

4.2.5 Biotic Integrity: Extent of Suitable Beaver Habitat

Authors: Richard Scherer, Ian Leinwand, Barry R. Noon, and David M. Theobald

Description/Purpose

A key indicator for ROMO is the extent of suitable beaver habitat. In North America, the beaver (*Castor canadensis*) has near iconic status as the quintessential ecosystem engineer (Baker and Hill 2003)—a species that changes the physical structure of the environment and in the process creates niches to be exploited by otherwise absent species. As a result of their dam building, canal construction, and foraging activities, beaver have profound effects on ecosystem structure and function. Their alteration of hydrological regimes, and the many subsequent effects resulting from these hydrology changes, has been well documented (Naiman et al. 1988, Baker and Hill 2003). In a nutshell, beaver-induced changes to the structure and function of the aquatic environment have many beneficial effects on plant and animal diversity (Baker and Hill 2003). The absence, or low abundance, of beaver from a landscape can serve as a powerful indicator of declines in biological diversity. Thus, the distribution of current and potentially suitable beaver habitat was a logical choice as an important indicator of biological integrity of ROMO. Though beaver occur in lentic and riverine (and disconnected wetlands) systems, the focus of our modeling work for ROMO was on streams and rivers.

Within ROMO beaver abundance and distribution may be at a historic low because of declines in tall (> 3m) willow (*Salix* sp.; Peinetti et al. 2002, Baker 2003). In fact, declines in beaver and willow populations are strongly correlated in environments within ROMO that are heavily browsed by elk (*Cervus elaphus*). There is an apparent mutualism between beaver foraging on willow for food and building materials, and the establishment and survival of willow (Baker 2003). Beaver preferentially select tall, unbrowsed patches of willow and avoid short, hedge willow patches created by heavy elk browsing. The correlation between elk browsing, decline in the stature and vigor of willow, and declines in beaver populations has led Baker (2003:177) to conclude “...when beaver cut willow, and intense elk browsing suppresses growth, the interaction of beaver and elk herbivory will create a feedback mechanism that is negative for beaver and willow but positive, or negative, for elk depending on local conditions.” In addition to elk, moose are increasingly significant browsers on willows.

While demographic and distribution data on beaver have been periodically collected in ROMO over the last 70 years, collection of these data was based on *ad hoc* sampling plans, thus inference to the entire park is problematic. However, these data can be used to examine trends in beaver populations in particular areas of ROMO. Data were collected in 1939-1940, 1964, 1980, 1994, and 1999-2000. Surveys conducted prior to 1999 are less spatially explicit and only provide data on beaver activity and abundance that can be attributed at the drainage scale. Surveys conducted by Mitchell et al. in 1999 and 2000 provide a more spatially explicit description of the areas surveyed as well as coordinates for active and historic beaver signs such as lodges, dams, and food caches. From the early survey descriptions and the results reported by Mitchell et al. (2000) we mapped current and historic beaver activity observed in 1999 and 2000 (Figure 47 and Figure 48).

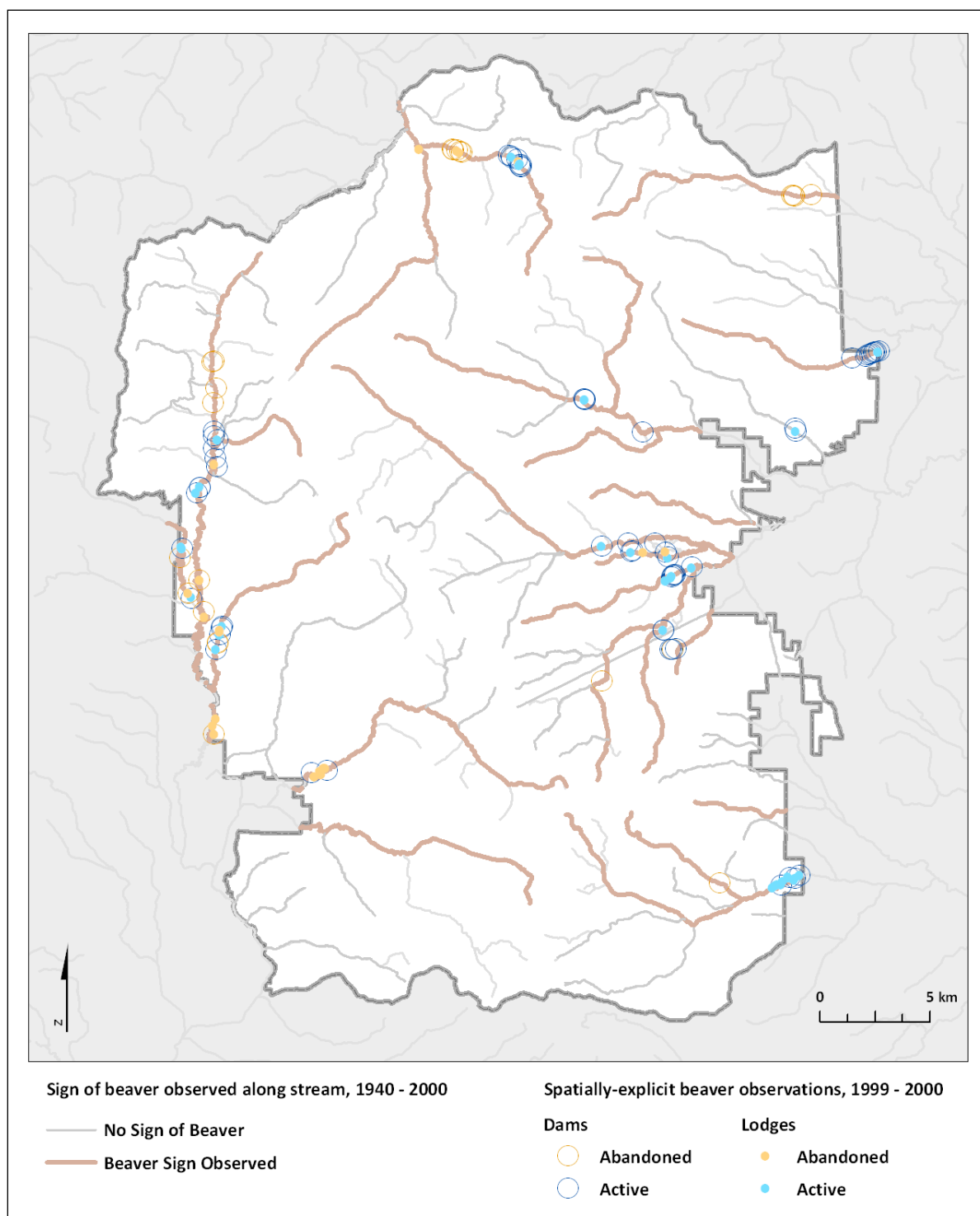


Figure 47. Historic distribution of beaver based on park survey data from 1940 to 2000. Location of lodges and dams digitized from Mitchell 1999 to 2000 data. Only portions of the drainages displayed as having signs of beaver are suitable beaver habitat. No spatial data were available for surveys conducted prior to 1999; therefore we assume that historic beaver activity mainly occurred in areas where active and abandoned dams and lodges were located. That is, we assume that dams and lodges are useful surrogates for beaver activity.

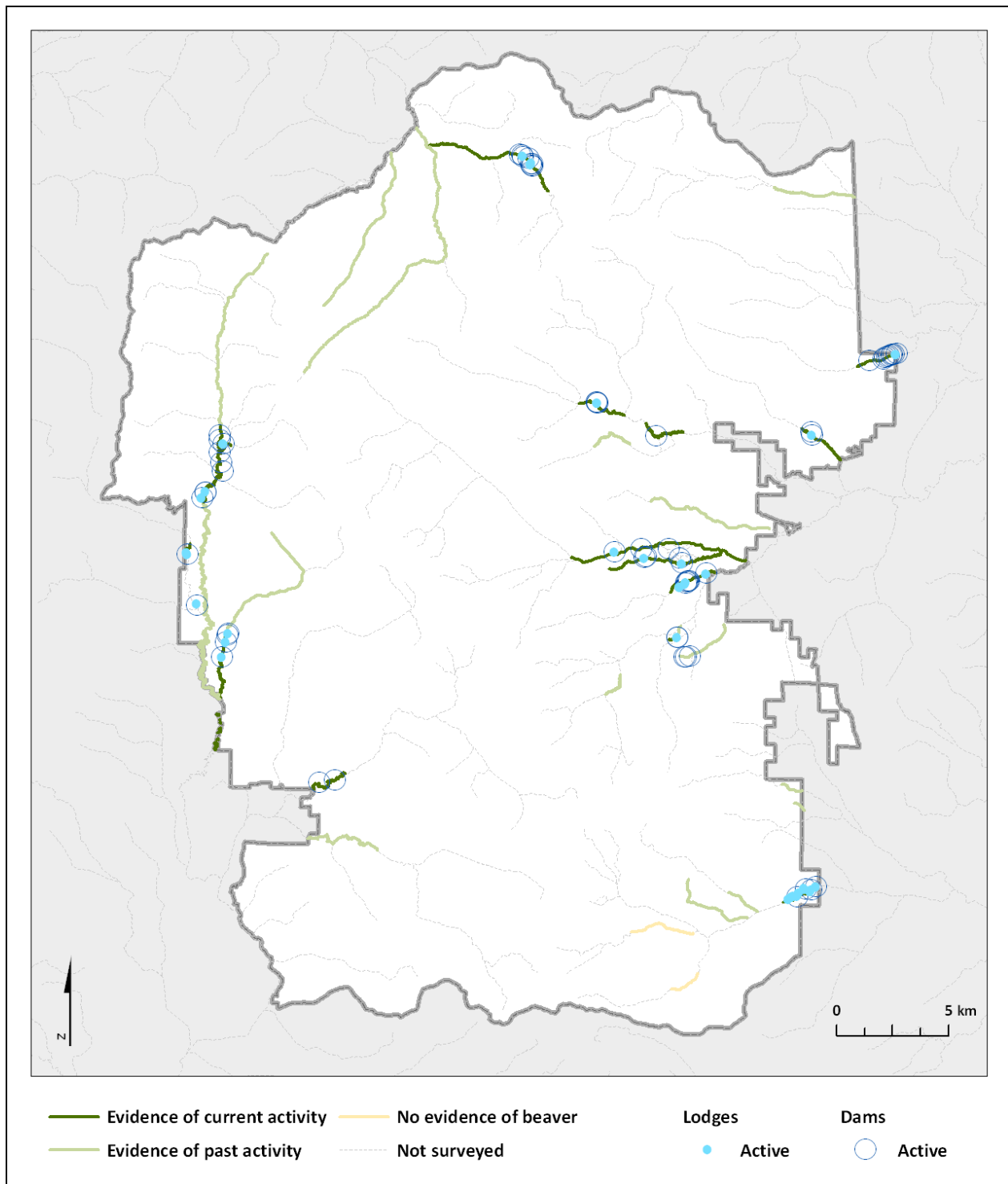


Figure 48. Areas surveyed for beaver sign in 1999 to 2000. Data digitized from ROMO beaver survey reports by Mitchell et al. (2000).

Approach/Methods

We developed a GIS of potential beaver habitat using information from the published literature and then used these data to develop a habitat suitability model. Though the published literature suggests many biotic and abiotic variables influence landscape use by beaver, spatial data were

not available for many of these variables (e.g., width of stream channel; Beier and Barrett 1987, Barnes and Mallik 1997). Our final model identified potentially suitable beaver habitat in ROMO primarily using three spatial datasets: data from a digital elevation model (DEM), a stream gradient dataset and a vegetation dataset. Our map provides an estimate of the suitability of locations in the park (as pixels in the GIS data) to beaver based on the degree to which a location is accessible to beaver (defined by streams of 0-2% gradient), and the suitability of vegetation.

Below we provide an overview of the data and methods used to produce and validate the final map; see Technical Appendix 4 for more detailed methods.

We developed stream gradient using a 10 m DEM. Our model used cost distances to delineate the area around streams that was accessible to beaver. The concept of cost distance arose out of the observation that a species' behavior, perceptual abilities, and physiology will make movement relatively more costly (or less probable) across some locations or cells. For example, wood frogs (*Rana sylvatica*) are known to avoid movement through areas with dry soils and low canopy cover (Vasconcelos and Calhoun 2004). Therefore, we would expect wood frogs to avoid movement through these areas, and if they choose to move across them, we would expect the cost (in terms of physiological condition and/or survival) to be high relative to pixels that represent areas that are wetter and have high canopy cover.

Conceptually, we thought of source pixels as those pixels beaver would most likely select for dam-building. In many parts of their range, beaver create favorable aquatic conditions by damming streams (Baker and Hill 2003). We assumed pixels that represented streams where beaver would most likely build dams would serve as the centers of home ranges for individual beaver colonies. We identified the initial set of source cells by reclassifying the stream gradient dataset to select those pixels with the most suitable gradients for beaver dams. Insights into a suitable stream gradient were based on a literature review of studies from mountainous terrain in the western U.S. Of the 53 beaver dams detected by Beier and Barrett (1987) in the Truckee River Basin in California and Nevada, 48 (91%) were found at locations where the stream gradient was 0 – 2%. Of the 45 sections of stream with beaver dams sampled by Slough and Sadelier (1977) in British Columbia, 36 (80%) had gradients < 2%. Therefore, we reclassified stream pixels as source cells if their gradient was < 2%. All other stream pixels were not considered source cells (i.e. they were reclassified as 'NoData').

We removed from consideration short (<50 m) stretches of stream as well (roughly 10%). Beaver are characterized as central-place foragers, which means they cut vegetation from one location and bring it back to a central location (e.g., dam, food cache or lodge; Baker and Hill 2003). As they exhaust the supply of suitable vegetation around a central place, they must establish a new central location. Therefore, we assumed short stretches of stream would not be able to support beaver over long periods of time, as they would not be able to move up and down the stream in response to the dwindling supply of suitable vegetation. Therefore, we eliminated all source cells that were connected to fewer than six other source cells. We suspect stretches of stream much greater than 50 m are required for beaver populations to persist over long periods of time. However, the literature did not provide clear guidance on a more appropriate length, and we chose to error toward inclusion.

We designated the resistance or cost of movement to be an integration of the willingness of the species to cross a particular landscape type, the physiological cost of movement across the landscape type, and expected reductions in survival associated with movement across the landscape type (Compton et al. 2007). We assigned costs to pixels based on the gradient of the pixel. We assumed beaver would be less willing, or find it more costly, to move through pixels with steeper slopes. For a given slope, we also assumed the cost of movement for beaver within a stream channel was much lower than the cost of movement over land. Therefore, we assigned different costs to pixels based on the slope of the pixel and whether the pixel represented a stream or terrestrial area (Table 30). Cost was assumed constant across vegetation types.

Table 30. Cost weights assigned to stream and terrestrial pixels of different gradients.

Gradient	Stream	Terrestrial
0 – 2%	Source pixels	10
> 2% – 10%	1	30
> 10% – 20%	3	50
> 20%	100	150

We then found all locations within 1,000 cost-meters of source pixels. This maximum distance assumed beavers could access terrestrial areas up to 100 m from a source pixel, if the intervening terrestrial landscape had a gradient from 0% to less than 2%. Since each pixel is approximately 9 m on a side and the relative cost of movement across pixels that represent terrestrial areas with a slope from 0% to 2% is 10 (Table 30), a beaver would use approximately 90 cost-meters to move across a single pixel. Therefore, it could travel across a maximum of 11 of these pixels or 99 m. In terrestrial areas of higher slope, the maximum geographic distance of accessible terrestrial areas was approximately 30 m. This geographic distance is consistent with the maximum movement distances for beaver away from water reported by Baker and Hill (2003).

To identify pixels that were more likely to contain vegetation and other cover types used by beaver, we used the ROMO vegetation dataset (Salas et al. 2005). Nearly all of the cover types in the map were characterized by a list of associated plant species. We used this list to identify classes that were likely to contain vegetation used by beaver. For the vegetated cover types, we considered classes characterized as having deciduous shrubs and trees of a variety of species such as willow, alder, aspen, and cottonwood (Table 31); Baker and Hill 2003, DeStefano et al. 2006). Beaver appear to prefer relatively tall ($\geq 3\text{m}$) shrubs (Baker 2003). However, we had limited data with which to infer shrub height from the vegetation dataset, so our map will likely overestimate the area of vegetation useful to beaver. Beavers are also known to use lakes, reservoirs and other water bodies (Baker and Hill 2003) with access to suitable vegetation. Therefore, we also considered pixels classified as streams, lakes or reservoirs as suitable for beaver. Ultimately, we identified 10 of the 46 classes as likely to contain vegetation used by beaver and 3 of the 46 classes as suitable types of water bodies (Table 31). Although herbaceous wetlands may facilitate dispersal, they were considered unsuitable habitat because they generally do not support the size of woody plants needed for dams, lodges, and forage. All other classes were considered unlikely to contain vegetation used by beaver or to represent unsuitable habitat.

Table 31. The original vegetation classes of Salas et al. (2005) and our reclassification with respect to each class's utility and suitability to beaver.

CLASS	LIKELY/SUITABLE BEAVER HABITAT	CLASS	UNLIKELY/UNSUITABLE BEAVER HABITAT
13	Shrub Upland – Alpine	1	Herbaceous Upland – Alpine
15	Riparian Aspen	2	Herbaceous Upland - Alpine Fellfield
18	Upland Aspen	4	Herbaceous Upland – Montane
32	Cottonwood	5	Herbaceous Wetland – Marsh
51	Streams – Rivers	6	Herbaceous Wetland – Wetland
52	Natural Lakes – Ponds	7	Herbaceous Wetland - Alpine Meadow
53	Reservoir - Stock Tanks	9	Alpine - Ice Field – Glacier
120	Shrub - Riparian - Cross Zone > 9600 ft	10	Rock (Alpine - Upper Subalpine)
121	Shrub - Riparian - Cross Zone < 9600 ft	11	Rock (Foothill - Lower Subalpine)
161	Mixed conifer w/ aspen (Ponderosa Pine)	14	Shrub Upland - Lower Montane
162	Mixed conifer w/ aspen (Lodgepole Pine)	20	Montane Douglas Fir
163	Mixed conifer with aspen (Douglas-fir)	22	Subalpine mixed conifer
164	Mixed conifer with aspen (Spruce - Fir)	23	Lodgepole - high elevation > 9500 ft.
		24	Lodgepole - low elevation < 9500 ft.
		26	Lodgepole pine – Rock
		33	Juniper Woodland
		34	Ponderosa Pine – Graminoid
		35	Ponderosa Pine – Rockland
		36	Ponderosa Pine – Shrubland
		38	Limber Pine
		39	Ribbon Forests
		41	Disturbance – Dead and Down
		43	Blue Spruce
		46	Talus
		47	Outwash
		48	Exposed Soil - Man made
		49	Cliff Face - Bare Soil
		141	Shrub Upland - Big Sagebrush
		142	Shrub Upland – Bitterbrush
		190	Upper Montane, Mixed Conifer – Riparian
		191	Upper Montane, Mixed Conifer – Riparian
		400	Krummholz
		999	Un-vegetated Surfaces

We assumed that pixels would have relatively high suitability scores if they contained a suitable cover type and were accessible to beaver from sections of stream with low gradient. Pixels that had suitable vegetation cover but were outside the 1,000 cost-meter boundary were not considered suitable. Pixels that had suitable vegetation cover and had a cost distance <1,000 cost-meters were considered suitable.

The preceding steps resulted in a pixel-based map of habitat suitability for beaver across the park (Figure 49). Pixels in the map are approximately 80 m². However, daily and seasonal movements and dispersal occur over much broader spatial scales for beaver (Wheatley et al. 1997, DeStefano

et al. 2006), which suggests they would integrate information across multiple pixels in our map. Therefore, we aggregated pixels into patches of suitable beaver habitat. We delineated patches by considering a pixel part of a larger patch if it had a beaver habitat suitability score greater than 0 and was directly adjacent (i.e., shared an edge or corner [an 8-cell neighborhood]) to another pixel with a suitability score greater than 0. In some areas, our model identified lakes, ponds and reservoirs as suitable beaver habitat despite the fact that no suitable vegetation was nearby (e.g., alpine lakes). We considered these to be misclassification errors. These errors were caused by the fact that some lakes and ponds were represented as streams in the original stream gradient data set, and we included lakes, ponds, and reservoirs as useful cover types for beaver. To correct these errors, we eliminated patches when the majority of pixels in the patch were classified as lakes, ponds and reservoirs and no pixels of suitable vegetation types were nearby. We used aerial photography of the park to confirm that the deletions were appropriate. Our logic was that a pixel classified as a lake, pond or reservoir would only be used by beaver if it were adjacent to pixels with suitable vegetation.

To validate our suitable habitat map, we used data on current and past beaver presence. Mitchell et al. (2000) and Mitchell and Ducharme (*unpublished data*) conducted surveys for beaver in four drainages and nine creeks in Rocky Mountain National Park in 1999 and 2000. These reports include lists of locations of current and past beaver presence (e.g., dams, lodges, and food caches). Current locations of beaver activity were distinguished from locations of past beaver activity by the presence of fresh sign (e.g., active beaver trails, fresh cuttings, and mud; Mitchell et al. 2007). The reports yielded evidence of beaver presence at 180 locations in the park. If our final beaver habitat suitability map was useful, we would expect the locations of current beaver presence to be within pixels of high suitability.

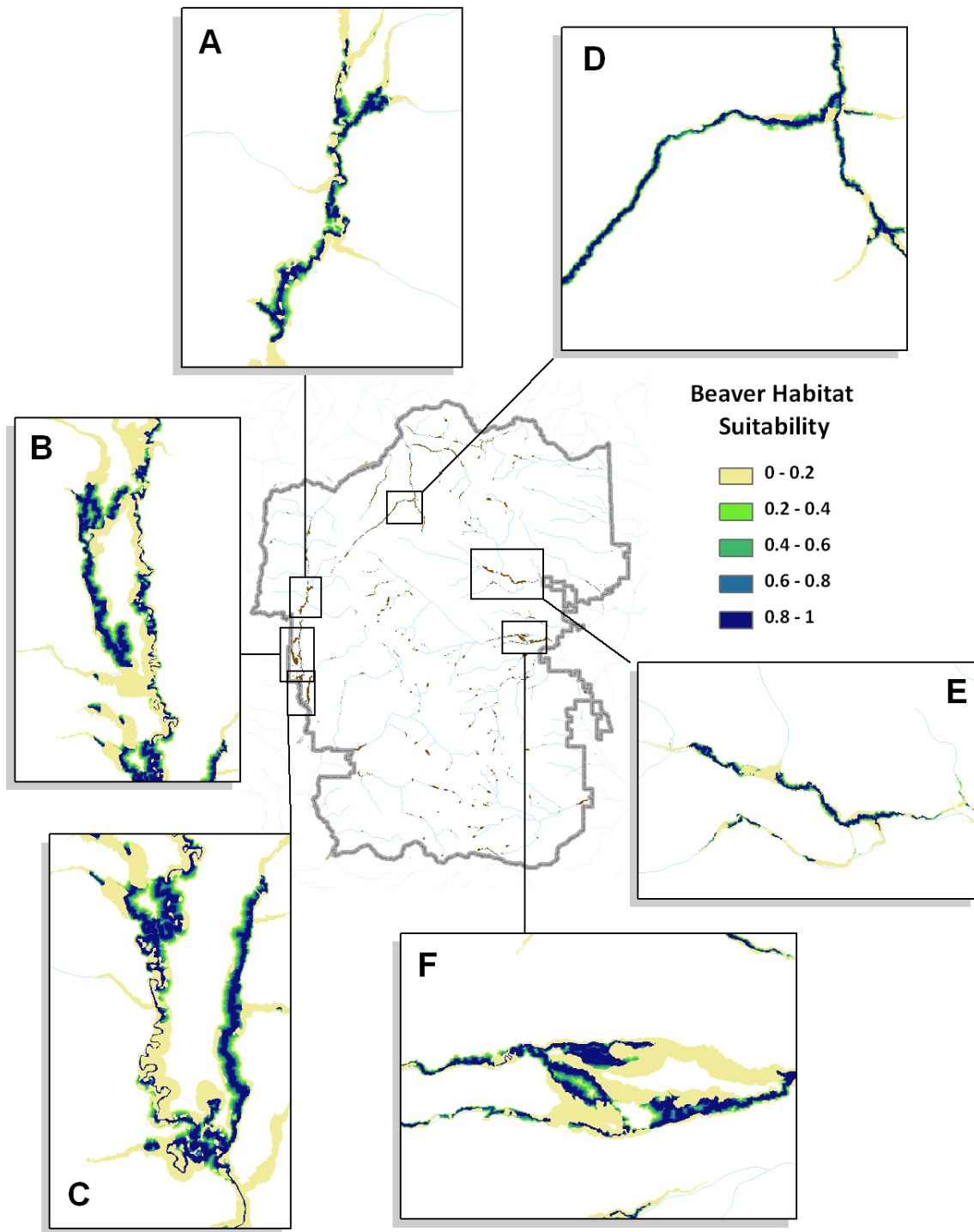


Figure 49. Areas of beaver habitat suitability in Rocky Mountain National Park. Areas in boxes represent the largest and highest scoring areas of potential beaver habitat within the park. A) The confluence of the Colorado River with Squeak Creek, Phantom Creek, Beaver Creek, and Timber Creek from north to south; B) The Colorado River and Baker Creek; C) The confluence of the Colorado River with Onahu Creek; D) The Cache la Poudre River meeting Chapin Creek; E) Fall River with Roaring River in the northwest and Hidden Valley Creek to the south; F) The Big Thompson River to the north of Cub Creek and Mill Creek.

Our final beaver habitat suitability map would not have predicted the locations of 66 of the 180 locations of current or past beaver presence (from Mitchell et al. 2007). These omission errors may be attributable to a too conservative definition of suitable habitat. Forty (22% of all the locations) were greater than 1000 cost-meters from the nearest source cell (i.e., inaccessible to beaver according to our model). However, the fact that over 80% of these locations were close to patches (within 50 m; Figure 50) suggests our map provides a reasonable representation of current and potential suitable beaver habitat in the park. It also indicates that our assumptions resulted in a fairly conservative estimate of beaver space use. Twenty-six of the 180 locations (14%) were in pixels that were accessible to beaver but not likely to be useful or suitable (beaver habitat suitability score = 0). These may be a consequence of inadequacies in the map or any of a variety of mapping errors (e.g., errors in the vegetation data set, errors in the locations of beaver presence, or projection errors). The majority of locations of beaver presence (114 of 180 locations or 63%), however, were in pixels with suitability values that ranged from greater than 0 to 1, even though pixels with these suitability values were rare according to our map (< 3% of the pixels). Seventy-eight locations of beaver presence (43%) were in pixels with high suitability values (suitability values > 0.8), but only 0.2% of the pixels in our model had the suitability values > 0.8.

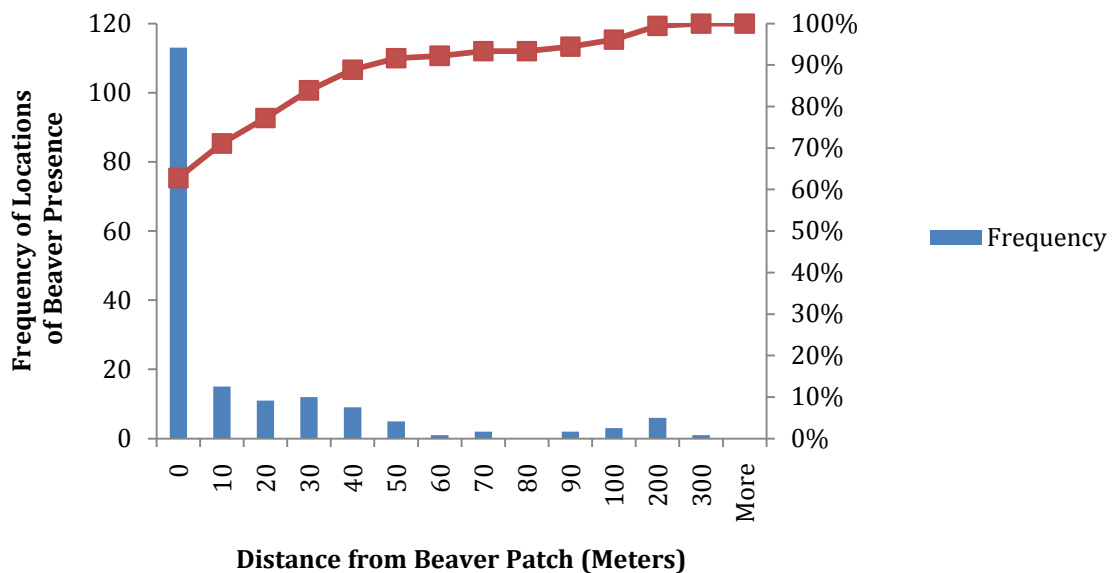


Figure 50. The distribution of geographic distances of locations of current and past beaver presence from the nearest patch. Most locations (114) of beaver presence are within patches (0 m from the nearest patch). However, some locations were greater than 300 m from a patch.

Reference Condition

Establishing the reference condition for beaver abundance or density in the park requires historic data from a comprehensive survey of all watersheds or from surveys based on a well-designed sampling plan. Though much less desirable, reference condition could also be established using data on beaver abundance or density from other locations that are similar to ROMO. Based on the benchmark typology of Stoddard et al. (2006), *Interpreting Historical Condition* may not be available. Instead, the reference distribution used for beaver habitat mapping is based, for the

most part, on *Best Professional Judgment*, informed by published empirical habitat studies and incomplete historic survey data from ROMO. The key data limitation was the structural condition of the vegetation. Vegetation structure, as well as composition, is essential for reliable habitat mapping of most wildlife species.

Results/Discussion

To qualitatively assess trends in the beaver population over the past 70 years, we summarized and mapped the data from the surveys in 1939-1940 (Packard 1947) and 1999-2000 (Mitchell et al. (2000) and Mitchell and Ducharme (*unpublished data*); Figure 51). Estimated population was based on the number of active lodges and dens observed. For each active site we assumed a colony of six beavers occupies the site (Packard 1947).

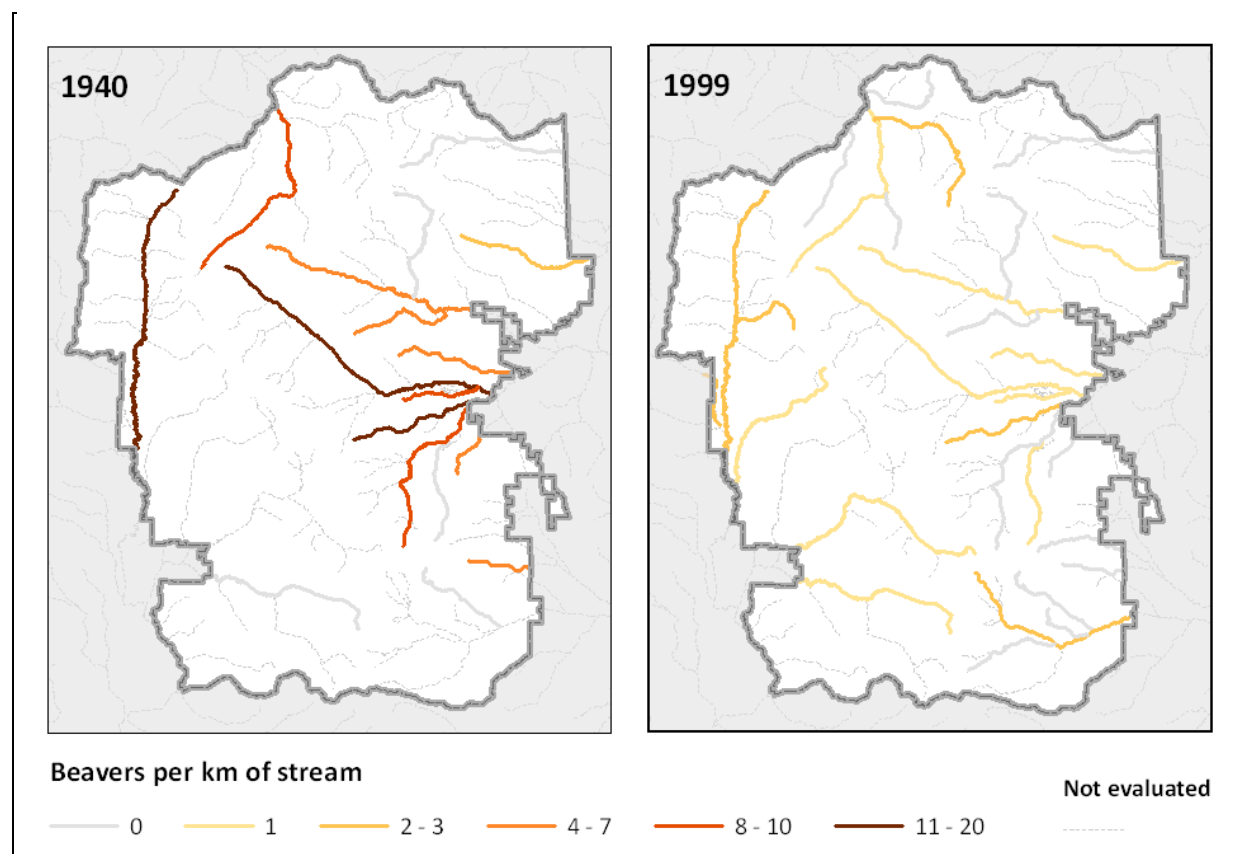


Figure 51. Comparison of beaver densities from surveys in 1939-1940 (left) and 1999-2000 (right) in several drainages in ROMO. Estimates of beaver density from surveys in 1939-1940 are generally much larger than estimates from surveys in 1999-2000. Data attributed to 1:24K stream reaches.

These data suggest declines in beaver populations over that time period, and beaver populations appear to have disappeared from several drainages. The methods used to collect survey data varied between the surveys, but in general, they collected the same kinds of data. Therefore, we suspect the declines in beaver abundance suggested by these surveys are real and not an artifact of different field methods. Based on these surveys and an assessment of willow populations in Moraine Park, Baker et al. (2005) noted declines in beaver populations and a corresponding decline in tall willow over the same time period:

Beaver were once abundant in the study area but declined dramatically after 1940; for example, population estimates in Moraine Park were 315 in 1939–1940, 102 in 1964, 12 in 1980, and six in 1999. In a comparison of 1937/1946 and 1996 aerial photographs, Peinetti et al. (2002) found that tall willow (> 3 m) cover declined by 54% in Moraine Park and 65% in Horseshoe Park. Short willow plants (< 1.5 m) have dominated the study area for several decades, probably a result of a change in individual plant stature rather than in willow species composition. Thus, beaver and willow populations have both declined in heavily browsed environments within [ROMO].

Mitchell et al. (2000) estimated browsing impact on willows during the 1999 to 2000 beaver survey (Figure 52). Packard (1947) estimated that 600 beaver lived in the Kawuneeche Valley around 1940. Today, beaver are rare in the valley (Rick Scherer, *personal observation*).

Estimates of beaver abundance and density from similar habitat in other locations also tend to be much higher than current densities in ROMO. Baker and Hill (2003) summarized densities reported in the literature and found there to be a wide range in the density of beaver colonies, from near zero to at least $4.6/\text{km}^2$ (reviews by Hill 1982; Novak 1987). Observers in different regions have attempted to estimate the maximum density or saturation point in local populations. Saturation has been reported to vary from 0.4 colony/km of stream in northern Alberta to 1.2 colonies/km of stream in New York and Utah (reviews by Hill 1982; Novak 1987). In the headwaters of four Alabama watersheds, saturation approached 1.9 colonies/km of stream (Hill 1976). Based on available survey data and other published research, it appears the abundance of beaver in ROMO is far below historic levels.

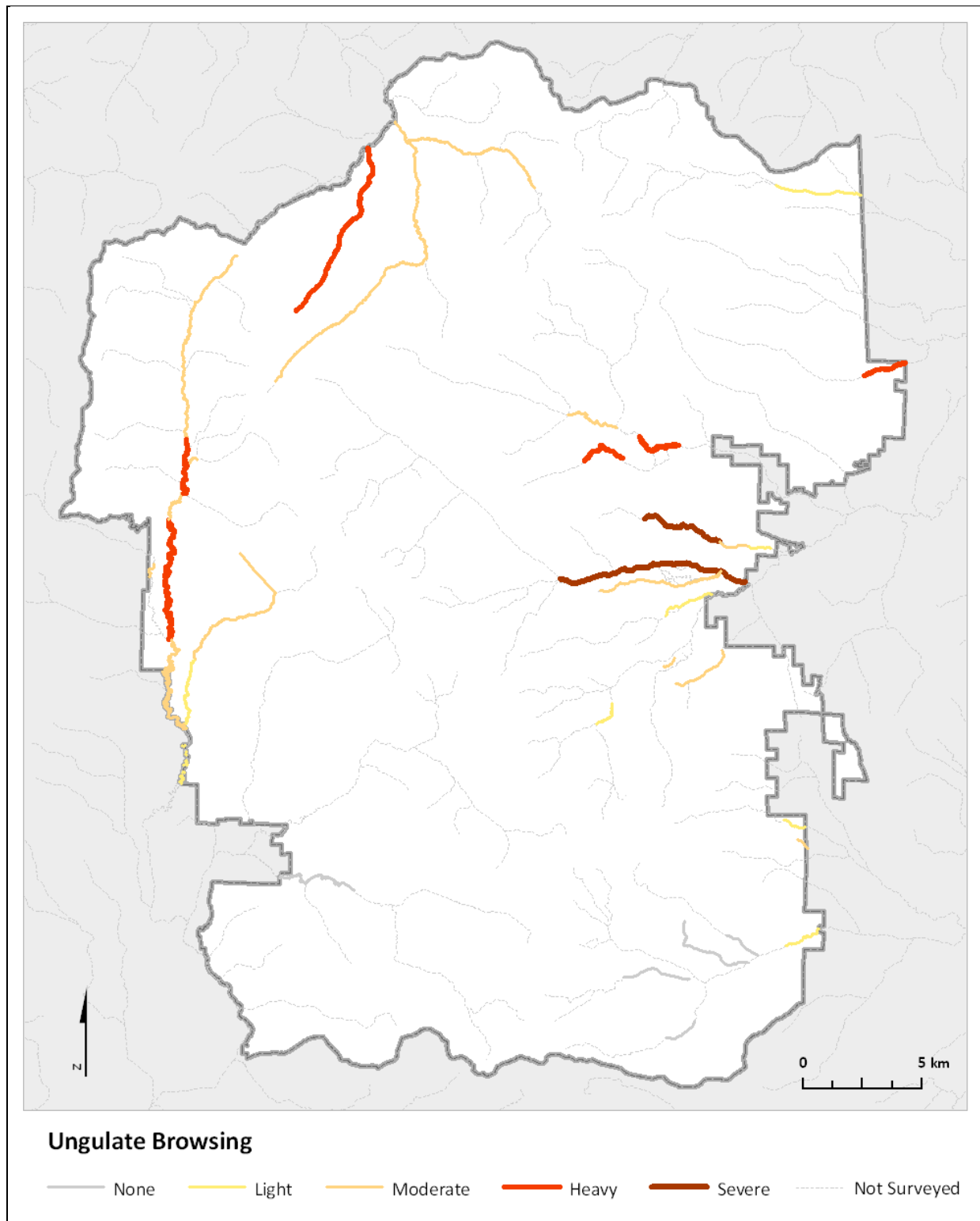


Figure 52. Map showing drainages surveyed in 1999 to 2000 classified based on impact of browsing on willow. Drainages in dashed light grey were not surveyed. Browsing data comes from the 1999 to 2000 beaver surveys conducted by Mitchell et al. (2000).

We delineated 536 patches for a total area of suitable beaver habitat of 1,040 ha (about 1%; Table 32). We considered a patch to be active if it contained at least one of the locations of current beaver activity from the surveys of Mitchell et al. (2007) and Mitchell and Ducharme (*unpublished data*). A patch was considered no longer active if it was surveyed and only locations of past beaver activity were observed. Most patches (409) were in drainages or along creeks that were not recently surveyed.

Table 32. Summary statistics for the patches of suitable beaver habitat in Rocky Mountain National Park. Std. Dev. Area and Std. Dev. Suitability Score are the standard deviations of patch area and average patch suitability score, respectively.

Summary Statistics	All Patches	Active	Past	Not Surveyed	No Activity
Number of Patches	536	39	87	409	1
Area (ha)	1040	497	297	244	2
Average Area (ha)	1.94	12.7	3.42	0.6	N/A
Std. Dev. Area(ha)	7.8	21.53	9.6	1.61	N/A
Maximum Area (ha)	93.6	93.6	67.9	18.2	N/A
Avg. Suitability Score	0.43	0.62	0.6	0.37	0.61
Std. Dev. Suitability Score	0.26	0.18	0.24	0.24	N/A

A general principle of ecology is that larger patches of suitable habitat and habitat of higher quality should support larger populations of a species (Hanski 1999). Our data provide further support for the validity of this principle. Higher proportions of large patches (≥ 10 ha) and patches of high quality (high average beaver habitat suitability score across pixels in a patch) contain evidence of current or past beaver activity (Figure 53). One possible reason for the higher proportion of large patches with evidence of current or past beaver activity is that they cover a larger percentage of the study area, and therefore, it is more likely that beaver locations fall within their boundaries.

According to our model and the method we used to delineate patches, most patches of suitable beaver habitat in the park are small (≤ 1 ha; Figure 54) relative to estimates of home range size for beaver. Wheatley (1997) reported home range sizes as large as 18 ha and the results of a modeling project suggest a colony of beaver comprised of 6 individuals requires a minimum of 4 ha for long-term persistence (Baker et al. 2005). Thus, much of the potentially suitable habitat in the park may be in patches that are too small to support persistent beaver populations. Of course, the abundance of small patches of suitable beaver habitat may be an artifact of the method we used to delineate patches. A limitation of the method is that individual suitable pixels were considered part of a larger patch only if they shared an edge or corner with another suitable pixel. Individual pixels that were suitable (had a suitability score greater than 0) but did not share an edge or corner with a neighboring suitable pixel were identified as individual patches. In some cases, patches comprised of a single pixel were near, but not connected to, other suitable patches. While our model considers these pixels to be individual patches, beaver may perceive collections of unconnected, suitable pixels that are near one another as part of a single, larger patch. In fact, our data support this idea. Evidence of recent beaver activity in patches as small as 0.01 ha (one

pixel) was observed during the surveys in 1999 and 2000. It is highly unlikely that suitable patch sizes were smaller than our data resolution.

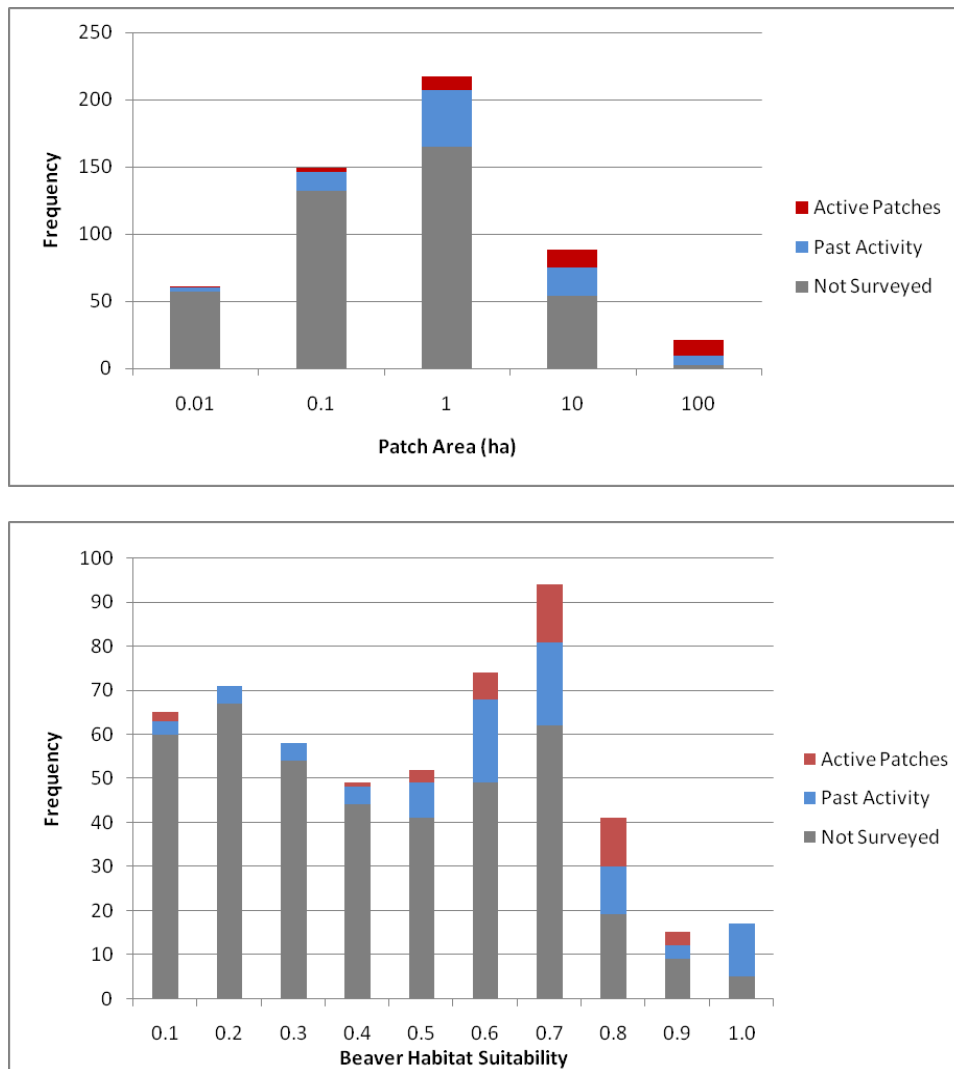


Figure 53. Distribution of size (top) and quality (bottom) for the 536 patches in the study area. The number of patches in each size or beaver habitat suitability class that contains evidence of beaver activity is shown by the portions of each bar shaded in red (current beaver activity) and blue (past beaver activity). The beaver habitat suitability scores in the bottom figure are averages across all pixels that make up each patch. Small proportions of the patches in the smaller size classes and of lower quality contain evidence of current or past beaver activity, while larger proportions of patches in the larger size classes and of higher quality contain evidence of current or past beaver activity.

In general, however, evidence of current beaver activity was found in larger patches with higher average suitability scores (red squares in Figure 54). Examination of the distribution of patch sizes and average habitat suitability scores for patches with evidence of active beaver colonies suggests a minimum patch size of 0.10 ha and a minimum average suitability score of 0.4 for beaver to occupy a patch.

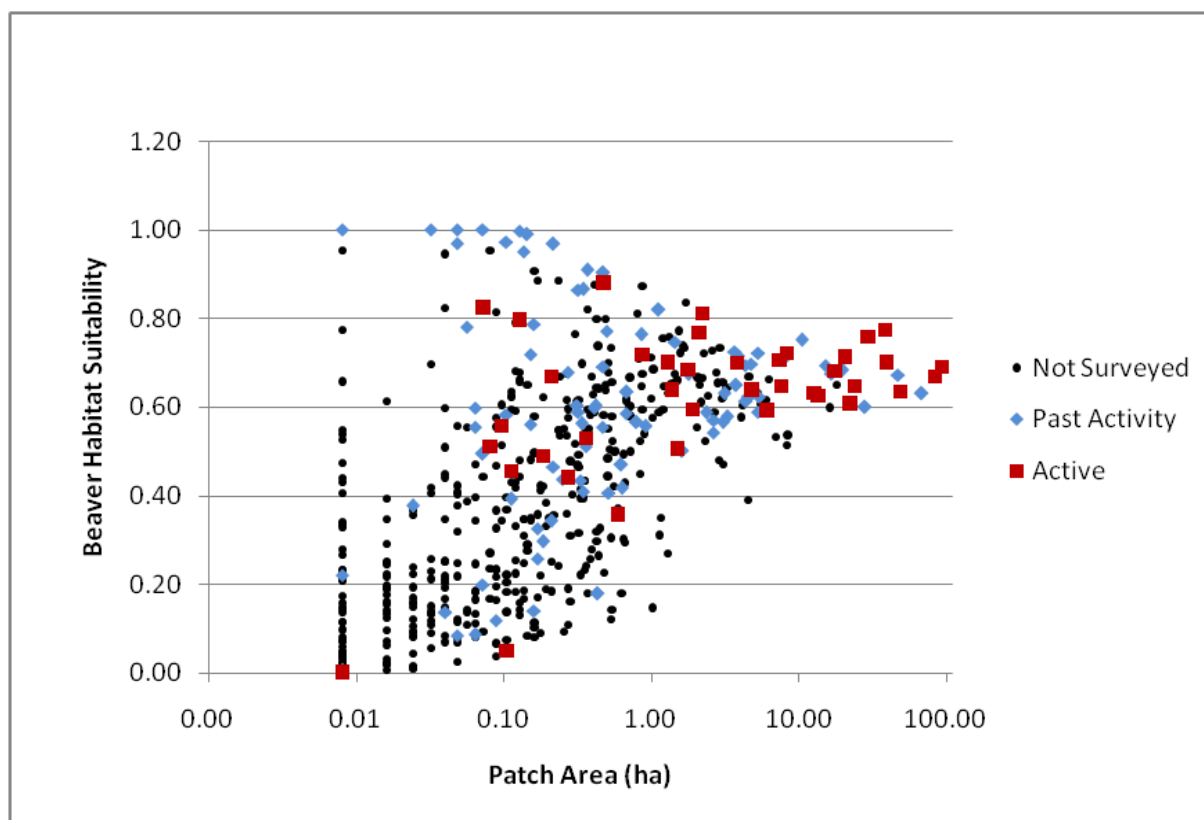


Figure 54. Minimum patch size of 0.01 ha and a minimum average suitability score of 0.4 for locations of current beaver activity.

Potential beaver habitat is not distributed evenly within the park. Our model identified more potential beaver habitat of higher quality in the western half of the park compared to the east. The Colorado River as it flows through the Kawuneeche Valley has the greatest area of potential beaver habitat within the park, estimated at 189 hectares. Two other drainages in the Kawuneeche Valley, Onahu Creek (98 hectares) and Baker Creek (84 hectares) had the second and third highest amounts of potential beaver habitat within the park. On the east side of the park Fall River and the Big Thompson River had an estimated 62 and 56 hectares of potential habitat respectively.

Scenarios for Restoration

Given that the current distribution and abundance of beaver in ROMO is far below historic levels (Figure 51), it is important to prioritize areas for habitat restoration or reintroduction of beaver. We have addressed the question of prioritization in two ways: first, by summing the area of potentially suitable habitat within all HUC-12 drainages in the park; and second, by computing the proportion of a HUC-12 drainage that is potentially suitable beaver habitat. We combined these two ways of evaluating potential for suitable habitat into a map we referred to as restoration potential (Figure 55). The HUC-12 drainages of highest restoration potential are Colorado River-North, Big Thompson River-West, Onahu Creek, Cache la Poudre-South, Fall River, and Glacier Creek.

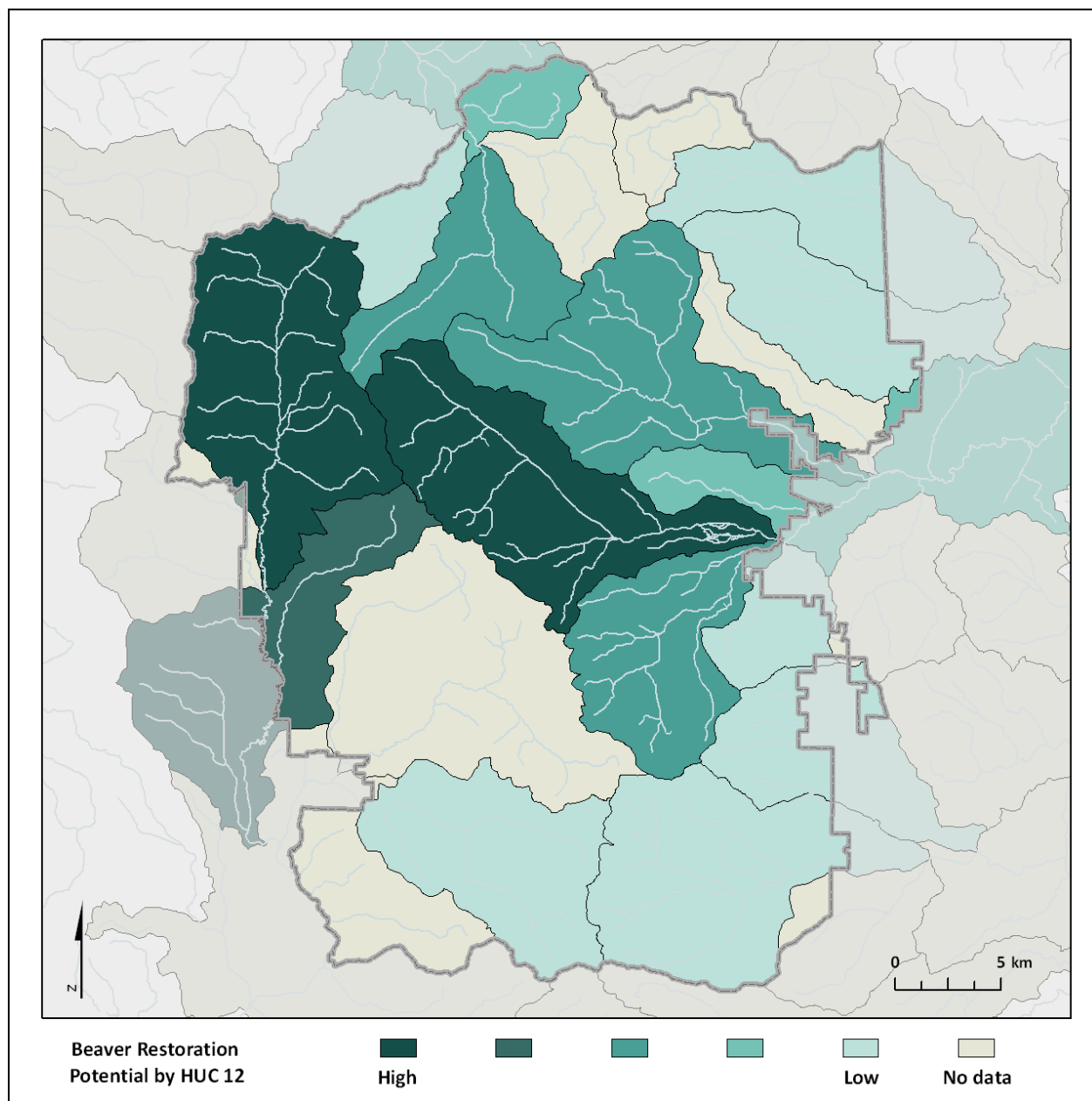


Figure 55. Beaver restoration potential by HUC12. Restoration potential was based on the total area of potentially suitable beaver habitat multiplied by the change in estimated beaver population between 1940 and 1999.

Uses and Limitations

Although the data on beaver locations suggest the beaver habitat suitability map provides a reasonable approximation of the amount and location of beaver habitat in the park, there are a number of caveats that should accompany our research results.

We primarily used data on stream gradient, the slope of the terrestrial environment and the distribution of suitable vegetation and other land cover types to develop the map. Clearly, the set

of environmental elements that influence the suitability of an area for beaver exceeds those used to build our habitat model. The results from field studies in other parts of the geographic range of beaver suggest beaver presence is correlated with stream width and depth, the amount of bare ground and other elements of the landscape (Beier and Barrett 1987; Barnes and Mallik 1997). These components were not incorporated into our map because data were not available or were at a spatial resolution that we felt was inappropriate for this project. For example, the map of Salas et al. (2005) contains data on the locations of areas of bare ground in the park. However, Salas et al. (2005) used aerial photo interpretation to classify vegetation and land cover in the park. Consequently, they could only delineate relatively large, contiguous areas of bare ground, so their data were too coarse to be useful in our mapping process.

Despite apparently high levels of interest in beaver by natural resource managers and the general public, there was a surprising lack of information on movement behavior. Radio telemetry is often used to collect movement data on animal species, and problems associated with mounting radio telemeters on beaver appear to be an important cause of this lack of information (Baker 2005). In particular, we lacked information with which to develop more than coarse, general estimates of the relative costs of movement through various habitat types. That is, we were only able to assign costs to pixels based on a coarse assessment of the slope of the pixel and whether the pixel represented a stream or the terrestrial environment. If information becomes available from future studies, it could be incorporated into the mapping process and may improve the utility of the map.

Also, the vegetation map provided little information on willow height, and willow height appears to be an important criterion when it comes to determining beaver use. We used the vegetation map without consideration of the actual height of shrubs. Beaver need taller shrubs for dam and lodge construction.

Beaver use other habitat types besides streams, so our source cells may have been too restrictive.

Due to the limited availability of relevant spatial data and movement behavior in beaver, the final beaver habitat suitability map should be considered primarily a map of potential beaver habitat. This model is a first-run approximation and is likely to include both errors of omission and commission with regard to identifying suitable beaver habitat. A follow-up study to inventory beaver sites would be valuable.

At this point it appears that the amount of suitable habitat in the park may be limited by the area of mature willow stands within riparian areas (Baker et al. 2005). In order for willow stands to develop sufficient girth for dam and lodge construction, elk browsing intensity will need to decrease (Baker 2003, Baker et al. 2005). Thus, at this time the size of the elk population may be indirectly limiting the size of the beaver population through herbivory. Our mapping exercise was unable to discriminate mature willow stands from those heavily browsed by elk. As a result of the extent of elk browsing in willow stands, we have mapped potential habitat rather than currently suitable habitat.

Overall, we believe that this indicator supports a *high degree of concern*, because of the key role beaver have in riparian ecosystems of the park and the extent and widespread disruption of the

hydrologic processes in the park. We rank our level of confidence in this indicator as *moderate/moderate*. We rated this as *moderate agreement*, because some uncertainty remains among experts as to the direct role beaver play in riparian condition. Because of the complicated linkages of riparian condition with other factors such as elk population levels, trapping of beaver, and lack of top predator (wolf), the additive effects of beaver to riparian ecosystems is difficult to estimate. We rated this indicator as *moderate level of evidence*, because this indicator is mapped on consistent landscape data, validated by aerial photography for current (and some historical distributions), and relatively consistent with historical surveys of beaver and expert opinion.

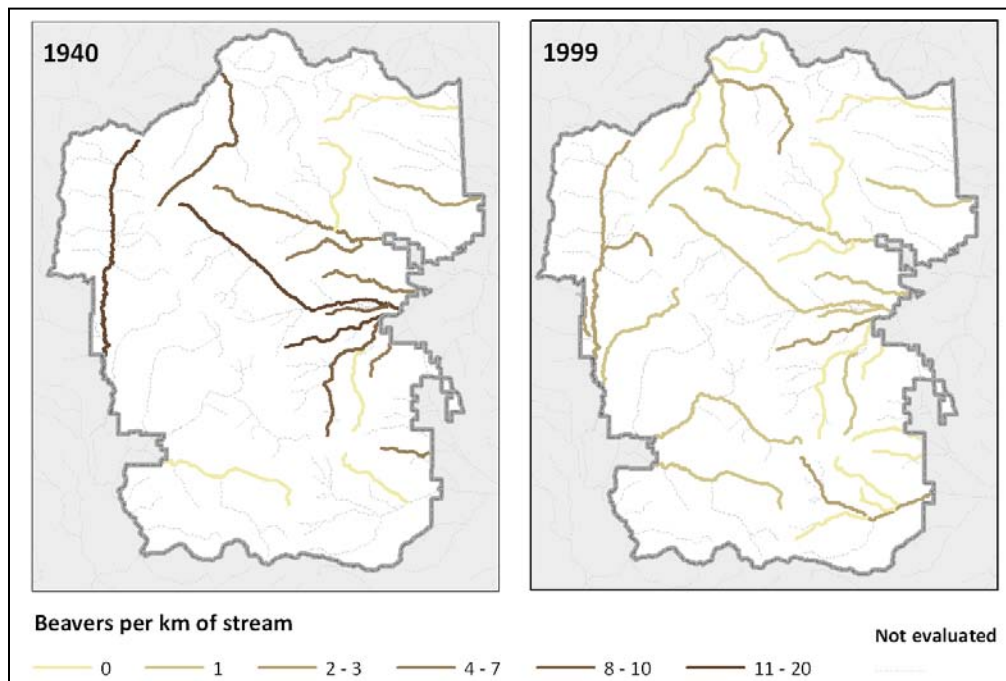
Summary: Biotic Integrity - Extent of Suitable Beaver Habitat

What: Measures the distribution and proportion of potentially suitable beaver habitat and compares it to historical surveys.

Why: Important to understand the historical role beaver had in riparian vegetation and is critical to understand elk/willow dynamics.

Stressors: Over-abundance of elk, Grand Ditch, climate change

Confidence: High degree of concern; moderate evidence, moderate agreement



The current distribution of beaver is far below historic levels (bottom map). Highest areas for restoration potential (right map) include Colorado River (north); Big Thompson River (west), Onahu Creek, Cache la Poudre (south), Fall River, and Glacier Creek watersheds.

