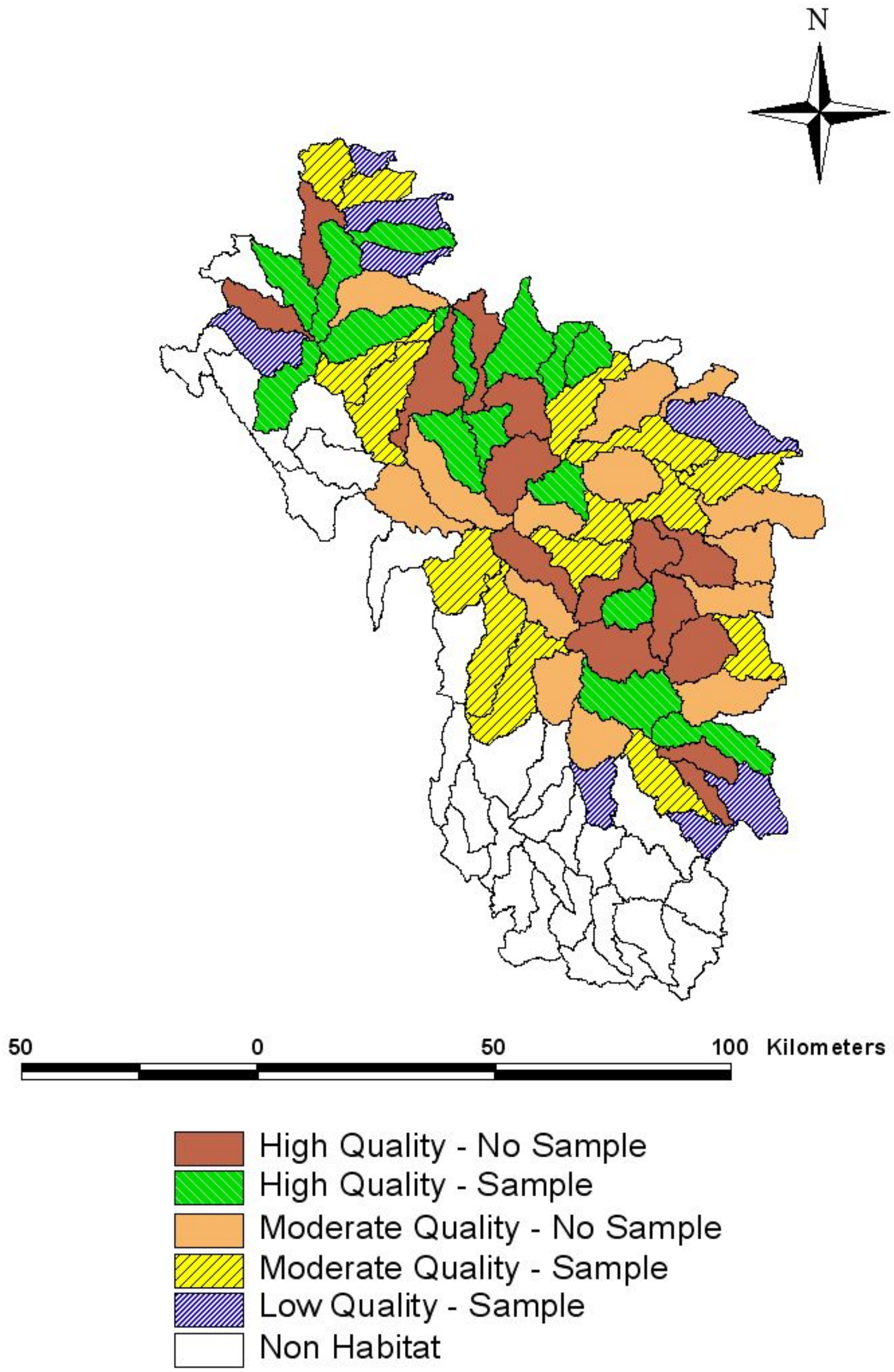

Figure 2. Proposed sampling units to monitor abundance of beaver with a food cache index on the Black Hills National Forest, South Dakota and Wyoming. Sampling units are 6th level hydrologic unit codes that have been designated as strata.

Appendix A. Modeling to Define Strata

We used data collected on the 448,259 ha (1,107,671 ac) Bighorn National Forest in fall 2003, and data collected on the 485,623 ha (1,200,000 ac) Black Hills National Forest in September 2004 to model habitat suitability and ultimately to define sampling strata on each forest. On the Bighorn National Forest, a helicopter and fixed wing aerial survey to locate beaver food caches was conducted from 26 August to 23 October, 2003. The Bighorn survey located 60 active food caches and 106 historical lodges (Emme and Jellison 2004. Managing for beaver on the Bighorn National Forest. Wyoming Game and Fish Department, Sheridan, Wyoming, USA.). Among the 6th level HUCs on the Bighorn National Forest that contain perennial water in streams, rivers, or other water bodies, there are 66, 6th level HUCs with potential beaver habitat. An analysis provided by GIS personnel on the Bighorn National Forest identified 74, 6th level HUCs on the forest, 65 (88%) of which contained perennial streams or rivers within the boundaries of the Bighorn National Forest. We modeled suitable beaver habitat on the Bighorn National Forest with 154 beaver locations identified in 2003 and occurring within the boundaries of the Bighorn National Forest as well as 500 random locations.

A combined helicopter and ground count survey conducted from September 14 to 16, 2004 on the Black Hills National Forest resulted in locating 85 beaver lodges. Of these, 80 (94%) had sign of active use, and 74 active lodges occurred on Forest Service lands (K. Burns. 2004. Beaver Survey Report. Black Hills National Forest, South Dakota and Wyoming, Black Hills National Forest, Custer, South Dakota, USA). An analysis provided by GIS personnel on the Black Hills National Forest identified 95, 6th level HUCs on the Black Hills National Forest, 68 (72%) of these HUCs contain perennial streams or rivers within the boundaries of the Black Hills National Forest. The list of HUCs with perennial water sources will potentially be larger if the length of all water bodies in each 6th level HUC is included. We used the 85 beaver lodge locations identified in 2004 as well as 400 random locations to model beaver habitat suitability on the Black Hills National Forest.

We developed a logistic regression model to stratify 6th level HUCs into non habitat, low quality habitat, moderate quality habitat, and high quality habitat strata based on criteria indicative of beaver habitat suitability. All data used to evaluate habitat suitability were obtained from geographic coverages provided by GIS personnel with the Bighorn and Black Hills National Forests. Predictor variables included elevation (m), slope (gradient), elevation deviation (m), distance (m) to water source (perennial or intermittent), and distance to aspen and/or willow. Elevation was recorded for each 30-m pixel (USGS National Elevation Dataset). Percentage slope was calculated using a 3 × 3 neighborhood window centered on each cell. We determined for the center cell, the down slope direction, or the greatest rate of change within a window. The rate of change of elevation values was then calculated and assigned to the center cell. We repeated this analysis for every grid cell within the analysis window with units expressed as percentages. We measured the distance to streams and water bodies and distances to aspen and/or willow with the Euclidean distance (i.e., right angle distance) from each cell to the nearest water feature or vegetation type coded as aspen or willow. We calculated elevation deviation to estimate the topographic complexity in the area surrounding a grid cell with a 5 × 5 neighborhood window. For each cell, the standard deviation of elevation values within the 5 × 5 window was calculated, and assigned to the center cell. Neighborhoods of high complexity have higher standard deviations relative to those areas of lower topographic complexity.

We used independent sample *t*-tests on raw data to test for differences in habitat variables at beaver and random locations (Proc TTEST; SAS Institute 2001). We evaluated equality of variances with the Folded F method and used the Satterthwaite (1946) method to calculate *t*-values in those instances where variances were unequal. The Satterthwaite statistic is an approximate *t* statistic, and is used if the population variances of two groups are unequal. We computed degrees of freedom for this statistic with the Satterthwaite (1946) approximation.

We used binary logistic regression (Proc Logistic; SAS Institute 2001) to model suitable beaver habitat on each forest, where we coded the beaver lodge or food cache locations as 1s and random points as 0s. We assessed the strength of evidence for each model with Akaike's information criterion for small samples (AIC_c; Burnham and Anderson 2002). We selected the model with the lowest AIC_c value as the best-fitting model, and we used Δ_i, the difference between AIC_c for the best model and AIC_c for the $_i$th candidate model to identify models competing with the best model. Akaike weights (w_i) allowed us to assess the weight of evidence in favor of each model (Burnham and Anderson 2002). We ranked the relative importance of variables using methods described by Burnham and Anderson (2002:167–169).

We used the parameter estimates from the best model to compute probabilities of beaver habitat suitability with the logistic function, $\exp(\beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4) / (1 + \exp[\beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4])$. We used 6th level HUCs on each forest as analysis regions to clip and subsequently summarize beaver habitat selection probabilities by dividing the probabilities (i.e., *P*-values) on Forest Service lands in each HUC into quartiles as follows:

Bighorn National Forest – probabilities of beaver habitat suitability

Number	Quartile	Range of *P*-values
1	0.0–24.9	0.000000000–0.013595855
2	25.0–49.9	0.013595855–0.074777203
3	50.0–74.9	0.074777203–0.305906738
4	75.0–100	0.305906738–0.866735756

Black Hills National Forest – probabilities of beaver habitat suitability

Number	Quartile	Range of *P*-values
1	0.0–24.9	0.000000000–0.015686158
2	25.0–49.9	0.015686158–0.078430788
3	50.0–74.9	0.078430788–0.313723153
4	75.0–100	0.313723153–0.999992549

For each forest we used identical criteria to define sampling strata. We designated the non habitat stratum where at least 95% of Forest Service area in each HUC was dominated by probabilities in quartile 1. We designated the low quality habitat stratum as all 6th level HUCs where 85.0 to 94.9% of Forest Service area was dominated by probabilities in quartile 1. To define moderate and high quality strata we used an index where probabilities in each quartile were multiplied as: $\text{Index} = 0 \bullet Q1 + 1 \bullet Q2 + 5 \bullet Q3 + 10 \bullet Q4$. We then ranked the index values for the HUCs not previously classified as non-habitat or low quality strata and designated the top 50% HUCs as high quality stratum and the bottom 50% as moderate quality stratum (Figures 1 and 2).

Appendix B. Cross Validation Procedure

We performed a 5-fold cross validation to evaluate goodness-of-fit of our beaver habitat suitability models for both Forests (Boyce et al. 2002). For each Forest, we divided beaver and random locations randomly into 5 cross validation groups. We used cross-validation iterative procedures to model 4 of the 5 data sets using logistic regression (PROC LOGISTIC; SAS Institute 2001; Boyce et al. 2002). We estimated parameters in the best model identified with AIC_c. We evaluated model performance by examining predicted probabilities of beaver presence for validation testing data against actual beaver presence, with the predicted probabilities grouped into bins. We sorted predicted probabilities and placed them into 10 groups per forest.

Predicted probabilities for the Black Hills National Forest were grouped with the first 5 bins containing 49 values and the last 5 containing 48 values. For the Bighorn National Forest we sorted predicted probabilities with 65 values in the first 6 bins and 66 values in the last 4. We ranked bins according to increasing probabilities of beaver presence. Within each of the 10 groups, we calculated the ratio of observations with observed beaver occurrence. We calculated a Spearman's rank correlation (PROC CORR; SAS Institute 2001) between bin ranks and cross-validated prediction ratios of beaver presence. Strong positive correlations would indicate our models had good predictive performance, because more suitable beaver habitat would fall into higher ranked probability bins (Boyce et al. 2002).

Appendix C. Suggested form when recording food caches to monitor trends in beaver abundance.

Food Cache	Sampling unit name/number	Date of flight	Time of Location	UTM East Coordinate	UTM North Coordinate
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					

Appendix D. Suggested form when recording food caches to monitor trends in beaver distribution.

Sampling unit name/number	Present (1)[a] Absent (0)	Date of flight	Time of Location	UTM East Coordinate[b]	UTM North Coordinate
Total	[c]				

[a]To indicate presence, record a 1 when the first beaver food cache is located in each sampling unit. Record a 0 to indicate absence when no beaver food caches are observed after entirely searching each respective sampling unit.

[b]UTM coordinates are only recorded when food caches are present.

[c]Total is $\sum y_i$ used to estimate proportion of sampling units occupied by beaver.