Recreational Disturbance Modeling of Elk Habitat in Medicine Bow-Routt National Forests

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Abstract – Medicine Bow-Routt National Forests (MBRNF) [1] extend from north central Colorado to central Wyoming. The forests provide year-round recreation opportunities for thousands of people. The Colorado portion also provides habitat for the E2 Bear's Ear elk herd [2], with a winter population of approximately 24,000 [3], making it the second largest elk herd in Colorado. Since 2006, the calf:cow ratio trend of the E2 herd has fallen from 0.64 to approximately 0.48 in 2019. There are seven Game Management Units (GMUs) included within the E2 range. GMU 14, which is often combined with GMU 214 for analysis purposes, is an area within Routt County near Steamboat Springs. Over the same period, the elk calf:cow ratio of GMU 14 has fallen from 0.52 to 0.37. This matches a post-hunt population decline of GMU 14 from approximately 750 to 510 individuals as analyzed with a linear trend. The state wildlife agency, Colorado Parks and Wildlife (CPW), has recognized that "Human recreation is increasing in Colorado, and its effects on big game are of concern to many sectors of the public and to CPW." Status of Colorado's Deer, Elk, and Moose Populations (February 2020) [3].

This paper uses modern disturbance distance modeling of elk behavior and GIS tools to test the hypothesis that recreation may be having a significant and deleterious impact on elk in the area. To do so, this paper models the impact from recreation and related human disturbances on elk habitat in GMU 14, specifically the area east of Steamboat Springs in MBRNF. This area includes significant recreational development including a ski resort, hiking and biking trails, and motorized trails and roads. To perform the analysis, each linear structure (e.g., road or trail) within the analysis area was assigned a principal activity, and up to three elk disturbance distances were assigned to each activity. Two close-in disturbance distances based on mean minimum separation distance and mean distance to trail were used to model avoidance. A further disturbance distance based on initiating a flight response was also used. Together, these disturbance distances indicate a range of possible habitat disturbance impacts. These disturbance bands were superimposed on maps of MBRNF along with CPW-indicated elk production and summer range areas. The results show significant habitat fragmentation and loss, with approximately half the analysis area impacted under the separation disturbance models, and over three quarters impacted using the flight disturbance model. The paper concludes that habitat loss from recreational development in the analysis area is likely to be a significant contributing factor in the declining productivity of the GMU 14 resident elk herd, and possibly for the larger E2 herd.

1 OVERVIEW

Biologists are increasingly concerned about the impact of recreation on wildlife and wildlife habitat. We use disturbance band modeling to estimate the impact of recreational activities on elk and elk habitat in a section of Medicine Bow-Routt National Forest (MBRNF) in northwest Colorado.

We chose elk as our specific species of study for a number of reasons. Elk are migratory animals who need large, connected landscapes of healthy habitat to thrive. They are also wary and easily disturbed by humans. These features allow them to serve as a proxy for numerous species that are timid and share the same habitat. This includes, but is not limited to, wet owls, goshawks, merlins, numerous raptors, dusky and ruffed grouse, mule deer, and pronghorn. In this regard, we are using elk as an umbrella species for the observation and protection of a wide range of species and habitat.

Being a populous big game animal, there is a wealth of scientific research about elk, their characteristics, their habitat, and about their interactions with humans and human recreationists. Colorado Parks and Wildlife tracks elk populations, harvest rates, calf:cow ratios, and other metrics at the herd level, and occasionally at a GMU level. Together, there is a large body of knowledge about elk, elk behavior, and the local elk populations that facilitates the creation of this analysis.

Elk are also an iconic species, appreciated by hunters, conservationists, and wildlife watchers. Big game hunting adds approximately $600M to Colorado’s economy each year [4], while wildlife watching adds approximately $2.4B [4].

The precipitous decline of the elk population in the nearby Eagle and Roaring Fork Valleys over the past two decades, often blamed on human development and recreation activities, has raised similar concerns about the elk population in Routt County. [5] [6] [7] [8] [9] [10]

For the above reasons, we chose elk as our analysis species. The analysis area is known for elk habitat in the spring, summer, and autumn. The area includes numerous elk production (calving) areas in the spring and identified summer range in summer and autumn. For these reasons we constrained our analysis to non-winter recreation activities, as the elk have largely migrated from the area when they seek their winter range.

Our analysis consists of superimposing “disturbance bands” on linear structures (e.g. roads and trails) over the analysis area. Two types of output are generated. Table data is generated that sums disturbed and undisturbed acreage in the area. This can be valuable when calculating incremental changes. Maps are also generated that show the area and type of disturbance. This is particularly useful for viewing habitat compression and fragmentation.

We end our analysis with observations from the derived maps and tables.

2 Methodology

The September 2019 issue of Science Findings, a publication of the US Forest Service's Pacific Northwest Research Station, summarizes some of the research in [Seeking Ground Less Traveled: Elk Responses to Recreation]. [11] The summary reads:

"*Recreating on public land is increasingly popular in the Pacific Northwest. Recreation management requires balancing opportunities for people to enjoy the outdoors with mitigating the effects on wildlife and other natural resources. Recreation and wildlife managers grappling with these issues asked Forest Service scientists to quantify the impacts of motorized and nonmotorized recreation on elk. Elk are highly valued for hunting and viewing by the public, and as large herbivores, they play a critical role in many ecosystems of the Intermountain West.*

A large fenced area within the Starkey Experimental Forest and Range in eastern Oregon provided a unique setting for assessing how a wide-ranging species like elk respond to four types of recreation. Real-time data recorded by telemetry units worn by people and elk alike allowed scientists to establish a cause-effect relationship between human movements and activities and elk responses. Scientists found that elk avoided areas where humans were recreating. This avoidance resulted in habitat compression. All-terrain vehicle use was most disruptive to elk, followed by mountain biking, hiking, and horseback riding. When exposed to these activities, elk spent more time moving rather than feeding and resting.

Land managers can use this information to assess tradeoffs between multiple, and often competing, land uses. When combined with planning efforts that include stakeholder engagement, it may offer a clearer path forward."

Disturbance from Recreational Trails

Two of the published research studies from the Starkey experiments include Effects of Off-road Recreation on Mule Deer and Elk (Wisdom et al. 2004) [12]and Elk responses to trail-based recreation on public forests (Wisdom et al. 2018). [13] Both studies were based on the same primary research of initiating two disturbances a day on each trail, and only by a single recreation activity (hike, horse, bike, or ATV). This treatment would be repeated for five days, followed by a control period of nine days of no disturbance, before switching to a different disturbance activity. The 2004 study quantified the probability of elk flight (an elk fleeing the disturbance) as a function of activity type and distance from the trail. The second study used the same data to calculate the mean minimum separation distance of elk from the activity and mean distance to trail for separation distance from the trail when the activity was absent. These three metrics are used in our analysis.

A May 2018 presentation by Dr. Mary Rowland (co-author of Wisdom et al, 2018) titled Elk Responses to Recreation on Public Forests [14] summarized the probability of flight from the 2004 study for a single disturbance with the following graphic:

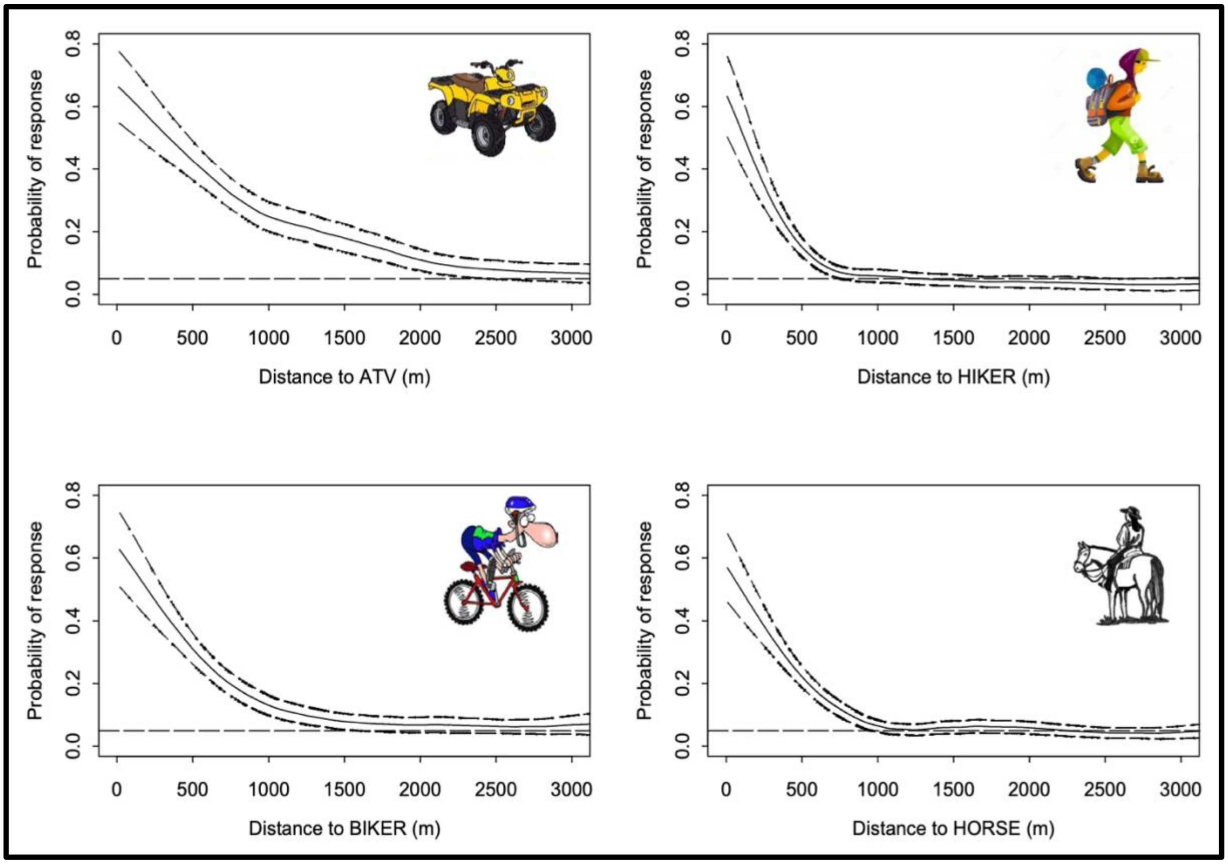


Figure 1 shows the probability of flight response versus activity type for each of the four activities. The solid line shows the calculated average possibility, while the nearby dotted lines show the 95% confidence interval (C.I.). A horizontal dashed line is set at the 5% probability of flight level. [14]

The horizontal dashed line shows the 5% probability of flight point. This is presumed to be the outer reaches of eliciting a response. We used where it crossed the lower C.I. line as the flight disturbance distance. Therefore, this distance is at the 95% probability of initiating a flight response 5% of the time. All distances are in meters. The flight disturbance distances of each activity are:

Flight Distance	
Activity	Disturbance Distance
HIKER	750m
HORSE	900m
BIKER	1500m
ATV	2400m

Table 1 above shows the distance from a recreationist that a flight response can be initiated. Distances reflect 95% confidence of a 5% probability of a flight response. [12]

The 2018 research paper that followed looked at how the spatial location of elk varied with activity type. The figure below shows two diagrams from the paper, one during a control period of nine days of no human activity (ATV-C), and the other during the five days that treatment occurred (ATV). The treatment was one morning ATV pass on the trails and one afternoon ATV pass on the trails.

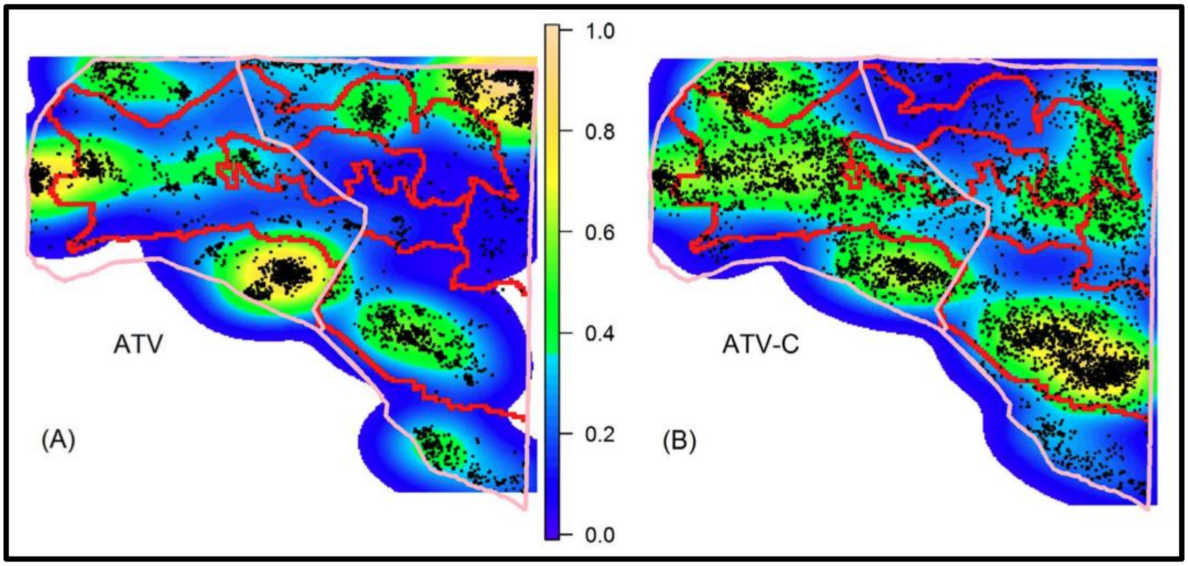


Figure 2 is captured from Figure 4 of Wisdom et al. 2018. It shows the locations of 35 elk during ATV riding (A) versus the corresponding control periods (B), superimposed on estimates of the spatial probability distribution of elk locations. [13]

Probability of use is scaled from 0 to 1, with warmer colors (yellow and green) indicating higher use, and cooler colors (light blue and dark blue) indicating lower use. Recreation trails are shown in red, and pink lines indicate fences. ATV-C (B) essentially shows the elk locations and probabilities in the undisturbed control case, while ATV (A) shows the distribution of elk when disturbed by ATVs twice a day. The usable habitat is clearly compressed during the ATV treatment period.

The study calculated two distances that elk avoided trails or recreationists during the treatment period. One was the mean distance of elk to the nearest trail, while the other was the mean minimum separation distances that elk maintained from recreationists. The second metric can be thought as the real-time response to recreationists. We've renamed these to Path Separation Disturbance distance and User Separation Disturbance distance respectively on the map legends to be more descriptive. The values are:

Avoidance Distance		
Activity	Mean distance to trail (Path Separation Disturbance)	Mean minimum separation distance (User Separation Disturbance)
HIKER	276m ±18m	547m ±44m
HORSE	240m ±13m	558m ±45m
BIKER	286m ±26m	662m ±53m
ATV	311m ±28m	879m ±68m

Table 2 above shows two avoidance distances. Mean distance to trail reflects the minimum separation distance an elk would keep from a trail, even in absence of recreationists. Mean minimum separation distance reflects the minimum distance an elk would keep from a recreationist. [13]

As noted in the study, "*Separation distances from recreationists were significantly farther than elk distances from trails…, illustrating the difference in real-time responses of elk to recreationists (five-minute time windows each morning and afternoon) versus the more static responses to trails (8-hour time window each day).*"

The figure below graphically shows the three disturbance metrics:

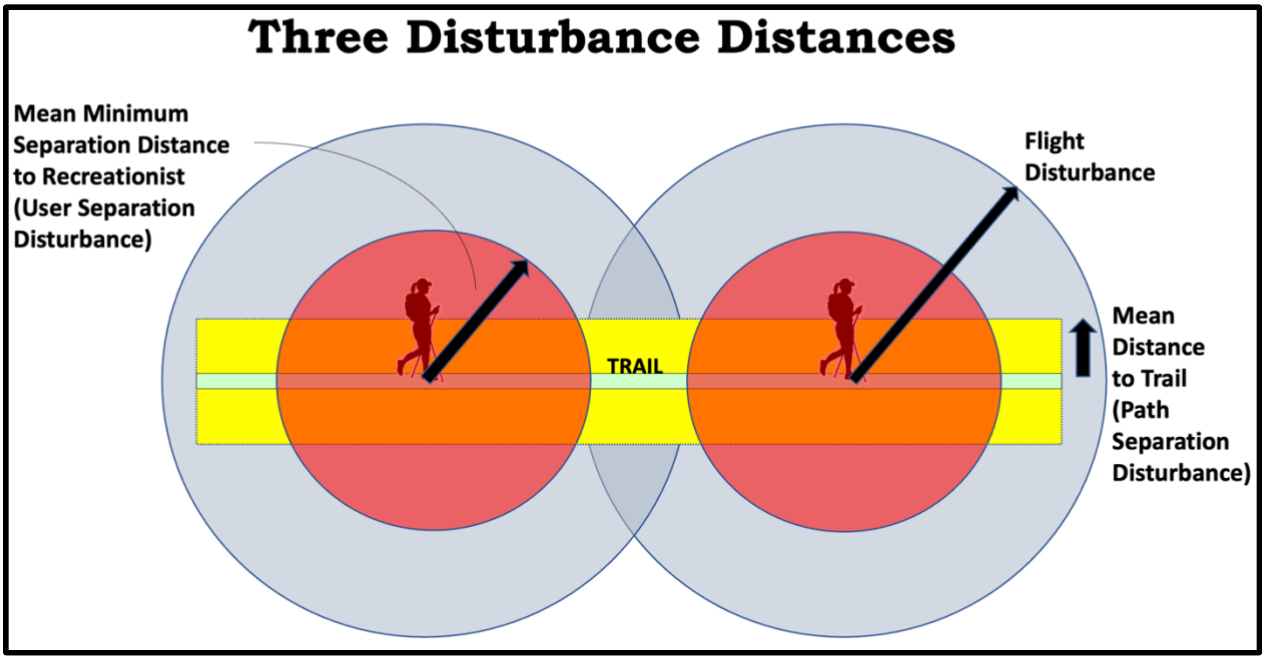
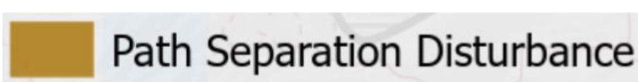


Figure 3 graphically depicts the three disturbance metrics for recreational disturbance. Mean distance to trail (Path separation distance) depicts avoidance to trail even when a recreationist is absent. Mean minimum separation distance from recreationist (User separation distance) depicts a bubble of avoidance in real time as a recreationist moves along a trail. Flight distance is the distance from a recreationist that a flight response may be initiated.

Figure 3 depicts the three disturbance band metrics. Path separation disturbance and user separation disturbance distance both reference an area of avoidance, an effect that gradually diminishes as flight probability decreases further from the trail. The flight distance is the furthest distance from a trail that any human disturbance was detected. When trail volume is low, the shorter distance metrics are more meaningful. As trail volume increases and recreational disturbance occurs more frequently, the longer distance metrics become more meaningful.

For the purpose of our analysis, we've shown all three disturbance distances superimposed onto the analysis area. Each brings a different insight.



Path Separation Disturbance distance is the band of avoidance from the trail even when recreationists were not present. This was observed at Starkey for two disturbances per day- one in the morning and one in the afternoon. This is an appropriate avoidance metric for low volume trails. It shows that some habitat may be reclaimed following recreational use if the time between recreationists is sufficiently long. It also provides additional insight into habitat fragmentation where there is a concentration of multiple trails or roads in an area, as an elk must cross multiple paths to move from one intact habitat area to another. We've colored this disturbance as dark brown on the maps.

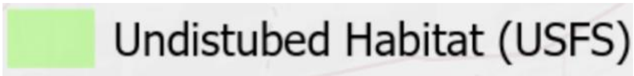
User Separation Disturbance

As trail use increases, the User Separation Disturbance distance becomes a key avoidance metric. This indicates the distance elk will actively avoid a recreationist. In high use scenarios, multiple recreationists on the trail form an aggregate avoidance zone that extends beyond the Path Separation Disturbance distance. This is formed either by the avoidance bubbles of independent recreationists overlapping, or when the length of time between disturbances is insufficient for elk to reclaim habitat they abandoned as the recreationist passed by. This is a good avoidance metric when trail volume is high. This is a characteristic of the majority of trails in the analysis area of MBRNF. We've colored this disturbance as light brown on the maps.

Flight Disturbance

The Flight Disturbance distance metric is a useful metric of a different type of disturbance, one where a flight response may be initiated. While the User Separation Disturbance distance shows the area that elk actively avoid when recreationists are present, the Flight Disturbance distance shows extended areas where there is some probability of a flight response. The probability of a flight response decreases as the distance from the trail or road increases. When a flight response is initiated, elk are expending energy and calories fleeing instead of consuming calories by grazing. The article from Science Findings states, "*Avoiding motors, wheels, hooves, or feet takes a toll on elk in two ways: increased energy expenditures and decreased access to food sources. Moving more than necessary and not having enough to eat can be detrimental to the viability of elk populations. For example, if females don't put on enough body fat, they may not be able to reproduce*." [11] This is particularly true while cow elk are lactating, the period in time when caloric consumption is highest. The flight distance band is a useful indicator of where habitat effectiveness may be less than its otherwise undisturbed state. We assume that habitat use is lowest closest to the trail, and increases as the distance from the trail increases, until reaching the original habitat use at the flight distance. For very popular trails with high volume, we speculate that the user separation distance increases into the flight disturbance zone. We've colored this flight disturbance as hashed brown over a light green background.

The flight distance is also a useful tool for appraising the impact to elk production (calving) areas. A study jointly executed by CSU and CPW "Reproductive Success of Elk Following Disturbance by Humans in Calving Season" [15] found that reproduction success fell nearly 40% when cow elk were disturbed by simulated recreationists during calving season. The definition of disturbance in that study was a cow elk taking flight, the same definition as the flight distance in the Starkey studies. Eight disturbances led to the 40% reduction in surviving calves, approximately 5% mortality rate per disturbance. The researchers speculated that causing an elk calf to change locations makes it more susceptible to predation, and thus the decline in the number of surviving calves. This impact is greatest during the calf's "hiding period", a period of time 10 to 14 days after birth. Due to the distribution of elk birth dates, this period can extend beyond June and into July. [16]



Undisturbed habitat includes all habitat not included in any of the above disturbance bands. We've colored undisturbed habitat on US Forest Service lands as light green.

These four disturbance indicators together show the decreasing disturbance impact with distance from a trail or road. The colors range from dark brown (most disturbed) to light green (undisturbed) as shown in the following legend. We found that this progression offered map readers an intuitive "heat map" of disturbance across the analyzed landscape.

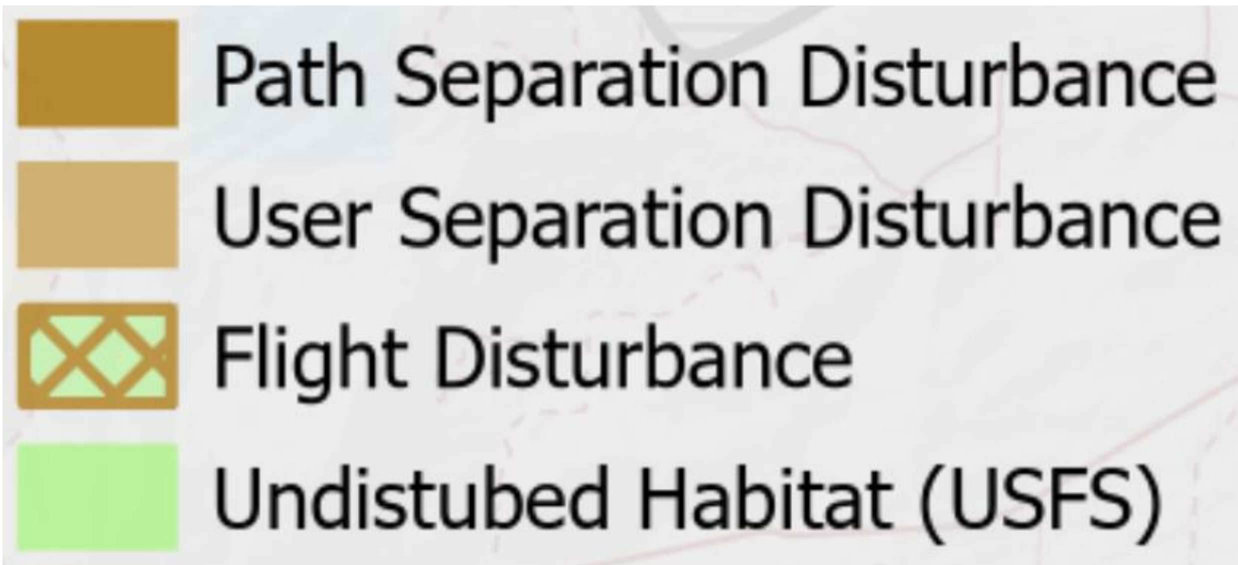


Figure 4 shows the legend of disturbances used on the analysis maps ranging from most disturbed to undisturbed as the distance from a trail or road increases.

Since the two separation distances above each indicate an avoidance area, we did further analysis to see which one would be most relevant as the principal avoidance metric in our analysis area. We used trail counter data from 2020 for trails on nearby BLM and Forest Service lands to estimate disturbances/day of representative trails during summer months. [17] These ranged from 17 users/day (Ridge/Rotary trails) to over 100 users/day (Flash of Gold, magnetic-MTB). We divided by two to approximate the number of disturbances, which were 8.7 and 54 disturbances/day respectively. Since all trails indicated a frequency of disturbance substantially higher than the two/day treatments in the Starkey studies, we chose user separation distance as the key separation metric for the area of study in Medicine Bow-Routt National Forests in our quantitative analysis. A more nuanced evaluation in the future may lower this disturbance zone to path separation distance for trails identified as having lower disturbance frequencies. We included the path separation bands in the maps as they gave a qualitative indicator of high disturbance and potential habitat fragmentation in areas of multiple paths. Path separation distance varied little between activities, so we used 286 meters (the nominal value for bike path disturbance) for all path disturbance distances.

We used the 95% probability of initiating a flight response 5% of the time for our flight distance band.

Disturbance from Roads

While the Starkey experiments produced disturbance bands for recreational trails, the impacts from roads were not examined. For unpaved roads through MBRNF, we used ATV metrics as a proxy. Our observation is that ATVs and other users accessed these roads, and that they exhibited similar behavior to ATV use, such as starting and stopping.

The one paved road of interest is US40, which traverses MBRNF near Rabbit Ears Pass. We used two studies to determine the near and far disturbance distances of elk to highway traffic. The first study was Effects of Highway Operations, Practices, and Facilities on Elk, Mule Deer, and Pronghorn Antelope (Ward et al, 1980). [18] A key passage from this study is this:

"*Elk show a preference to stay a minimum of 0.25 mile (400 m) from traffic while deer prefer a minimum of 100 yards (91.m), and antelope use the habitat up to the right-of-way fence. All three species are more responsive to people walking; elk prefer a distance of 0.5 mile (800 m), deer 200 yards (182 m) and antelope somewhere between the two distances, depending on habitat and experiences.*"

This study reports a minimum separation distance to walkers of 800m, somewhat higher than the user separation distance derived in the Starkey studies. It shows a 400m minimum separation distance to a highway.

A second study was performed in the Blue Mountains of Oregon and Washington. This study is still being peer reviewed, but data presented by Dr. Michael Wisdom [19] in a slide presentation titled Modeling Elk Habitat Use in the Blue Mountains of Oregon and Washington on February 6, 2020 offers additional insight. Slide 23 models the relative probability of elk use in relation to highways and county roads when all other conditions are held constant. It is shown below:

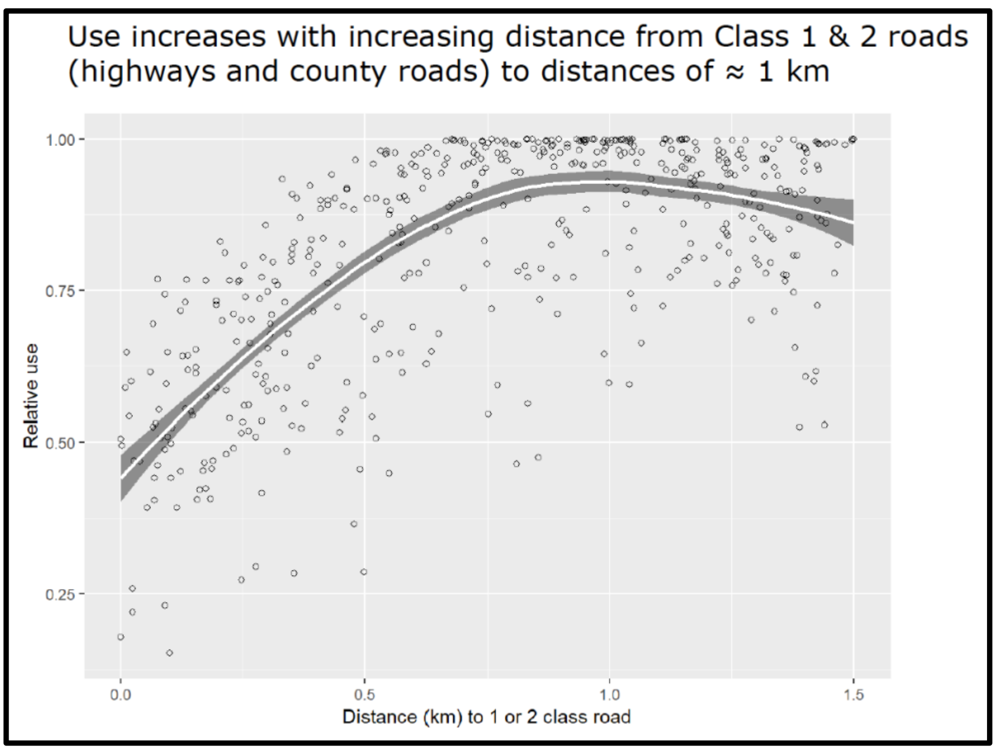


Figure 5 shows the relative use of habitat versus distance from a highway or county road. [19]

The figure above shows elk may use habitat close to a highway at a 50% relative use, but there is little effect past 800m, about 0.5 miles.

The two studies combined indicate a near disturbance distance of 400m, with a disturbance range of approximately 800m. For our analysis, we set 400m as the equivalent of user separation distance, and 800m as the equivalent of maximum flight distance or the limit of any human disturbance. We used 286 meters for path separation distance, as we did with all trails.

Unified Disturbance Bands

In our analysis we derived four disturbance models, each with a different user separation and a flight distance. We used 286 meters for path separation distance for all paths. The four models are:

Paved Road/Highway: 400m user separation, 800m flight
Hiking/Horse Trail: 547m user separation, 750m flight (note: we used hiking separation and flight distances, since hiking dominated over horse use on these trails)
Biking or Multi-use non-motorized: 662m user separation, 1500m flight
ATV Trails or Dirt Roads within Forest: 879m user separation, 2400m flight

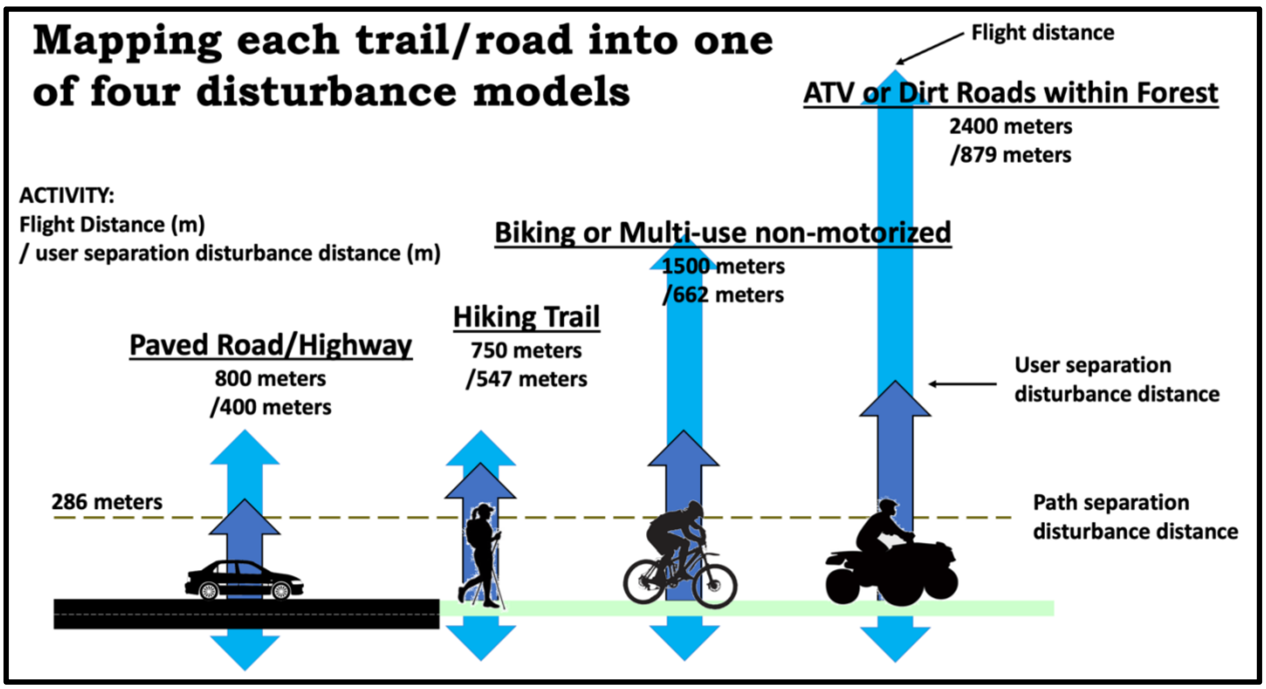


Figure 6 shows the path separation, user separation, and flight distances chosen for each of the four disturbance types.

Closed roads and trails

There was one road closed to the public within the area of analysis. It is a service road that is rarely used and is never used by the public. We treated that road as zero disturbance.

There was a service road open only to authorized vehicles near Long Lake, that is also used by hikers and bikers. Since the motorized use was rare, but non-motorized use was common, we treated the road as a non-motorized trail.

There are several non-motorized trails identified by the Forest Service as user-created unauthorized trails. We ignored them for this analysis, as we suspect their usage is under the two disturbances/day frequency of the Starkey studies. A more nuanced analysis may include them in the future. In that case an appropriate disturbance band for these non-marked and low usage trails may be path separation disturbance as the separation distances, with no flight distance added beyond the separation distance.

Indicating Roads and Trails

Early mapping efforts showed difficulty by some users to differentiate between the different path types on a map. This was particularly challenging for males with a degree of red/green color blindness. We experimented with color and dash type until finding a combination that was distinguishable by these individuals.

We used a single color, black, for all motorized trails, but a dashed line for ATV trails and dirt roads through the Forest and a solid line for a paved road. Similarly, we used blue for all non-motorized trials, with a dashed line for foot or horse trails, and a solid line for bike or multiuse trails. We used a yellow line with dark edges for any closed roads.

Finally, we used a thick purple border for the greater analysis region, with a dashed yellow line at the border of the Middle Yampa Geographic Area within that. We performed quantitative analysis for both areas – Middle Yampa Geographic Area and the expanded analysis region.

Figure 7 shows the legend for various paths and analysis region boundaries.

3 ANALYSIS AREA

We chose an area east of Steamboat Springs in the MBRNF to perform the disturbance band analysis. The analyzed area is shown in the map below.

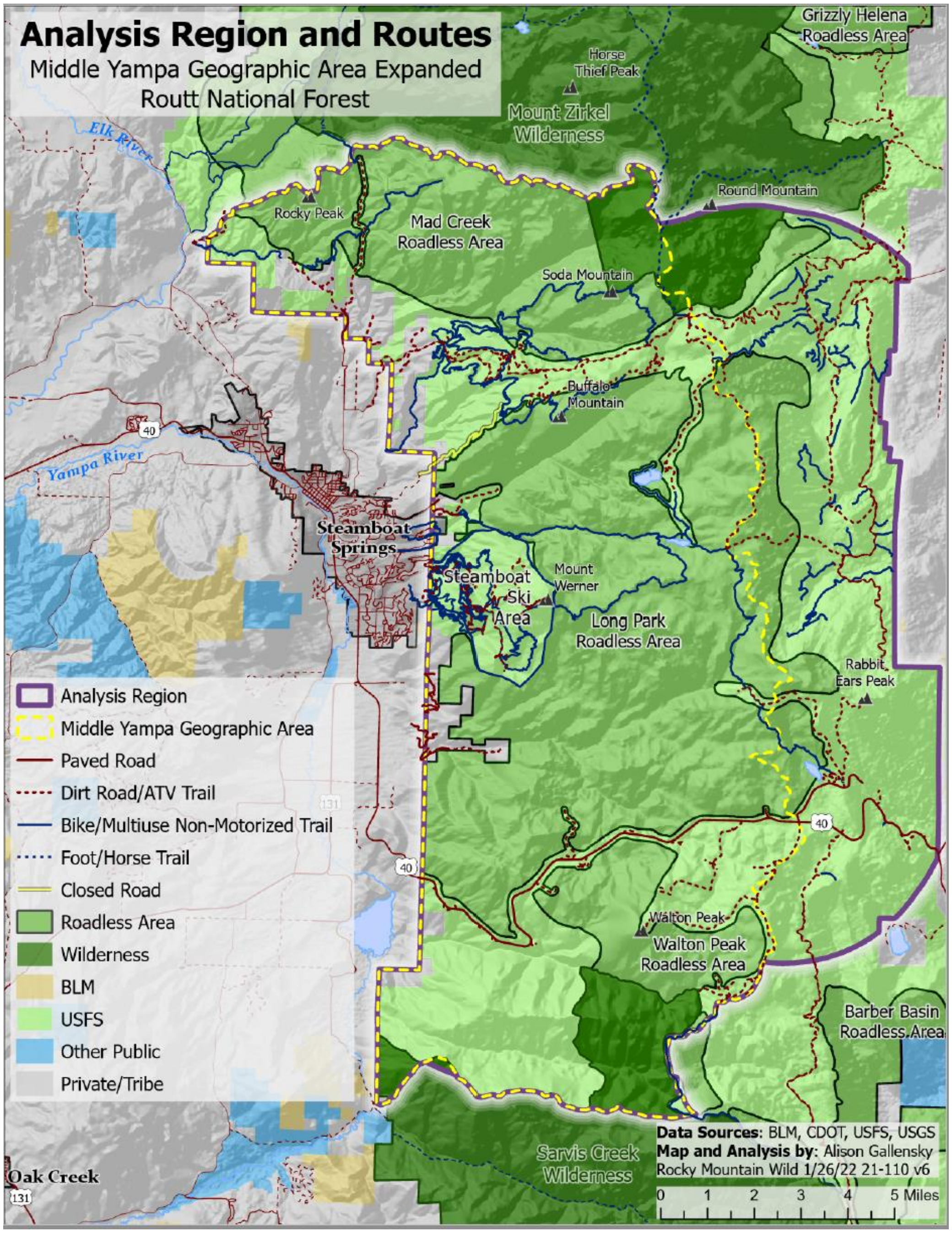


Figure 8 shows analysis area within Medicine Bow-Routt National Forests

The analysis area is an area in MBRNF east of Steamboat Springs. It is bounded by Mount Zirkel Wilderness to the north and the Sarvis Creek Wilderness to the south. There is a Forest boundary to the west, and the eastern edge of the analysis area is just east of the Continental divide. The analysis area is essentially the Middle Yampa Geographical Area (MYGA) as defined in the MBRNF Forest Plan [20] , but extends further to the east to include key recreation trails in the analysis area. The Forest Plan includes key metrics for the MYGA, such as Elk Habitat Effectiveness (EHE), so our own analysis includes evaluation of the MYGA by itself, as well as the expanded area shown in the map above.

It should be noted that the Forest Plan does not include a specific description of the MYGA boundaries. However, the maps included in the Forest Plan indicate that the MYGA is bounded by the Forest boundaries to the west, the Wilderness boundaries to the north and south, and by the Continental Divide to the east. Our calculated acreage of MYGA differs from that stated in the Forest Plan. The Forest Plan states total acreage of MYGA as 95,040 [21]. Our own definition totals 94,700 acres in the above definitions, with 90,140 of those acres being National Forest land when the private land is removed. We speculate that the discrepancy is due to slight differences in the boundaries, the inclusion or removal of private land holdings, and/or the accuracy of GIS analysis between the 1998 Forest Plan and today. Nevertheless, our analysis extracts percentage of habitat impacted, a calculation that does not change greatly due to minor differences in the analysis area boundaries.

The area supports a great deal of recreation year around. Summer and winter recreation is accessible from US40 and Buffalo Pass Road. The Steamboat Ski Area is a world class ski resort on the western boundary. The Continental Divide Trail, a popular trail for hikers and bikers, extends from US 40 to the north. There are three Colorado Roadless Areas (CRAs) in the MYGA. The MYGA contains the Mad Creek Roadless Area in its north, Long Park Roadless Area in its center, and Walton Peak Roadless Area in its south. There are numerous multiuse (hike, horse, and bike) non-motorized trails in the area including a number of new multi-use trails built recently in the Buffalo Pass area. There are also numerous motorized trails and forest roads, though all are outside of the CRAs.

The area is also popular with hunters, supporting archery, muzzleloader, and hunting seasons for elk. This area is part of GMU 14, which itself is part of the E2 Bear's Ear elk herd. A significant portion of the area is elk habitat, including elk production areas, elk migration corridors, and elk summer range. Other big game species include mule deer, moose, and black bear. A map showing the relationship of GMU 14 to the analysis area and the entire E2 DAU (Data Analysis Unit) is below.

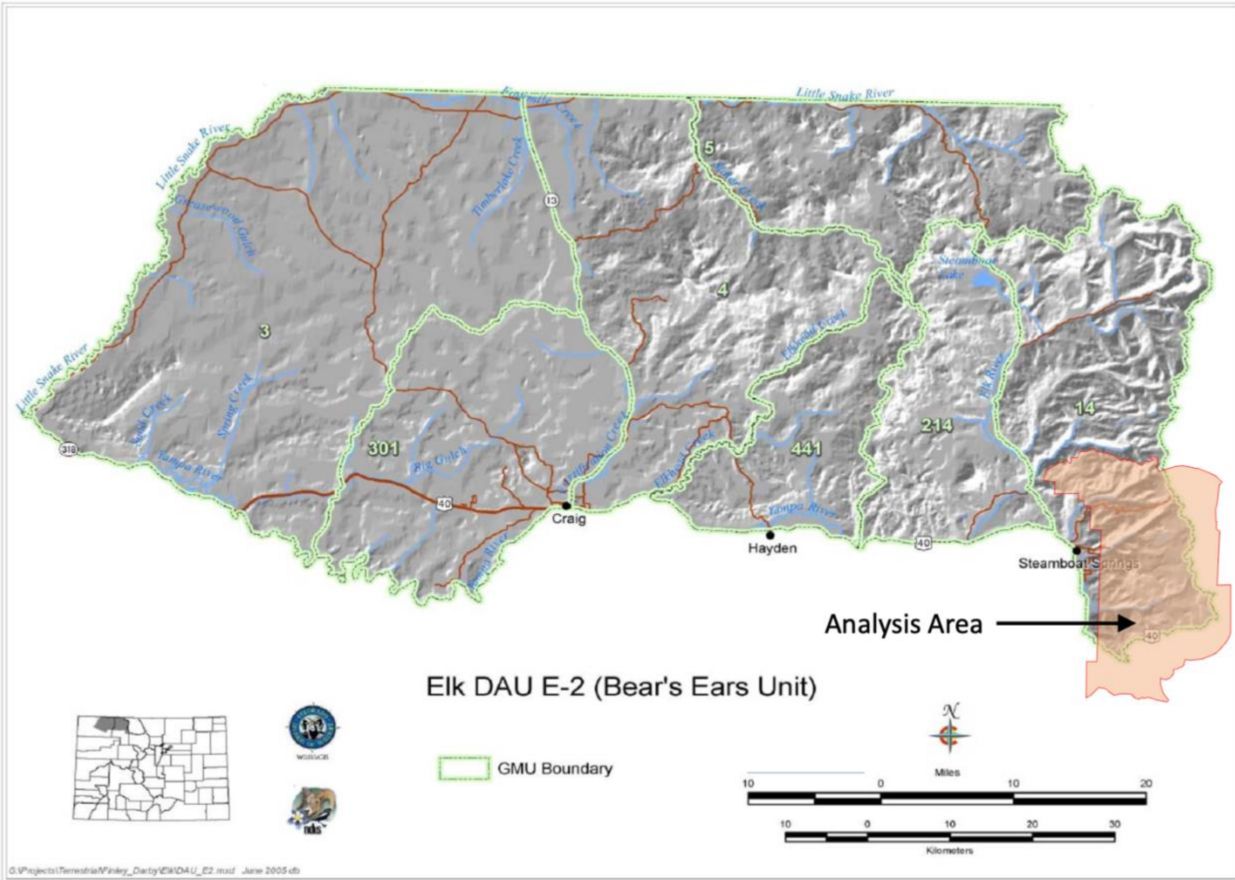


Figure 9 shows the GMU boundaries within the E2 DAU. The analysis area is highlighted.

While most elk migrate to the western portions of the E2 DAU to seek winter range, there is a resident herd that seeks low elevation areas in GMU 14 and 214. This allows the GMU 14 resident elk population and the calf:cow ratio to be measured independently from the greater E2 herd.

There has been a decrease over the past 15 years in both the population of the resident herd and the associated calf:cow ratio. This was documented in an issue paper (page 13) [22] presented to the CPW Commission in November 2021. The population trend graphic below comes from that issue paper, showing the decline in the resident elk population from approximately 750 to 510 individuals from 2006 to 2019. The most recent winter observations classified approximately 400 individuals in the area. The figure below it shows the decline in the calf:cow ratio of both the E2 herd and GMU 14. [23]

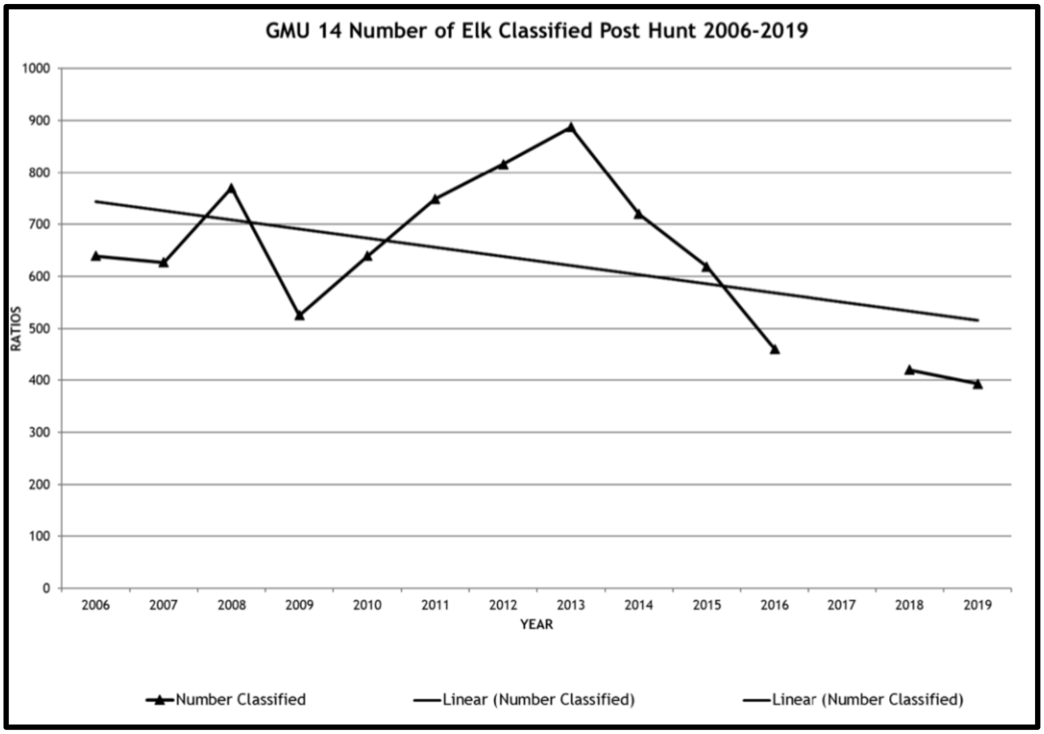
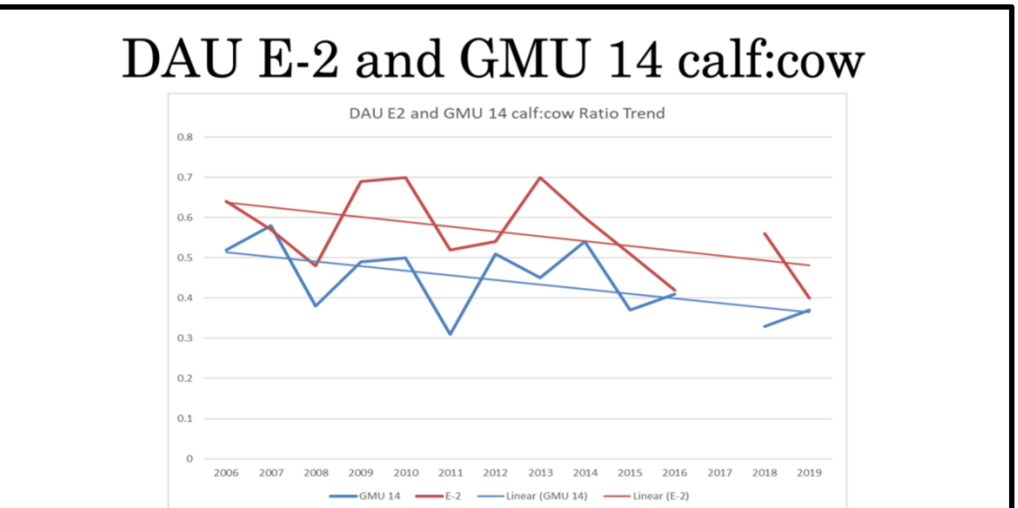


Figure 10 shows the elk population trend of GMU 14. [22]



	Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
GMU 14	calf:cow	0.52	0.58	0.38	0.49	0.5	0.31	0.51	0.45	0.54	0.37	0.41		0.33	0.37
E-2	calf:cow	0.64	0.57	0.48	0.69	0.7	0.52	0.54	0.7	0.6	0.51	0.42		0.56	0.4

Figure 11 shows the calf:cow ratio trend for both E2 and GMU 14. [23]

The issue paper proposed lowering the number of elk tags in GMU 14 and 214. It states, "*Due to the increasing amount of year-round recreation and human presence on the landscape, an increasing trend in archery pressure, decreasing calf to cow ratios and number of elk classified, and citizen feedback,* *Area 10 staff believes that GMUs 14 and 214 should be removed from the valid units included in the EF000U1A hunt code in an effort to relieve some pressure and harvest on cow elk in the residential elk herd.*" [22]

While there is some winter range in the analysis area, our analysis focused on recreational impacts during the non-winter seasons, particularly spring and summer where the analysis region offers elk production areas and elk summer range. Therefore, the analysis focused on spring and summer trail-based activities such as hiking, biking, horseback riding, and ATV use. These activities can lead to habitat compression, fragmentation, and declining habitat effectiveness. The hypothesis is that recreational development and activities in GMU 14 have lowered survival and reproduction success rates from earlier years and from the E2 herd as an aggregate, since the density of recreational development is higher in GMU 14 than elsewhere in the E2 DAU. With lower caloric intake in the summer, the lower body fat levels of elk can make it more difficult to survive the winter months and reduce reproductive success. We test this hypothesis by estimating the loss of habitat and habitat effectiveness in the analysis region and appraising its significance.

4 ANALYSIS

We examined each road and trail in the analysis region and assigned it one of five disturbance models: no disturbance, road/highway, hike, bike, ATV/dirt road. This is shown on the map below.

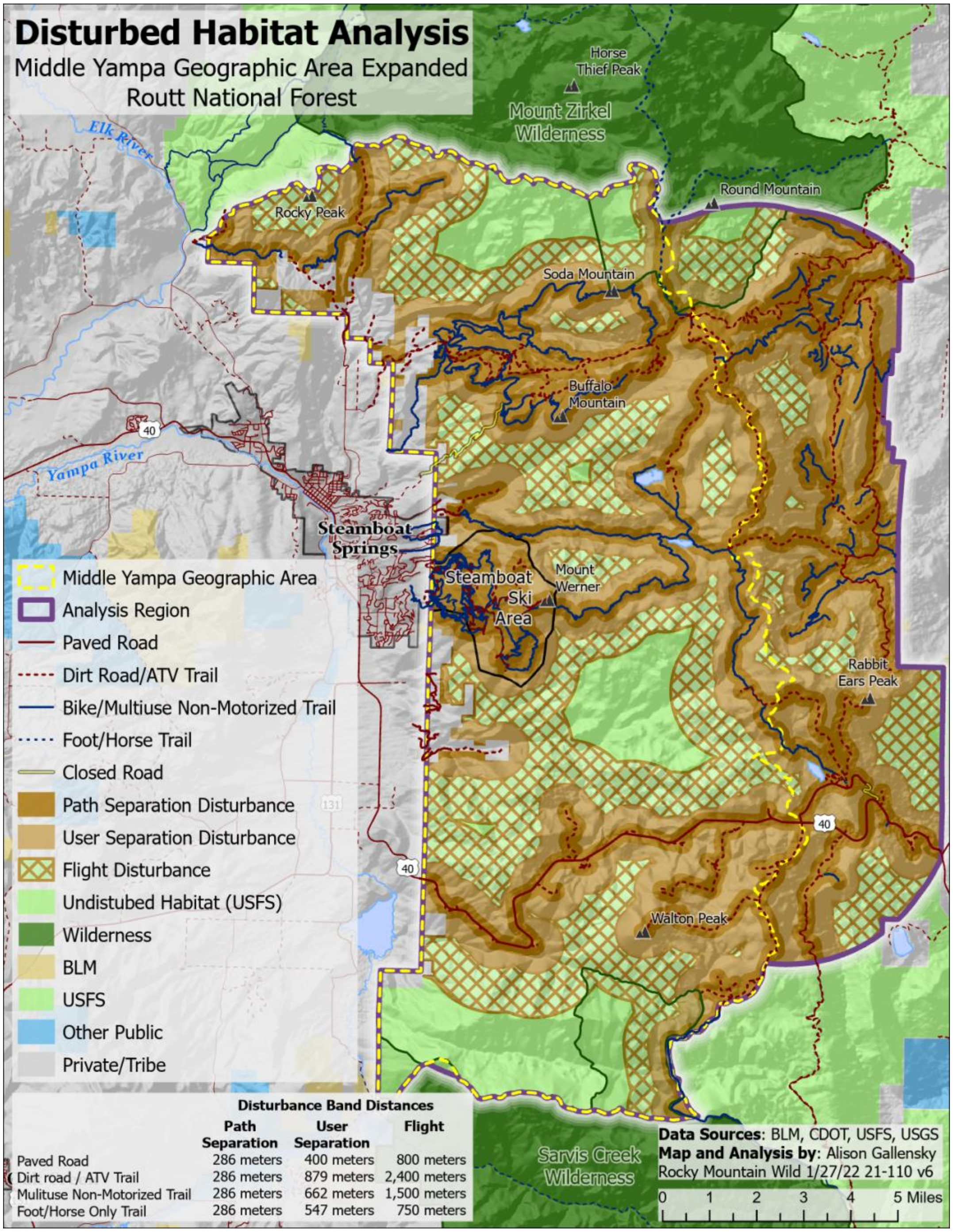


Figure 12 shows the disturbance bands superimposed on the analysis area.

The map shows significant habitat impact near roads and trails, and across much of the analyzed area. There were six areas of undisturbed habit, with significant separation distances between these habitat islands, suggesting a great deal of habitat fragmentation. Of those, three offered significant landscape without disturbance- one in the area north of US40 in the Longs Park Roadless Area, another south of US40 bordering the Walton Creek Roadless Area and the Sarvis Creek Wilderness Area, and the third north of Buffalo Pass Road in the Mad Creek Roadless Area. The latter two are likely larger than shown, as they appear to extend into the Sarvis Creek and Mount Zirkel Wilderness areas respectively, and beyond the analysis area. A small undisturbed area south of Buffalo Mountain is approximately a half-mile square, too small to be meaningful. An even smaller undisturbed area can be found south of the Steamboat Ski Area. A final undisturbed area about one square mile near Round Mountain may also extend further into the Mount Zirkel Wilderness.

The dark brown path separation areas show concentrated areas of trail development. They include the Steamboat Ski Area, the area around Buffalo Pass and Buffalo Mountain, and significant areas east of the Continental Divide. The high degree of trail concentration and disturbance makes these areas problematic for elk migration across these areas, another indicator of potential habitat fragmentation. The Steamboat Ski Area borders with the Steamboat Springs urban boundary to its west, but offers some less disturbed area to the east for elk movement. However, the disturbed areas around Buffalo Pass and east of the Continental Divide extend for many miles and likely create an impediment to elk movement. There is also significant habitat loss and compression due to these two areas.

Quantitative analysis adds more insight to the map. The table below shows quantitative totals for both, the Middle Yampa Geographic Area (MYGA) and the expanded MYGA area.

MYGA ANALYSIS	Acres	Percent of Area
Middle Yampa Geographic Area	**94,700**	
Middle Yampa Geographic Area National Forest Only	**90,140**	100%
Path Separation Disturbance	24,732	27%
User Separation Disturbance	47,602	53%
Flight Disturbance	76,247	85%
Undisturbed Habitat	13,893	15%

MYGA + EXPANSION ANALYSIS	Acres	Percent of Area
Middle Yampa Geographic Area - Expanded		
MYGA + Expanded National Forest Only	**124,515**	100%
Path Separation Disturbance	40,501	33%
User Separation Disturbance	74,256	60%
Flight Disturbance	109,978	88%
Undisturbed Habitat	14,536	12%

Table 3 shows the calculated disturbance impact for the MYGA area and the Expanded MYGA area.

The resulting undisturbed habitat is calculated as 15% (13,893 acres out of 90,140) for the MYGA area and drops to 12% (14,536 acres out of 124,515) for the expanded analysis region. Given that the undisturbed acres are split across six habitat islands, this indicates a significant habitat loss and compression.

Even if flight disturbance is ignored, over half of the analysis area remains disturbed, with 53% of the MYGA region disturbed by user separation disturbance (avoidance of recreationists) and 60% disturbed in the expended MYGA analysis. We presume that a singular averaged disturbance distance is somewhere between the user separation disturbance distance and the flight disturbance distance. In any case, over half of the analysis region is disturbed.

Path separation disturbance totals 24,732 acres (27%) for the MYGA analysis and 40,501acres (33%) for the expanded MYGA analysis. These are a little over half of the equivalent user separation disturbance areas. Due to the volume of trail use in the area, we previously determined that that user separation disturbance is a more meaningful metric for total habitat impact. The value of the path separation disturbance band is the visual indication it adds when multiple trails occur in the same local area, as we noted earlier for the Steamboat Ski Area, the Buffalo Pass area, and the area to the east of the Continental Divide. It may also be a valid metric when performing an incremental analysis, as it is more likely to capture an increased disturbance by one trail in the vicinity of another.

Elk Production Areas

A further analysis consists of superimposing the disturbance bands on top of CPW-indicated elk production (calving) areas and summer concentration areas. These are shown on the following two pages.

The following map shows elk production areas indicated by horizontal hashed blacklines. As stated earlier, flight disturbance can lead to increased elk calf mortality, approximately a 5% probability of mortality per disturbance. The map shows areas of user separation disturbance and flight disturbance significantly overlapping elk production areas. The user separation disturbance band indicates areas with high probability of a flight disturbance, as elk actively avoid recreationists in this band. The flight disturbance band indicates areas where the probability of disturbance is lower, but may still occur.

The most important period to avoid disturbance occurs from May 15 to approximately June 30, when many calves are in their hiding period to avoid predation. Many of the trails in this area are closed through June 15 to mitigate this issue. Other trails may be inaccessible to humans during part of this period due to snowpack. It should be noted that the indicated calving area is a subset of the entire calving area. A CPW GIS definition document states, “Only known areas are mapped and this does not include all production areas for the DAU.” [24]

From those maps we can see that there is significant disturbance of elk calving areas by overlaying the disturbance bands onto the indicated calving areas. This occurs in the US40 area, around Buffalo Pass, some areas around the Steamboat Ski Area, and areas east of the Continental Divide. There is likely deleterious impact to elk productivity, particularly since many trails open June 16.

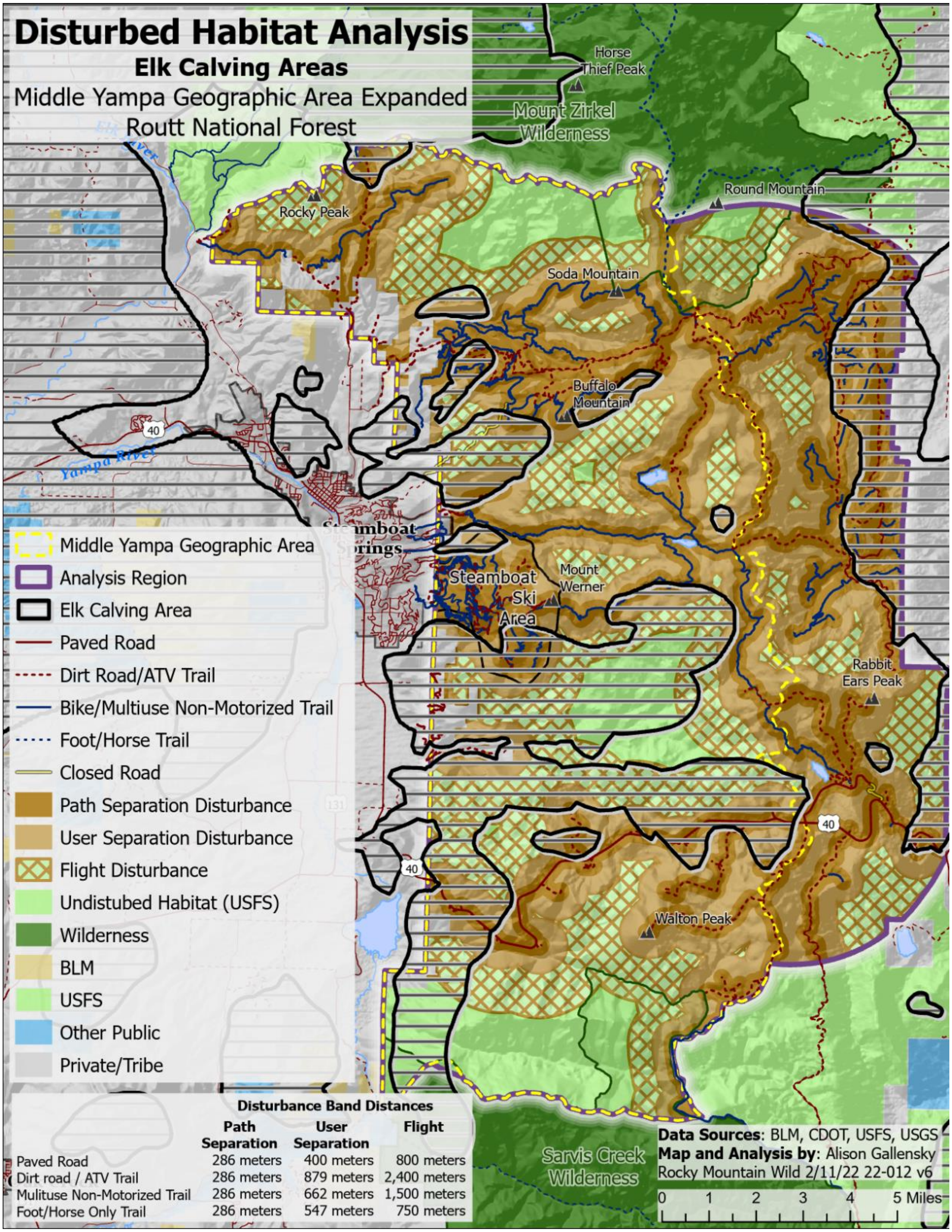


Figure 13 shows the disturbance bands superimposed on elk calving areas.

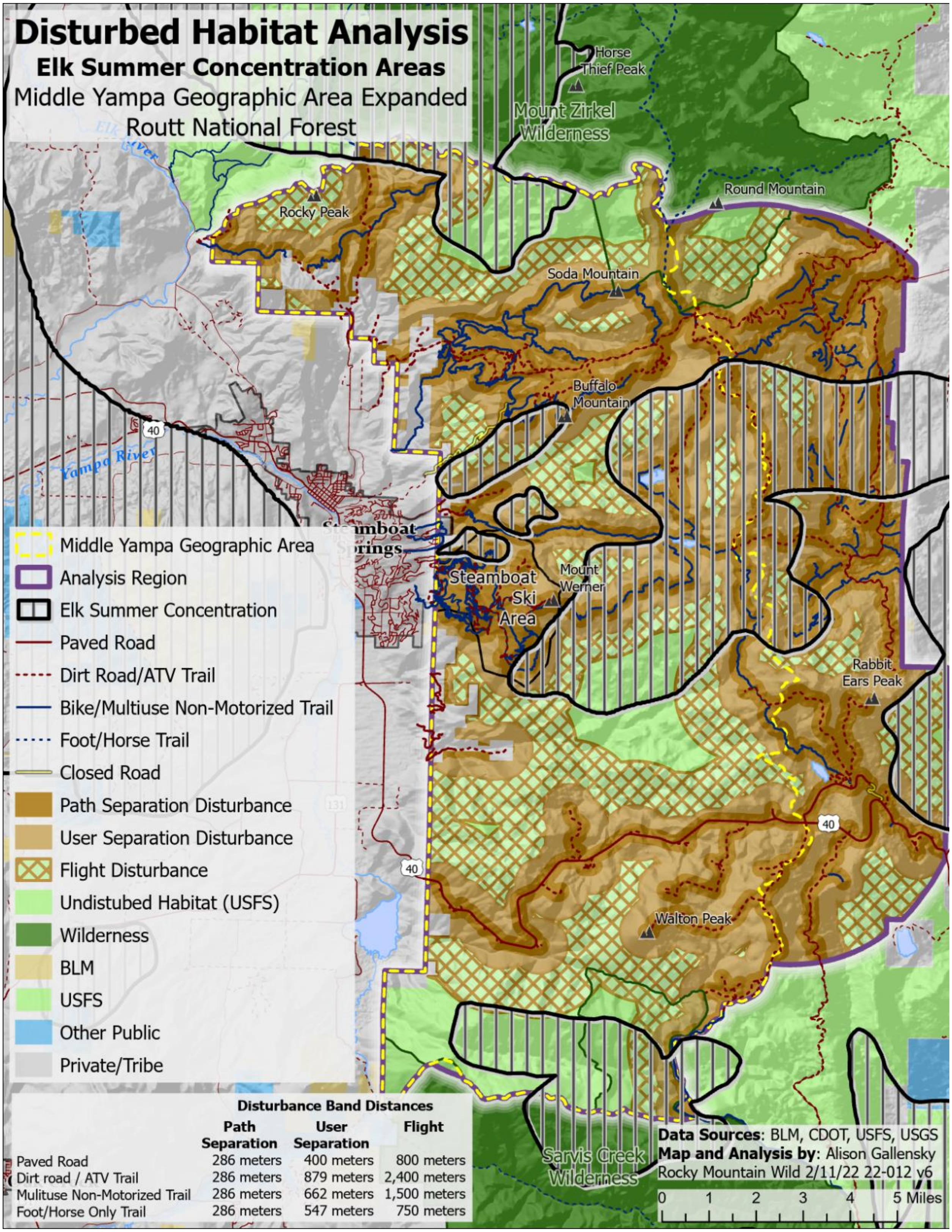


Figure 14 shows the disturbance bands superimposed on elk summer concentration areas.

Elk Summer Concentration Areas

The map above overlays elk summer concentration areas with the disturbance bands. Elk summer concentration areas are those areas where elk concentrate from mid-June through mid-August and are indicated by vertical hash marks. CPW states, "High quality forage, security, and lack of disturbance are characteristics of these areas to meet the high energy demands of lactation, calf rearing, antler growth, and general preparation for the rigors of fall and winter." [24]

Similar to elk production areas, elk summer concentration range is impacted from recreational disturbance. This is true of the summer concentration area to the east of Steamboat Ski Area, and to the north of Steamboat Ski Area towards the Buffalo Pass area. There is a significant area that is less disturbed south of US40. There is also a relatively undisturbed area to the north of Buffalo Pass.

Elk Habitat Disturbance Conclusions

The results show significant habitat fragmentation and loss, with approximately half the analysis area impacted under the user separation disturbance models, and 85% or more impacted using the flight disturbance models. Furthermore, the location of the disturbances shows significant habitat fragmentation.

Reserving the analysis to CPW-indicated elk production and summer concentration areas does not change this conclusion in a meaningful way. Both areas are significantly impacted from recreation disturbance.

We conclude that habitat loss from recreational development in the analysis area is likely to be a significant contributing factor in the declining productivity of the GMU 14 resident elk herd, and possibly for the larger E2 Bear's Ear elk herd.

Alternate Disturbance Bands

The disturbance bands used in this analysis are taken from the Starkey research nominal values. We note that the user separation disturbance and flight disturbance distances were larger than the sight distance at Starkey, which averaged approximately 300 meters. This indicates that elk use additional sensory cues beyond sight. This may include scent, sound, and responding to flight responses of other elk. It is unclear how these responses differ with different forest types or different recreational behavior.

We searched for other disturbance band analyses performed in Colorado forests. We found a 2016 CPW analysis of the City of Avon Trails Master Plan [25] that used a similar technique to determine AOI (Area of Influence). Appendix F (page 53) of that document contains the complete CPW analysis. The CPW assessment includes this paragraph:

"Many of the research projects were designed to assess possible impacts on wildlife from general public recreational use. Most of these projects did not assess the impacts from highly concentrated uses and the treatments were based on a set number of treatments twice per day. While these research projects provide the baseline for documenting impacts to wildlife from off road recreation, they often don't replicate the intense level of use observed on lands surrounding resort areas. The research studies also had clear constraints on what subjects could do during treatments. The majority of studies did not allow the subjects to stop to view or take pictures of wildlife nor were they allowed to follow wildlife. Due to these restrictions these studies may underestimate the actual impact to wildlife from off road recreation. In addition, there is a lack of information on impacts to wildlife from commercial or recreational race events or recreational activities at night."

The CPW analysis chose the following areas of influence for elk:

Pedestrians (hikers): 500 meters both sides of trail.
Mountain bikes: 1500 meters both sides of trail.

Our own analysis used 750 and 1500 meters respectively for flight distance. Since there were very few non-motorized trails in our analysis area that were hiking only (bikes not allowed), we believe adopting these CPW disturbance bands would make little differences in the results. We did not find a CPW disturbance analysis that included motorized vehicles such as ATVs. We did note that CPW recommended that closure periods for elk calving should be May 1 to June 30.

Another alternative to calculate disturbance bands would be to use the flight distance at a set probability of initiating a flight response. We did this for the four activity types by choosing 5% probability of flight at 95% confidence. This is at the outer edge of the disturbance area. In order to insert margin to make the estimate more conservative, a different probability could be chosen. The figure below shows the flight disturbance distance when probability of flight is set at 20%.

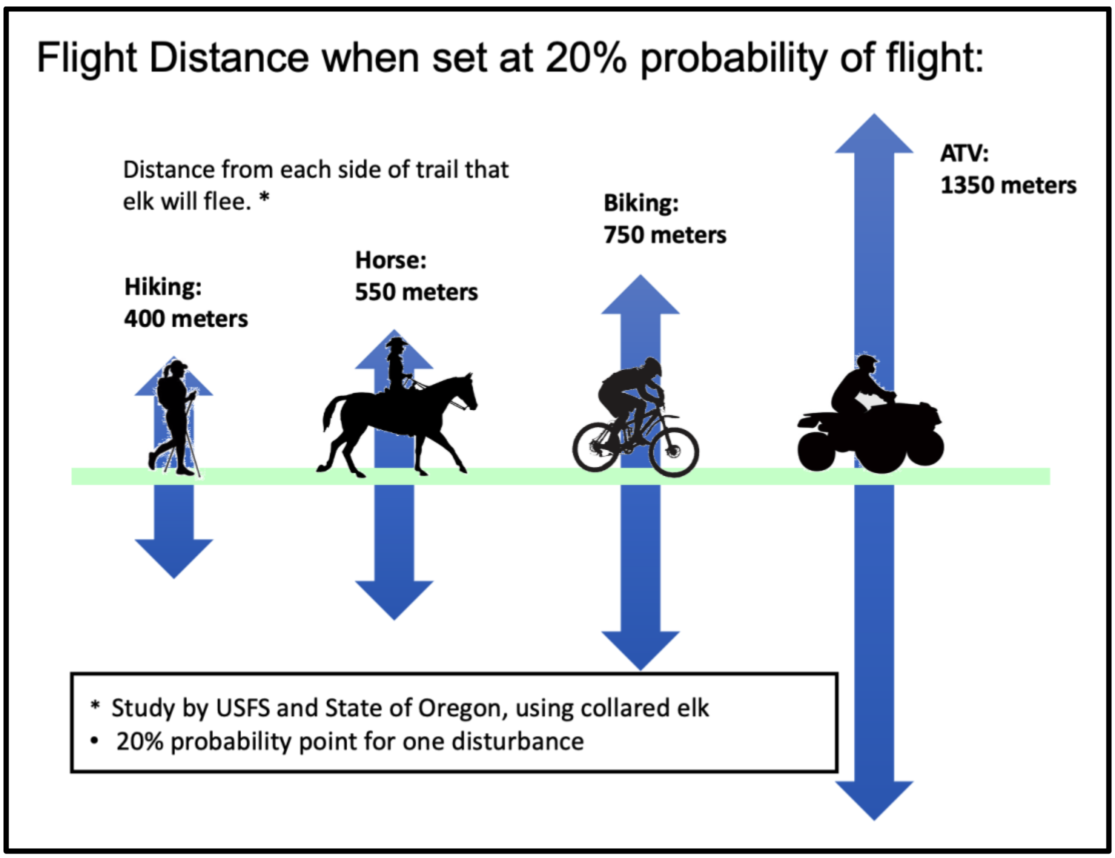


Figure 15 shows the disturbance band width for flight probability of 20%.

The distances for biking and ATV at 20% flight probability fall between our user separation disturbance distance and the flight disturbance distance, are almost identical for horse user separation distance (558m), and are lower than hiking user separation distance. Due to most non-motorized trails in the analysis area allowing bikes, we expect that adopting the 20% flight probability as a single disturbance band would create a disturbance band width somewhat larger than the user separation distance and somewhat shorter than the flight disturbance distance. This would not fundamentally change the results of the analysis, and would also result with the disturbed habitat being significantly greater than 50% of the analysis area.

From these examples, we do not believe small changes to the disturbance band distances will lead to significantly different results.

Elk Habitat Effectiveness

We note that Elk Habitat Effectiveness (EHE) metrics may provide a quantitative measure of the quality of the habitat in the presence of human disturbance.

The Forest Plan [26] articulates a habitat effectiveness metric for each Geographic Area:

"In forested ecosystems, maintain habitat effectiveness for deer and elk at 50% or greater, as measured at the Geographic Area scale."

Habitat effectiveness (HE) is defined as the percentage of usable habitat during the nonhunting season. Early models used crude estimates of road density and cover availability irrespective of their location to estimate habitat effectiveness. Modern methods now use disturbance band analysis superimposed on habitat to calculate HE.

From Effects of Roads on Elk: Implications for Management in Forested Ecosystems (Rowland et al, 2004) [27] :

"*Knowledge has been gained not only about elk response to roads, but also about modeling this relationship. Results from research at Starkey suggested that a road-effects model based on distance bands provides a more spatially explicit and biologically meaningful tool than a traditional model based on road density (Rowland et al. 2000). This analysis, based on more than 100,000 radiolocations of cow elk during spring and summer, found no relation between numbers of elk locations and HE scores based on open road density in 15 elk "analysis units." (We define habitat effectiveness as the "percentage of available habitat that is usable by elk outside the hunting season" [Lyon and Christensen 1992:4].) However, elk preference increased strongly (as measured by selection ratios) as distance to open roads increased. Such distance-to-roads analyses are readily accomplished using widely available spatial data layers in a GIS.*"

Further in the study:

"*A method to evaluate effects of roads on elk using a distance-band approach has been suggested both by Roloff (1998) and by Rowland et al. (2000), as described above. Based on radiolocations of elk at Starkey, Rowland et al. (2000) found no relation between number of elk locations and HE based on open road densities. By contrast, the authors found a strong, linear increase in selection ratios of elk as distance to roads increased. For this analysis, elk locations were assigned to 109-yard (100-m) wide bands away from open roads. Roloff (1998) also developed a road-effects module in which habitat adjacent to roads was buffered into distance bands in a GIS. Habitat effectiveness in the bands was adjusted according to level of security cover, as well as road use or road type.*"

The paper above articulates a more accurate method of calculating HE that considers the spatial relationship of elk to open roads. Since the method uses disturbance bands and distance from roads, the same method can be extended for trails.

The calculation of HE is beyond the scope of this analysis. However, the disturbed landscape percentage across the entire MYGA of 53% for avoidance bands and 85% for flight bands suggests that the HE may be below the 50% Forest Plan metric. A proper HE analysis, using modern methods and disturbance bands, should be performed across the Middle Yampa Geographic Area.

5 SUMMARY

This paper documents using disturbance bands to analyze the impact from trails and roads on elk and elk habitat. The summary is in two parts- the use of this technique for evaluation of the impact of recreational disturbance onto elk, and observations of the results of this analysis on elk and elk habitat in the Medicine Bow Routt National Forests.

Summary of using activity-based disturbance models

The analysis itself can be performed with standard GIS tools. The disturbance distances derived from the Starkey studies give three disturbance distances- two separation distances based on low or high usage, and a flight distance. We found that using these three disturbance distances with appropriate colors and patterns can communicate disturbance intensity with spatial distribution to a viewer of a map without undue complexity. We found that this choice of colors and patterns was intuitive to many viewers.

We also found that using selected colors and dashed patterns together can distinguish the different types of paths and the activities presented. We found that some viewers cannot distinguish path type based on color alone, and that some color patterns are difficult to distinguish.

We found that most trails and roads can be easily assigned an activity with the appropriate disturbance bands depending on what their authorized use is. However, for a few trails or roads it was necessary to modify their principal activity or eliminate the disturbance bands completely to reflect their actual use. This operation is best performed by including reviewers knowledgeable about the area.

This technique does not always show incremental disturbance. That is, it does not always indicate an area of having higher disturbance due to disturbances from multiple trails or roads. This may be lead to developing a new technique for incremental analyses. The path separation disturbance model may be a component of this.

Overall, we find that the analysis technique leads to maps that convey habitat disturbance in a very intuitive way, both quantitatively and spatially.

Summary of analysis of Medicine Bow Routt National Forest

This analysis shows that there is likely significant impact from recreational use to elk and elk habitat in the analysis area. To this point, the analysis shows significant habitat reduction, compression, and fragmentation in the analysis area of Medicine Bow Routt National Forests.

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