GRIZZLY BEARS AND HUMANS AT TWO MOTH AGGREGATION SITES IN WYOMING

by

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DEDICATION

I dedicate this thesis to Fred Thomas and his wife Kay. Fred is a multi-generational Wyoming rancher with an unusual bear problem, a reputation that preceded him. As soon as I mentioned my southern study site folks throughout Park County would say, “Have you met Fred yet?” Well, I finally met Fred and we hit it off. He has spent a lifetime at our southern study site watching the bears and climbing the peak. He provided valuable insight only someone who has climbed the peak as many times as he has could. If the area needed to be renamed, I believe “Fred’s Shangri-La” would be suitable. He has shared videos and pictures with me, he and Kay have fed me many dinners, taken me mountain lion hunting. Thank you, Fred and Kay!

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ABSTRACT

Human interactions with grizzly bears at moth sites is an important management issue because of the potential for displacing bears and the implications for human safety. The objective of our study was to quantify human and bear use overlap and interactions associated with two of the most human-accessible moth sites in the Greater Yellowstone Ecosystem. Our field work was conducted during the summers of 2017 and 2018. We conducted systematic bear surveys and analyzed the data using a resource selection function. Human use was quantified through trailhead monitoring, peak log entries, and opportunistic documentation. Hiking route data were collected using GPS tracking units distributed at trailheads. Human-bear overlap was assessed by comparing human and bear use and validated against interaction location data. We conducted 293 surveys and documented 266 bear locations. Landscape covariates describing temperature, moisture, terrain, and landcover were important to grizzly bear use. We recorded very different human use levels between the two study sites (North site: 3 groups/year; South site: 35 groups/year). Human use at the North site was dispersed and associated with hunting and use at the South site was most often associated with peak climbing and/or bear viewing and was concentrated along one primary route to the peak. We documented a total of 43 interactions (at the South site only) and obtained location data for 29 of those interactions. During human-bear interactions, bears strongly avoided human presence 80% of the time and had no apparent reaction 20% of the time. Most interactions occurred immediately around the South site peak (14/29) or along the primary route (12/29), areas that we identified to have high human and bear use overlap. We confirmed significant human safety and bear disturbance management concerns. Human safety concerns were most apparent in uneducated, and consequently unprepared, mountain climbing groups with small groups sizes (<4 people, n=64/70). Bear disturbance concerns were apparent from numerous interactions that resulted in bear displacement. Overall, we suggest that the concern expressed by managers over human and bear use overlap at the South site is warranted. Mitigation efforts should be explained in a management plan.

CHAPTER ONE

LITERATURE REVIEW

Army Cutworm Moth Life History and Alpine Aggregations

The army cutworm moth (*Euxoa auxiliaris*) is a migratory noctuid moth native to North America (Pruess 1967, French et al. 1994, Capinera 2001). The army cutworm moth has an expansive range centered on the Rocky Mountains extending from Canada to Mexico (Figure 1; Burton et al. 1980). Within its range, these moths migrate between high and low elevational habitats where they play two distinct ecological roles throughout a one-year life cycle (Chapman et al. 1955, Burton et al. 1980, French et al. 1994).

Most of the year (November-April) army cutworm moths are found in low elevation agricultural areas throughout the Great Plains and Intermountain West as developing larvae (Burton et al. 1980, Kendall 1981). Adult moths reproduce, oviposit eggs on disturbed soil early autumn, and subsequently die leaving the larvae to develop throughout the winter (Figure 2). Larval development starts immediately and progresses through seven instars as larvae feed above ground on leaves and stems of many emerging agricultural crops. Years with favorable weather conditions produce sporadic outbreaks that can be economically devastating and result in pesticide management. Outbreaks are infrequent, however, and low densities of the moth cause minimal crop damage so their presence is typically tolerated throughout their natal range (Burton et al. 1980).

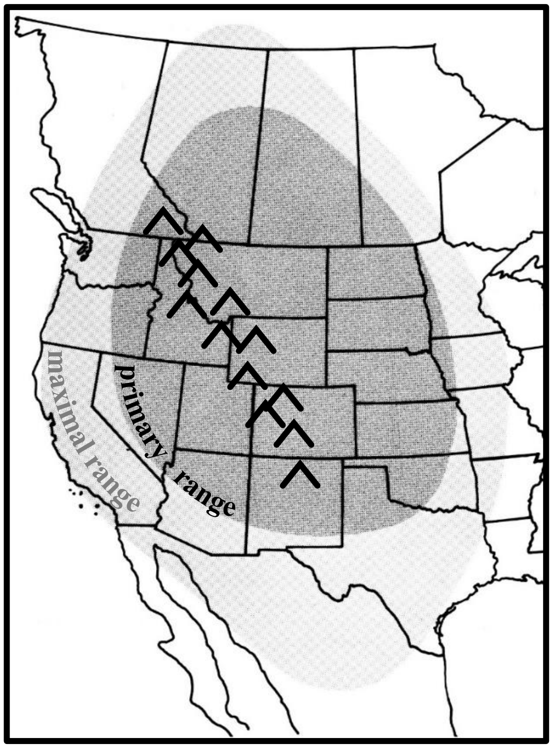

Figure 1. Army cutworm moth range, adapted from Burton et al. (1980)

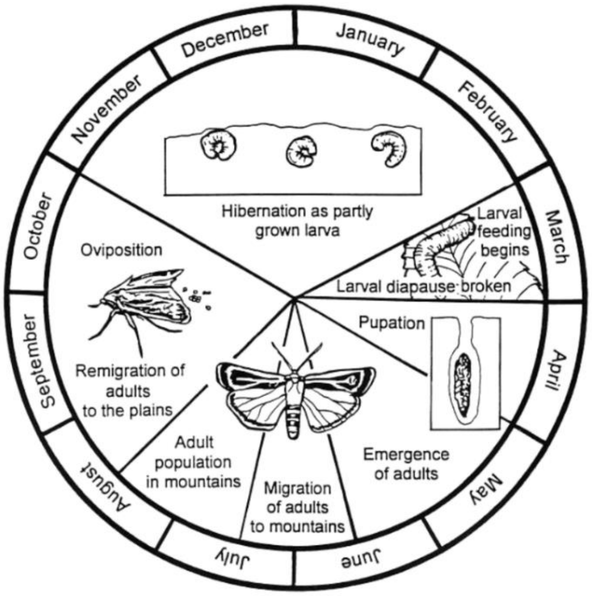

Figure 2. Army cutworm moth life history. Taken from White (1996), originally modified from Kendall (1981)

Fully grown larvae burrow into the soil, pupate, and emerge as fully-grown adult army cutworm moths in the spring (April – June, depending on latitude). Within two weeks of emergence, the adult moths undergo mass migration to the Rocky Mountains (Burton et al. 1980). Army cutworm moths cannot withstand the high summertime temperatures at low elevations and migration is thought to occur as they seek thermal refugia at high elevations (Pruess 1967, Burton et al. 1980).

At high elevations, army cutworm moths actively feed on alpine flowers at night and retreat in large aggregations to the interstitial spaces of talus during the day (Kendall and Kevan 1981, White et al. 1998*a*). As nighttime pollinators, army cutworm moths feed on a large variety of alpine plants and can increase their body fat from 13% to 83%

throughout the season (O’Brien and Lindzey 1994, Kevan and Kendall 1997, White et al. 1998*a*). This dramatic increase in body fat is fuel for migration back to low elevations and reproduction (White et al. 1998*a*). Fattened army cutworm moths start leaving high elevations mid-August (Pruess 1967, Kendall 1981). Fall migration consists of fewer individuals than spring migration and moths do not necessarily return to where they originated (Pruess 1967, Byers et al. 1987, Robison 2009)

The moths aggregate within talus because it provides a favorable microclimate with protection from the elements and predators, increased moisture, and decreased fluctuations in temperature. These factors allow the moths to self-regulate temperature by moving up or down in the talus layer and provide a buffer against desiccation at these high, arid, and windy sites (Mani 1968, White et al. 1998*a*). Selection for these optimal microclimates results in large aggregations of moths within a talus slope, and typically multiple large aggregations on one massif (O’Brien and Lindzey 1994).

Moth aggregation sites are typically found in areas where the geology and terrain result in talus formation and accumulation, such as cirques or drainages immediately below large headwalls or rocky outcrops (Mattson et al. 1991). Aggregation site characteristics vary in slope, elevation, talus formation, and aspect. Slope has been documented to range from 10-60°, but most commonly between 30-40° (Mattson et al. 1991, French et al. 1994, White 1996). Talus formation largely depends on local geology and studies have documented a range in composition. Talus has been described as uniform or nonuniform, angular, sometimes rounded, and ranging between 2-200cm in diameter (Mattson et al. 1991, French et al. 1994, White 1996). Elevation has been documented to range between 2141m and 3680m (Mattson et al. 1991, French et al. 1994, White 1996). Moth aggregations have been documented on all aspects, but more often face south and west than north and east (Mattson et al. 1991, O'Brien and Lindzey 1994, White 1996, White et al. 1998*b*).

Conservative moth density estimates at aggregation sites have been measured to be up to 178 moths per square meter of surface area (White et al. 1998*a*). Depending on latitude, peak moth abundance generally occurs mid to late July and often varies year to year (O'Brien and Lindzey 1994, White et al. 1998*a*, Robison 2009). Size and distribution of moth aggregations throughout the Rocky Mountains is poorly understood but generally seems to be tied to favorable geology. Talus aggregations have been documented in New Mexico, Colorado, Wyoming, and Montana and 'blizzards' of E. auxiliaris have been recorded at high elevations with light traps in Nevada (Chapman et al. 1955, Kendall 1981, Mattson et al. 1991, Coop et al. 2005, Seymour and Jensen 2014). Work by Robison (2009) created predictive models to identify potential moth aggregation sites throughout the Greater Yellowstone Ecosystem (GYE) and current work in Glacier National Park is also employing a modeling approach to help catalog moth aggregation sites (Erik Peterson, personal communication).

Although comprehensive knowledge on the distribution of moth sites throughout the Rocky Mountains is foundational to understanding the species, work has largely been focused in Montana and Wyoming due to a management emphasis on an unlikely predator, grizzly bears (*Ursus arctos horribilis).* The fat-filled army cutworm moths are equivalent to about 0.5 kcal (1 kcal = 1 Calorie) each and have been documented as a particularly important food source for grizzly bears, a species of conservation concern in North America (Klaver et al. 1985, Mattson et al. 1991). Although they have received less attention, a host of other species have been documented foraging on the army cutworm moths as well, including: black bears (*Ursus americanus),* ravens (*Corvus corax*), coyotes (*Canis latrans*), Clark's nutcrackers (*Nucifraga columbiana*), American pipits (*Anthus rubescens*), mountain bluebirds (*Sialia currucoides*), gray-crowned rosy finches *(Leucosticte tephrocotis*), black rosy finches (*Leucosticte atrata*), bats, mice, mustelids (species not identified), and wolf spiders (*Lycosidae*) (French et al. 1994, O'Brien and Lindzey 1994, White et al. 1998*b*, Robison 2009).

Grizzly Bears and the Importance of Moth Sites

Grizzly bears are an iconic large carnivore in North America. As with many species, grizzly bear populations realized significant declines with the advent of European colonization (Mattson et al. 1995, Schwartz et al. 2003). They were listed as a threatened species in 1975 after being extirpated from 98% of their range in the contiguous United States (Mattson et al. 1995). Successful recovery efforts due to the listing have contributed to an increasing and expanding population in the GYE (White et al. 2017, Bjornlie and Haroldson 2018*a*). Current population estimates within the Demographic Monitoring Area, 14.3 million acres including Yellowstone National Park (YNP) and the surrounding area, report at least 714 individuals , an estimate that is likely much lower than reality due to biases associated with the current population estimation techniques (Figure 3) (White et al. 2017, VanManen and Haroldson 2018).

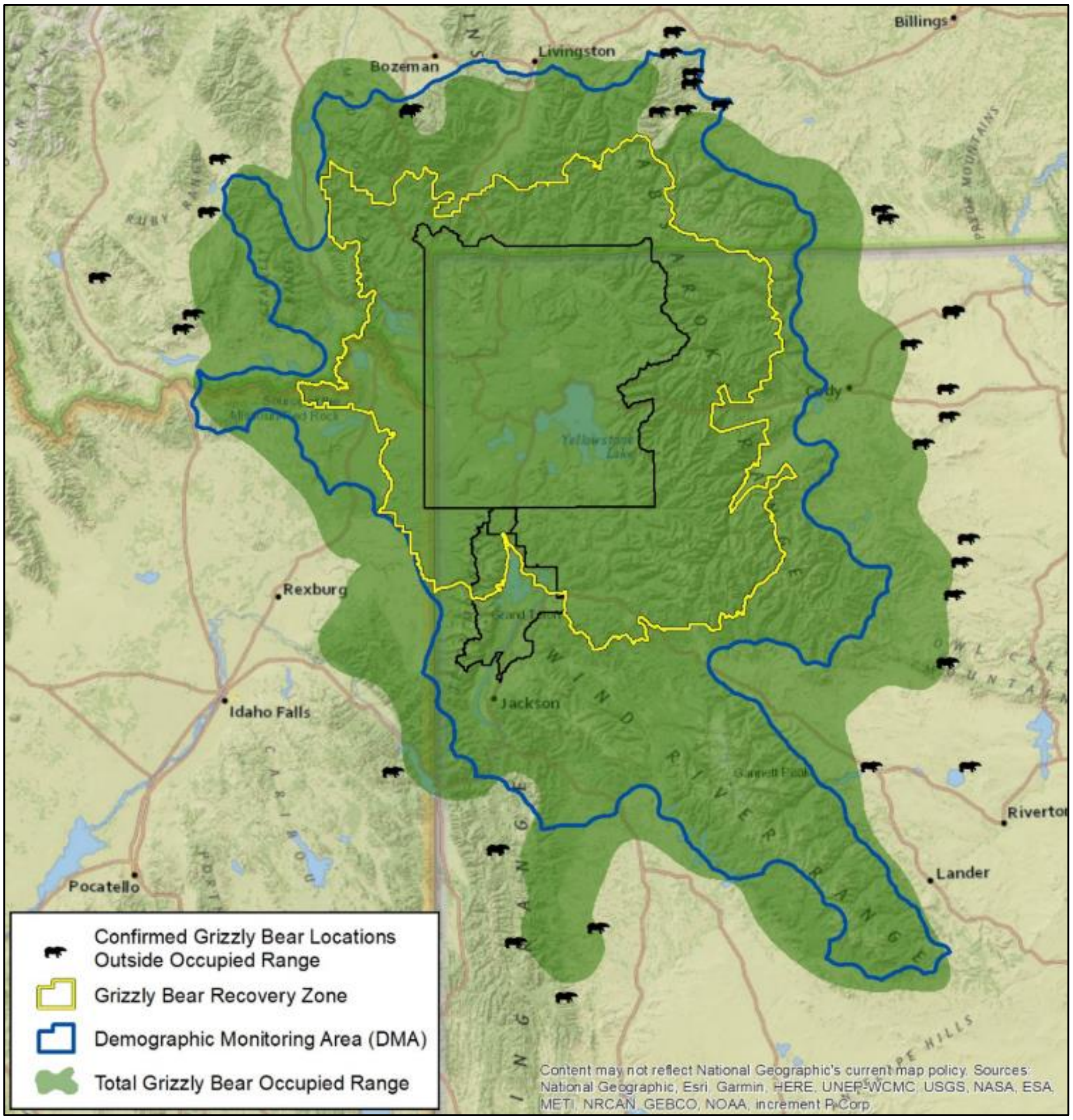

Figure 3. Grizzly bear range, demographic monitoring area, and recovery zone in the Greater Yellowstone Ecosystem, North America. Taken from Bjornlie and Haroldson (2018)

The availability of key grizzly bear foods has been shown to be important to reproduction and survival in the rebounding GYE population (Mattson et al. 1992, Schwartz et al. 2005). Key foods in the GYE, identified by their high caloric value and availability during important feeding periods, include white bark pine seeds (*Pinus* *albicaulis*), army cutworm moths (*Euxoa auxiliaris*), ungulates (scavenged and neonate prey), and, more historically, spawning cutthroat trout (*Oncorhynchus clarkii*) (Schwartz et al. 2003, 2005, IGBST 2013). Grizzly bears are classified as opportunistic omnivores, however, and have a much broader diet (Gunther et al. 2014). They have been documented to forage on at least 266 foods in the GYE including a wide variety graminoids, forbs, and root crops (Schwartz et al. 2003, Gunther et al. 2014). Importantly, dietary plasticity allows grizzly bears to maximize their foraging capacity and access alternative food sources when key diet items are in low abundance or unavailable (Gunther et al. 2014).

Of the key grizzly bear foods listed, army cutworm moths have clearly been identified as important in the GYE but remain one of the least understood facets of grizzly bear ecology (Mattson et al. 1991, Bjornlie and Haroldson 2018*b*). Army cutworm moths are available to grizzly bears from July through mid-September, overlapping with the beginning of fall hyperphagia (Kendall 1981, French et al. 1994, O’Brien and Lindzey 1994, Bjornlie and Haroldson 2018*b*). Not only are they available in abundance during this important feeding period, they have been documented to contain the highest gross energy per gram (7.91 kcal/g) of any other food source in the GYE (French et al. 1994, White et al. 1998*a*). Grizzly bears have been estimated to eat up to 40,000 moths a day, equivalent to nearly 20,000 kilocalories (White et al. 1999). It has been estimated that a grizzly bear spending an entire month foraging at a moth site could meet nearly half of its annual energetic needs (Sizemore 1980, White 1996). In addition to moths, several studies have documented bears foraging vegetation around moth sites as well (French et al. 1994, O’Brien and Lindzey 1994). This may provide an additional food source at moth sites, available when moths are less abundant or unavailable (e.g., before seasonal arrival or out foraging nectar). Although moth sites are clearly important, relative importance to other key foods and the extent to which the GYE grizzly bear population as a whole uses them is unknown. Key questions like these remain largely because of the inherent difficulties of acquiring data at these remote and high elevation sites and more recent scientific discovery.

Historical bear use of moth sites prior to European colonization remains unknown and there is some speculation on whether the advent of widespread agriculture in the western United States may have affected moth abundance and subsequently bear foraging (O’Brien and Lindzey 1994). First reports of the foraging behavior are from 1924 in northwestern Montana (Klaver et al. 1985). Since then, it has been scientifically documented throughout the Rocky Mountains ranging from black bears in New Mexico to grizzly bears throughout the GYE and Northern Continental Divide (NCD) ecosystems (Chapman et al. 1955, Mattson et al. 1991, White et al. 1998*b*, Coop et al. 2005). It was not scientifically documented in the GYE until 1986 during routine radio telemetry flights conducted by the Interagency Grizzly Bear Study Team (IGBST) (Mattson et al. 1991). However, interviews conducted by French et al. (1994) indicate that local outfitters may have observed the foraging behavior since at least the early 1950’s. It has been suggested that delayed scientific documentation was largely due to the fact that most grizzly bears were instead foraging at garbage dumps in Yellowstone National Park before they were closed in the 1970’s (O’Brien and Lindzey 1994). Other reasons may include low population numbers and legal hunting prior to 1975; these sites are very exposed, and any human-wary bear would likely avoid such exposure (French et al. 1994, O'Brien and Lindzey 1994).

Since initial discovery in the GYE, management agencies have confirmed 31 moth site complexes with confirmed foraging behavior and 21 other possible moth site complexes with inconclusive bear use (Bjornlie and Haroldson 2018*b*). The confirmed moth sites occur throughout the Absaroka Mountains, Wyoming, spanning two national forests (Shoshone, Bridger-Teton), three wilderness areas (Washakie, North Absaroka, Teton), Yellowstone National Park, and the Wind River Indian Reservation (IGBST 2018).

Because confirmed moth sites only occur in a portion of the GYE, it is uncertain to what extent this food source is available to grizzly bears. Currently, there is a lack of published information indicating whether bears using moth sites generally have home ranges overlapping that part of the GYE or whether some make long distance movements to access moth sites. Regardless, routine observation flights have recorded an increase in bear use at these sites since discovery in the 1980's (Bjornlie and Haroldson 2018*b*). A study in the early 1990's estimated that up to 44% of the GYE grizzly population utilized these moth sites, including around half of known sow and cub groups (O'Brien and Lindzey 1994). However, grizzly bears have high sightability at moth sites compared to other habitats, likely inflating that estimate (O'Brien and Lindzey 1998, Robison 2009, Bjornlie and Haroldson 2018*b*). In comparison, the IGBST has recorded 1,227 unique females with cubs since 1986, 347 (28.3%) of which have occurred at or near moth sites (Bjornlie and Haroldson 2018*b*).

Bear Viewing Tourism, Human Use at Moth Sites, and Management Concerns

Bear viewing is an increasingly popular recreational activity in North America (Herrero et al. 2005, Fortin et al. 2016, Penteriani et al. 2017). Although the revenue and interest generated through bear viewing ideally fuels conservation for the species, it is important to understand that human presence can have negative impacts as well through disturbance, habituation, habitat degradation, and conflict (Fortin et al. 2016, Penteriani et al. 2017). Recognizing the economic and ecological importance of most bear viewing areas, managers are often put in a difficult place balancing the two along with public safety concerns (Fortin et al. 2016).

Opportunities to view and photograph this large, charismatic carnivore are typically focused where bears congregate around highly abundant food sources such as spawning salmon in Alaska or, historically, garbage dumps in Yellowstone National Park (Herroro et al. 2005, Penteriani et al. 2017). Moth sites have the potential to provide a similar viewing opportunity but have remained relatively unknown for several reasons. For one, moth sites are generally inaccessible to most people because of the physical demand needed to access the sites. Secondly, management agencies have kept the phenomenon low-key recognizing the sensitivity of foraging bears at moth sites and potential impacts from human interest (O’Brien and Lindzey 1994).

Interest in viewing bears on moth sites started in the early 2000s, most notably from professional media organizations such as the British Broadcasting Corporation (BBC 2006). Since then, some additional interest has spread, mostly by word-of-mouth, but location-specific information has remained unavailable to the general public. As word spreads and outdoor tourism continues to increase, it is inevitable that human interest in viewing bears at moth sites will increase (Fortin et al. 2016). Consistent with other areas where bear viewing tourism at ecologically important grizzly bear sites exists (i.e. salmon runs), there is an inherent responsibility for managers to establish proactive human-bear management plans (Penteriani et al. 2017).

This is easier said than done, however, because there is a general lack of literature specific to human use at moth sites with management recommendations. The two studies that are available highlight site-specific differences in human use while identifying fundamentally similar management concerns (Klaver et al. 1985, White et al. 1999). Both studies were primarily concerned with unaware mountain climbing groups, not bear viewers, traveling through moth sites to reach a summit.

The Klaver et al. (1985) study took place on McDonald Peak in the Mission Mountains, Montana, within the Flathead Indian Reservation. This moth aggregation site was documented to have been used primarily by bear family groups (~ 10 individual bears a year) and deemed critical habitat for bear conservation. McDonald Peak also happens to be one of the most scenic peaks in the Mission Mountains and is relatively easy to access. As a result, climbing use increased from essentially zero in the 1950s to 8-10 groups a week in 1980 and several human-bear interactions were reported.

The second study, White et al (1999), took place at moth aggregation sites in Glacier National Park (GNP). Although human use at moth sites in this study was far less than at McDonald Peak, researchers also documented human safety and bear disturbance concerns associated with human climbing groups. They quantified bear disturbance by performing an activity budget analysis comparing bear activities before and after being disturbed by climbers. They observed grizzly bears spending 53% less time foraging moths due to disturbance by climbing groups and more time moving or acting aggressively. They estimated that grizzly bears can eat about 2500 moths an hour, so displacement for even one hour could cost more than 1000 kilocalories, and that is without taking into account the calories lost during displacement. If the same bears are repeatedly disturbed, this could have negative cumulative effects for individuals. Additionally, they noted that all the hiking groups seemed to be unaware of the foraging grizzly bears which brings up concerns regarding group preparedness and safety (White et al. 1999).

Both these studies clearly illustrate human safety and bear disturbance management concerns, however, habituation was an additional concern identified by Klaver et al (1985) and others (Jope 1985, O’Brien and Lindzey 1994, Herrero et al. 2005). Habituation is the gradual decline in response by bears to a repeated exposure to humans with no negative consequences. Habituation in bears is most commonly a concern in areas with high levels of human use, such as roadways or developed areas (Jope 1985, Herrero et al. 2005). Habituation is often documented in less dominant cohorts (i.e. subadults, sows with cubs) choosing to forage closer to humans rather than near more dominant bears (Penteriani et al. 2017). Although this may allow the less dominant bears to gain access to important food sources for a time, it becomes concerning if those bears travel to areas with low grizzly bear tolerance (i.e. agricultural or residential areas) (Klaver et al. 1985). This is because human habituated behavior often results in human-bear conflicts or bear mortality. (Schwartz et al. 2005, White et al. 2017, Haroldson and Frey 2018). It is important to note that although there may be very real habituation concerns associated with human and bear use overlap at moth sites, it could be difficult to distinguish from general indifference to human presence due to the surfeit of food and an already increased tolerance to other bears (Egbert and Stokes 1976, Herrero et al. 2005).

Despite the clear human safety, bear disturbance, and habituation management concerns associated with human use at moth sites, subsequent management actions were very different between the two human-bear moth site studies. In response to Klaver et al. (1985), the Confederated Salish and Kootenai Tribal Council established a perennial area closure mid-July through October 1 (Klaver et al. 1985). Although they were concerned about public response to the closure of the scenic peak, the general public were very supportive of the closure wanting to avoid harmful human-bear interactions (Klaver et al. 1985). In response to White et al. (1999), despite a call for careful management of these important foraging sites, the GNP moth sites remain without specific restrictions to human access.

The differences in outcomes reflect the management flexibilities across agencies but also the level of management concern at different moth sites. Of the two studies, White et al (1999) is more representative of what is likely occurring at most confirmed moth sites. Dozens of other moth sites throughout the GYE and NCDE are identified but human usage has not been well documented, presenting a quandary for managers. With the only extant example of management being complete closure, an action probably unnecessary and impractical for most moth sites, managers are left with little feedback on other management options.

A range of management options have been discussed but applicability is site specific. For managers to understand which options are realistic for known moth sites under their jurisdiction, some level of field reconnaissance and baseline understanding of human use must first be established. As discussed primarily in O’Brien and Lindzey (1994) potential management options, arranged from least to greatest management action, might include:

- No management. This is currently the situation at most moth sites but largely due to lack of information rather than widespread appropriateness. Areas where this will likely remain appropriate are inaccessible moth sites with no maintained trails nearby or additional attractions (hunting or peak climbing) (O’Brien and Lindzey 1994).
- Education. With the recognition that other uses exist around moth sites (hunting, backcountry travel, peak climbing), education may be a desirable tool to improve public understanding of the importance of moth feeding sites as well as potential public safety issues. Education could take several forms including trailhead kiosks, warning signs, educational talks, or increased agency presence at

trailheads. As discussed in Klaver et al. (1985), education acted as indirect discouragement with most groups preferring to avoid possible confrontation with bears and ultimately no longer wishing to visit the area (Klaver et al. 1985, O'Brien and Lindzey 1994).

- Indirect discouragement of human use. For moth sites with trails routed through or near them, management agencies could consider discontinuing trail and/or access road maintenance and removing designations on maps. O'Brien and Lindzey (1994) suggested that creation of new trails or maintenance of existing trails should be prohibited within 5 air km of moth sites used primarily by sows with cubs. This would be particularly applicable when said trails or roads are already in disrepair with low levels of use (O'Brien and Lindzey 1994).
- Re-routing trails or re-directing traffic. For moth sites with trails going through or near, and with popular human use unrelated to grizzly bears (i.e. passes), managers might consider rerouting trails to minimize human and bear overlap. If there are alternatives that already exist, management agencies might consider redirecting traffic away from the moth sites. These options would be appropriate for moth sites where alternative routes exist or management agencies have the man-power and funding to create alternative routes (O'Brien and Lindzey 1994).
- Access management under a permit system. Management agencies might consider regulating human access to moth sites by using a permit system. This strategy could be easily combined with education and routing traffic to good viewing areas or the best routes to minimize bear disturbance and human-bear interactions.

- Establish bear viewing areas. Although discussed by O'Brien and Lindzey (1994), it was an unrecommended management action because it sets a dangerous precedent and a designation difficult to remove into the future. They note that most potential viewing areas are too close to the moth foraging sites and any short-term economic gains would be far outweighed by the negative impacts of bear viewing (O'Brien and Lindzey 1994).
- Seasonal closures. The reality of implementing a seasonal closure will highly depend on the management agency but might be considered in areas where no human and bear use overlap is acceptable. This management action was implemented by the Confederated Salish and Kootenai Tribal Council for the McDonald Peak moth site (Klaver et al. 1985). Despite concerns about the public reaction to the seasonal closure, they observed a very reasonable response where most groups were happy to avoid human-bear encounters.

Project Justification in the Greater Yellowstone Ecosystem

This phenomenon provides a unique viewing opportunity and there has been a documented increase in human interest associated with moth sites in the Absaroka Mountain, Wyoming. Since 2007, Shoshone National Forest staff documented increased interest particularly from special use filming permits but also from permitted outfitters recognizing the unique business potential. Evidence from one peak log associated with a moth site also indicates increased public interest. This peak log shows fewer than 1 entry per year prior to 2003, after which there is a steady increase in peak log entries to around 60 entries in 2016 (USDA Forest Service, unpublished data).

Currently, no moth-site specific management plans exist throughout the GYE, but managers have recognized the potential vulnerabilities of foraging grizzly bears at these exposed alpine sites, particularly in regard to human use. There is limited literature, however, to help guide management decisions. There are only four moth-site studies specific to the GYE, none specifically focused on human use concerns (Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994, Robison 2009).

As a result, executive managers in the GYE have recognized that they have inadequate information to inform proactive management at these ecologically important grizzly bear foraging sites. In response, a revised Land Management Plan for the Shoshone National Forest called for more information regarding moth sites, specifically through collaboration (TES-GOAL-04; USFS 2015). Furthermore, it was identified in 2010 as one of three top research priorities by the IGBST and USFS related to land management activities in the GYE (Dan Tyers, personal communication).

Subsequently, staff from the USFS (Shoshone National Forest & the GYE Grizzly Bear Habitat Coordinator), USGS-Northern Rockies Science Center, and Montana State University (MSU) jointly developed research objectives to improve our understanding of the effects of human activities on foraging grizzly bears, the ecology of grizzly bears' use of moth sites, moth ecology, and to interpret findings for agency managers and the public(Dan Tyers, personal communication). Of these identified objectives, understanding the effects of human activities at moth sites is the highest priority for land management agencies.

CHAPTER TWO

GRIZZLY BEARS AND HUMANS AT TWO MOTH AGGREGATION SITES IN WYOMING

Introduction

Army cutworm moths are an important food source for grizzly bears in the Greater Yellowstone Ecosystem (Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994). Every summer, millions of army cutworm moths migrate to high elevation talus slopes throughout the Rocky Mountains from low elevation agricultural areas (Burton et al. 1980). Migration occurs because the moths cannot withstand the high summertime temperatures at lower elevations (Pruess 1967, Burton et al. 1980). This nocturnal species feeds on nectars of alpine flowers at night and aggregates within the interstitial spaces of talus during the day (Kendall and Kevan 1981, White et al. 1998*a*).

Grizzly bears travel up to the talus slopes to forage on the aggregated moths July-September (Chapman et al. 1955, Klaver et al. 1985, Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994). Not only are moths abundant, they have been found to have the highest gross energy of all food sources available to grizzly bears in the GYE (French et al. 1994, Gunther et al. 2014). Furthermore, the moths are available during early onset of fall hyperphagia, an important feeding period in preparation for winter hibernation (Schwartz et al. 2003, White et al. 2017). Vegetation (particularly graminoids) has been documented as an additional food source around moth sites, potentially providing an additional food source when moths are less abundant or unavailable (e.g., before seasonal arrival or out foraging nectar) (French et al. 1994, O'Brien and Lindzey 1994)

Grizzly bears foraging at moth sites was first documented in the GYE in 1986 during aerial telemetry flights conducted by the Interagency Grizzly Bear Study Team (IGBST) (Mattson et al. 1991). Since discovery, management agencies have documented 31 moth sites with confirmed bear use in the GYE, all within the Absaroka Mountains, Wyoming, spanning two national forests (Shoshone, Bridger-Teton), three wilderness areas (Washakie, North Absaroka, Teton), Yellowstone National Park, and the Wind River Indian Reservation (Bjornlie and Haroldson 2018*b*, IGBST 2018).

Because moth sites only occur in a portion of the GYE, it remains unclear to what extent this resource is available to the population. Regardless, routine observation flights have documented an increase in bear use at these sites since initial discovery (Bjornlie and Haroldson 2018*b*). A study in the early 1990's estimated that up to 44 % of the GYE grizzly population utilized these moth sites, including around half of known sow and cub groups (O'Brien and Lindzey 1994). However, grizzly bears have high sightability at moth sites compared to other habitats, likely inflating that estimate (O'Brien and Lindzey 1998, Robison 2009, Bjornlie and Haroldson 2018b). In comparison, the IGBST has recorded 1,227 unique females with cubs since 1986, 347 (28.3%) of which have occurred at or near moth sites (Bjornlie and Haroldson 2018b).

Moth sites not only attract concentrated grizzly bear use but they can attract human use as well (Klaver et al. 1985). The phenomenon of bears foraging on moths has been recognized for its bear viewing potential, an increasingly popular recreational activity in North America (Herrero et al. 2005, Fortin et al. 2016, Penteriani et al. 2017). In the GYE, there has been a documented increase in human interest associated with moth sites. Since 2007, Shoshone National Forest staff documented increased interest particularly for special use filming permits but also from permitted outfitters recognizing the unique business potential. Evidence from one mountain peak log associated with a moth site area indicates increased public interest as well; entries amount to fewer than 1 entry per year prior to 2003 to around 60 entries in 2016 (Dan Tyers, personal communication).

Overlapping human and grizzly bear use at moth sites generates several potential management concerns. Two studies from outside the GYE in northwestern Montana specifically address human use concerns at moth sites. Both studies were concerned with unaware mountain climbing groups, not bear viewers, traveling through moth sites to reach a summit. These two studies highlighted site-specific differences in human use while identifying fundamentally similar management concerns: bear disturbance, human safety, and bear habituation to human presence. As a result from these two studies, one site received season closure and the other remains without specific restrictions to human access (Klaver et al. 1985, White et al. 1999).

Currently, no moth-site specific management plans exist throughout the GYE, but managers have recognized the potential vulnerabilities of foraging grizzly bears at these exposed alpine sites, particularly in regard to human use. There is limited literature, however, to help guide management decisions. There are only four moth-site studies specific to the GYE, none specifically focused on human use concerns (Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994, Robison 2009).

As a result, executive managers in the GYE have recognized that they have inadequate information to inform management at these ecologically important grizzly bear foraging sites. In response, a revised Land Management Plan for the Shoshone National Forest (SNF) called for more information regarding moth sites, specifically through collaboration (TES-GOAL-04; USFS 2015). Furthermore, it was identified in 2010 as one of three top research priorities by the IGBST and USFS related to land management activities in the GYE. Subsequently, staff from the USFS (SNF & the GYE Grizzly Bear Habitat Coordinator), USGS-Northern Rockies Science Center, and Montana State University (MSU) jointly developed research objectives to improve our understanding of moth ecology, the ecology of grizzly bears use of moth sites, the effects of human activities on foraging grizzly bears, and to interpret findings for agency managers and the public (Dan Tyers, personal communication).

Understanding the effects of human activities at moth sites was identified as the highest priority. Subsequently, this project came into fruition. The specific objectives of this project are to:

1) Quantify bear use at the most human-accessible moth sites
2) Quantify human use at the most human-accessible moth sites
3) Quantify human and bear use overlap and interactions at the most human-accessible moth sites

The results from this project will help inform proactive management decisions regarding moth sites in the GYE. We also hope to provide additional insights to help educate the public about this important phenomenon while maintaining the integrity of these unique ecological sites.

Study Area

Our study focused on two of the most human-accessible moth sites in the GYE, identified from a modelling approach discussed later in this chapter. Study areas were defined using a polygon layer derived from spatial moth site data and was provided by the IGBST; details on how this layer was derived is discussed in Bjornlie and Haroldson (2018*b*). The two moth sites where we focused our efforts were in the Shoshone National Forest, and both were in the Absaroka Mountains, Wyoming, partially inside the Washakie Wilderness (Figure 4). Management concerns associated with human and bear use at these sites require that they remained unnamed; instead we will refer to them according to their relative latitudinal orientation, the “North site” and “South site”.

Volcanic activity initially formed the Absaroka Mountains and glacial erosion has further shaped the range (Sundell 1993, French et al. 1994, O’Brien and Lindzey 1994). The combination of these geologic processes has produced ample talus formation, and consequently, ideal areas for the large moth aggregations. Moth aggregations are often found on moderately steep slopes (30-40°) beneath headwalls or rocky outcrops that contribute to continual talus formation. Talus size and depth varies across moth sites but generally consists of medium-sized (8-40cm diameter), angular to rounded, volcanic

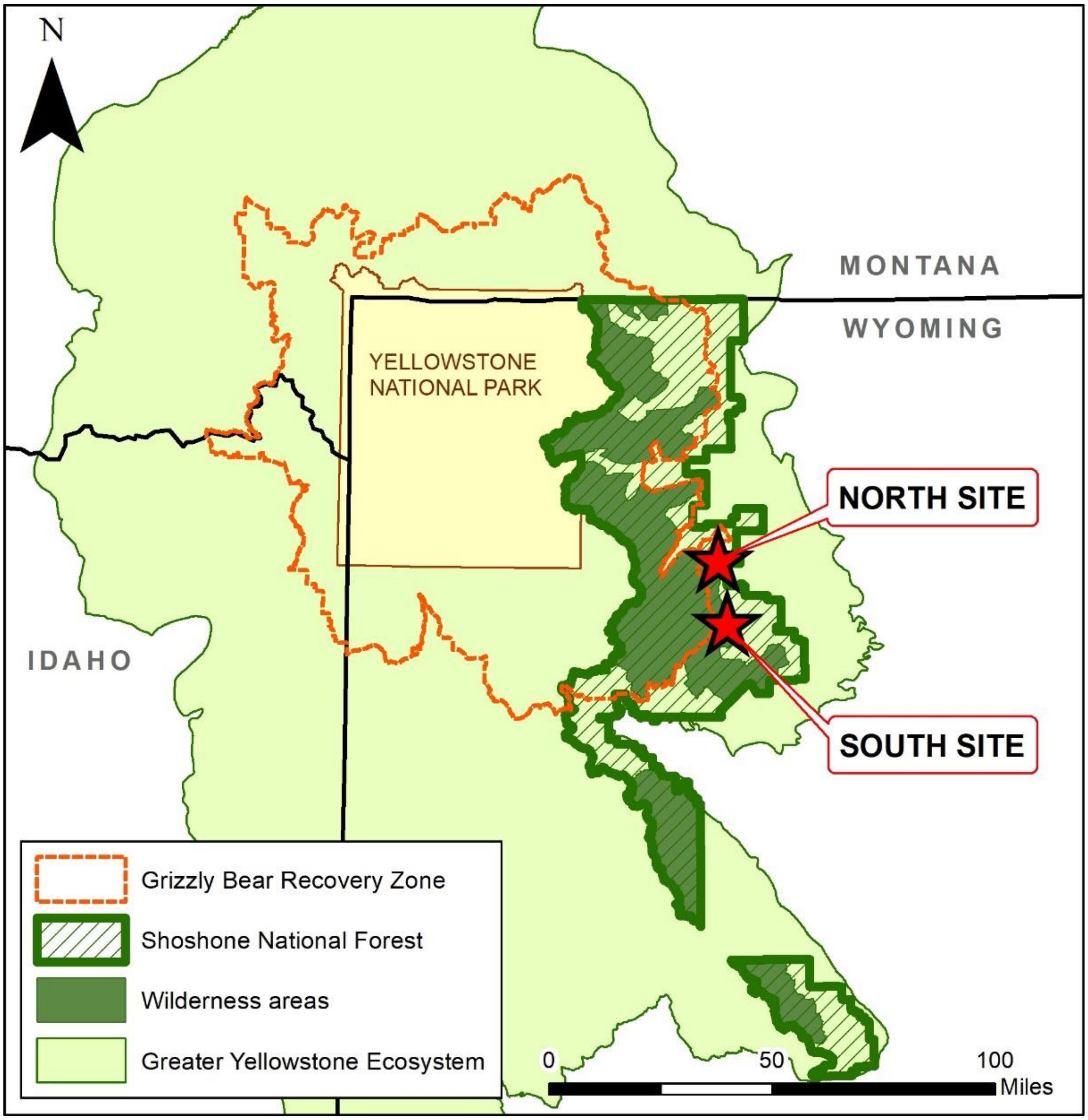

Figure 4. Study areas (North and South sites) within the Shoshone National Forest in the Greater Yellowstone Ecosystem, North America.

or sedimentary rock varying in depth from 10 cm to over 100 cm (Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994, Robison 2009).

The predominant weather patterns dictated both our season length and daily field work. Snow covers the Absaroka Mountains most of the year (NASA 2020, NRCS 2020) and we found that our sites were only consistently accessible for about two and a half months each summer (July 1 – September 15). Moderate to strong southwest winds (10-30 km/hr) were constant and typically brought in mid-afternoon thunderstorms accompanied by sometimes severe lightning and bursts of heavy rain or hail (O'Brien and Lindzey 1994).

Elevation at our sites ranged between 2809 and 3504 m with treeline typically around 3,110 m (10,200 ft) (O'Brien and Lindzey 1994, Robison 2009, USGS 2017). Mean July air temperature was 11°C, ranging between 2.8°C to 18°C, 2017 and 2018 (PRISM 2020). Wind direction, topography, and snow accumulation influence the distribution and composition of plant communities observed in our study sites (O'Brien and Lindzey 1994, Nagy and Grabherr 2009). Although the talus slopes are mostly void of vegetation, the adjacent plateaus, leeward slopes, and protected saddles support abundant vegetative communities (O'Brien and Lindzey 1994).

Methods

Bear Use

Bear use was primarily quantified through repeated bear surveys and a resource selection function (RSF) analysis (Manly et al. 2002). We also collected bear scats to analyze the diet composition of grizzly bears at moth sites to further understand their use of these sites. Lastly, we collected grizzly bear hair samples for DNA analysis using camera hair-snare traps; the purpose of this was both to test the hair collection methodology at alpine sites and contribute information to the current IGBST DNA database.

We conducted repeated bear surveys throughout our study sites to obtain bear location data. To define our survey extents, we used a polygon layer of moth sites provided by the IGBST that was derived from spatial data of moth sites from the last 30 years and is discussed in Bjornlie and Haroldson (2018*b*). Logistics and safety precluded randomized surveys across the moth sites. Instead, a view shed analysis in ArcMap (ESRI 2018) was used to identify observation points and survey extents to maximize the total area within the moth sites surveyed. Observation points and survey extents were refined during initial survey visits based on actual visibility and access safety. Final observation points and survey extents were revisited as many times as possible (3-5 times) each season for repeated surveys.

Each survey was conducted by two observers simultaneously and independently to validate bear location data. Observers situated themselves such that neither was influenced by the behavior and activities of the other, typically by placing a barrier (i.e., rock outcrop, ridge, backpack) between each other, ceasing communication, and maintaining a distance of at least 5 m to limit visual cues of detections. Prior to each survey, observers recorded date, start and end time, observer location, and any applicable notes. Surveys were conducted with 10x42 binoculars and 20–60x spotting scopes for 20 minutes, although more time was taken if necessary to complete the survey and enter all bear data. Observers had post-survey discussions to deal with data inconsistencies and validate bear-locations. We altered start times and travels routes each visit so that surveys were not conducted at the same time every visit.

Field computer tablets displaying survey viewsheds layered over an aerial photograph of the area and a custom program written in ArcPad 10.2.4 (ESRI 2016) allowed observers to record grizzly bear unit observations. Bear units were defined as an independent individual or group of bears (i.e., a lone bear and family group were each considered 1 bear unit). Locations and movements of grizzly bears observed within the survey extent during the survey period was recorded. Point locations for a moving bear were recorded at the last point seen during the survey or the bears last location within the survey extent. Cohort, number of cubs, cub age, activity (i.e., foraging moths, foraging vegetation, moving, sleeping, defense, playing, nursing), and time were recorded for all bear unit observations. Observers also recorded survey conditions prior to each survey including observer, temperature, cloud cover, wind, visibility, and precipitation.

We opportunistically documented all bear sightings outside of the surveys using the field computers, as described above. We only recorded opportunistic observations for bears that we were confident had not already been documented that day during surveys or opportunistically.

Distinguishing sex and age class in lone bears can be notoriously difficult; if there was any uncertainty about sex in our observations the bear was classified as ‘unknown sex’. Sex was only confirmed if we saw urination or genitilia, or in one case mating behavior. Subadults can also be difficult to distinguish from adults; we classified subadults loosely on size but primarily on behavior (i.e. family group association, yet clearly independent). Anecdotally, nearly all of our subadult observations were of a subadult pair that we saw numerous times and were often associated with a family group (consisting of a sow with two cubs of the year).

We created two sets of kernel density plots to visualize the distribution of different landscape covariate values in our survey observations. The first set of plots was used to compare our observations of aspect, elevation, and slope between sites and to means reported in previous literature specific to the GYE (Mattson et al. 1991, French et al. 1994, O’Brien and Lindzey 1994). For first set of kernel density plots only, we separated moth foraging bear locations from all other locations for further comparison. The second set of kernel density plots was used to compare descriptive landscape covariates for our observations between study sites and to assess if pooling data between sites was reasonable for the RSF model selection. All bear locations were compiled for this second set of plots and for all other analysis.

We developed a RSF to estimate the relative probability of grizzly bear use at the two moth sites as a function of landscape attributes. We used a population level (2nd order; Krausman 1997) used-available design where locations documented during our surveys represented the “used” locations. We sampled the “available” locations from the total area surveyed, which included all visible areas from our observation points within a one-kilometer buffer of the moth site. The “available” locations were sampled at a 1:500 (used:available) ratio to adequately describe each landscape covariate and avoid model convergence issues; a ratio produced when point estimates in an initial global model began to converge (Northrup et al. 2013). The 1:500 (used:available) ratio resulted in a density of 1 available point per 417 m^2. We pooled locations for both study sites to achieve a sufficient sample size. Similarities between the distributions of observed covariates between sites generally supported pooling the data; however, we recognize that differences between sites may reduce the strength of our pooled model and predictive surface (Beyer et al. 2010). We evaluated the efficacy of data pooling for our RSF development during our model evaluation process and determined that a single model was reasonable (Appendix A). Data processing was performed in ArcMap using spatial analyst and geomorphic toolboxes (Evans et al. 2014, ESRI 2018) and in the R environment (R Core Team 2019) using sf (Pebesma 2018), raster (Hijmans 2019), tidyverse (Wickham 2017) packages.

Landscape covariates were selected based on review of moth site literature (Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994, White 1996, White et al. 1998*a*, *b*, Robison et al. 2006). We selected covariates that have been discussed to influence moth selection and abundance (i.e. talus depth, moisture, temperature, landcover), and subsequently assumed to influence bear selection. We also selected covariates that we thought might influence the cost efficiency of foraging moths (i.e. talus depth and slope degree). As a result, although we refer to our RSF as a 'bear use' surface, it is really a 'moth-bear use surface' and our interpretations will assume that bear use is directly associated with moth abundance and foraging efficiency.

The covariates we considered fell into four suites, characterizing terrain, moisture, temperature and landcover. All covariate descriptions, abbreviations and development details are listed in Table 1. The terrain suite was comprised of three indices derived from

Table 1. Covariates considered and developed for RSF model development, organized by suite, detailing hypothesized relationships, spatial grains and functional forms considered, supporting literature, and covariate development

Covariate (abbv.)	Description	Hypothesized relationship	Spatial grains tested	Forms tested	Supporting literature	Data source; development
Terrain						
SLP	Slope (degrees)	(-) quadratic with apex centered around 35 °	100, 200, 400	li, sq	Mattson et al. 1991; French et al. 1994; O'Brien and Lindzey 1994; White et al. 1998	(USGS 2017); Derived from elevation layer in ArcMap
CRV	Curvature where (-) represent concave down and (+) represents concave up	(+) linear selection for more concave up slopes	100, 200, 400	li, sq	Mattson et al. 1991; French et al. 1994; O'Brien and Lindzey 1994; White et al. 1998	(USGS 2017); Derived from elevation layer in ArcMap
VRM	Vector ruggedness measure; A ruggedness measure implemented from Sappington (2010)	(-) linear decrease in selection as ruggedness increases	100, 200, 400	li, sq	Robison 2009	(USGS 2017); Derived from elevation layer in R using 'spatialEco' package (Evans et al. 2014)
Temperature						
HLI	Heat loading index; Proxy for surface temperature, takes into account aspect and slope	(+) linear increase in selection as surface temperature increases (i.e. S – SW slopes)	100, 200, 400	li, sq	Mattson et al. 1991; French et al. 1994; O'Brien and Lindzey 1994; White et al. 1998; Robison 2009	(USGS 2017); Derived from elevation layer in ArcMap
COSASP	Cosine Aspect; Proxy for surface temperature; Aspect centered on NNE and cosine taken, effectively scaling from -1 to 1	(+) linear increase in selection as surface temperature increases (i.e. S – SW slopes)	100, 200, 400	li, sq	Mattson et al. 1991; French et al. 1994; O'Brien and Lindzey 1994; White et al. 1998; Robison 2009	(USGS 2017); Derived from elevation layer in R
Moisture						
CTI	Compound topographic index; a proxy for moisture, calculates all upslope contribution to moisture accumulation for each cell	(-) quadratic with apex centered on mid-range CTI values	100, 200, 400	li, sq	French et al. 1994; Robison 2009	(USGS 2017); Derived from elevation layer in R using 'spatialEco' package (Evans et al. 2014)
Landcover						
GRN	Tassled cap greenness; uses imagery to calculate greenness	(+) quadratic with selection for least and most green areas, lowest selection in the mid-range	100, 200, 400	li, sq	French et al. 1994; Robison 2009	(USGS 2018); Derived from Landsat 8 OLI imagery from July 18, 2018 in R using 'Rstoolbox' package (Leutner et al. 2019)
NDVI	Normalized difference vegetation index; uses imagery to calculate greenness	(+) quadratic with selection for least and most green areas, lowest selection in the mid-range	100, 200, 400	li, sq	French et al. 1994; Robison 2009	(USGS 2011); Derived from landsat 8 from August 2011 imagery in ArcMap

digital elevation models (DEM) including slope (SLP), ruggedness (VRM), and curvature (CRV). We expected that grizzly bear selection would be associated with moderate to steep slopes (~35°), less rugged areas, and curvature describing concave up geologic formations (i.e., drainages, not ridge tops). The moisture suite included compound topographic index (CTI) which can be considered a moisture potential index and is a function of slope and upstream contributing area to flow accumulation across space (Evans et al. 2014). We expected that grizzly bear selection would be associated with low to moderate CTI values describing areas with some moisture potential but not so much as to form an actual water body. The temperature suite was comprised of two competing measures of surface temperature indices including heat load index (HLI) and cosine-aspect (COSASP). Both indices describe the biological assumption that north-northeast slopes have cooler temperatures while south-southwest slopes have warmer temperatures. Heat load index additionally takes into account slope. We expected that grizzly bear selection would be associated with slopes with higher heat load, or south to southwest slopes. The landcover suite was comprised of two competing measures of greenness extracted from satellite imagery including tasseled cap greenness (GRN) and normalized difference vegetation index (NDVI). Tasseled cap greenness was derived from Landsat 8 OLI imagery from July 18, 2018 and NDVI was derived from Landsat 8 imagery from August 2011 (the most recent available imagery, captured during the summer and without cloud obstructions). We expected that grizzly bear selection would be most associated with the least green areas (i.e., talus slopes). However, we observed grizzly bears using vegetative resources as well which we expect may either result in a dual selection in the form of a positive quadratic or increased error. All covariates were mean centered and divided by their standard deviation to aid in model convergence and covariate comparisons.

We used a multi-tiered model selection process to test hypotheses and select a final model following similar approaches described in DeVoe et al. (2015) and Lowrey et al. (2018). The first tier was used to explore spatial grains and functional forms for all univariate models describing each covariate. To our knowledge, previous moth site work has not looked at different spatial grains, however literature has emphasized the importance of considering different spatial scales when considering habitat selection (Wiens 1989, Hobbs 2003, Mayor et al. 2009). Three spatial scales were developed and tested based on our survey location accuracy (100m), daily selection of a moth aggregation slope (200m; White et al. 1998*b*), and broader, drainage wide selection of a moth site area (400m). All covariates were tested at both linear and quadratic functional forms to lend flexibility to our hypothesized relationships and increase the predictive accuracy in our final model. All univariate models for each covariate were ranked using AICc (Akaike information criterion corrected for small sample sizes) in the *AICcmodavg* package in the R environment (Mazerolle 2019, R Core Team 2019). Models <4 AICc were retained for further model selection (Burnham and Anderson 2002).

The second model selection tier was used to select between competing covariates within each suite (i.e., GRN vs. NDVI and HLI vs. COSASP) and to assess relative support between suites. Pairs of covariates with Pearson correlation coefficients of $|r|>0.60$ were not considered together in the same model to avoid collinearity problems.

All models within each suite, and the null model, were ranked using AICc. Models <4 AICc were retained for further model selection. We expected the landcover suite to have the most support across suites because talus is necessary for moth aggregations and the most consistent descriptor at areas of observed concentrated bear use (Mattson et al. 1991, French et al. 1994, White et al. 1998*a*, Robison 2009). We evaluated this expectation based on the AICc ranking across suites.

The final selection tier was used to select between top models within each suite and test for support to retain each suite in the final model. All models within each suite, and the null model, were ranked using AICc and models <4 AICc were retained and reported. A top model was selected based on AICc ranking, comparison of model components across top models, and summary output. Coefficient point estimates from the top model were used to create a predictive RSF surface representing cumulative probability for grizzly bear use across our study areas. We applied a linear stretch to scale the final RSF surface from 0-1 for interpretation and later comparison with the human use layer, described in the *Human use* section later in this chapter (Johnson et al. 2004).

To assess the top model’s predictive performance, we used k-fold cross-validation (Boyce et al. 2002). The “used” location data were divided randomly into 10 bins (each 10% of the data) and one bin at a time was withheld while the model was trained using the remaining 90% of the data. The withheld data was then tested on the trained model, and the process was repeated until all bins (e.g. folds) had been tested (Boyce et al. 2002). We assessed if there was concerning variation resulting from each bin withholding by comparing kernel density plots, boxplots, and prediction curves for each fold. We summed the occurrence of used locations falling into 10 equal-area predictive RSF value bins to evaluate the correlation between the frequency of occurrence and the relative RSF score using the Spearman rank correlation coefficient (r_s). Values of r_s equal to 1 indicate that the cross-validated used locations occurred at rates expected by chance and a strong model predictive performance (Boyce et al. 2002). The minimum acceptable r_s is 0.564 (Boyce et al. 2002, Wiens et al. 2008, Gehr et al. 2017).

To further understand bear use at moth sites, we collected scat for diet analysis. Fresh bear scats (<2 weeks old) were opportunistically collected while crew members were conducting field work. Location and date were recorded for all scats. Scats were primarily collected within vegetation areas and were not intended to fairly represent moth foraging. Within 24 hours of collection, scats were set to dry on paper plates until all moisture was gone from the samples. Dried samples were placed in paper bags and stored in a dry place until ready for scat content analysis. Scat content analysis consisted of rehydrating scats in water for about 24 hours, mixing rehydrated scat into a homogenous mixture, and taking a representative sample (usually about 1 cup) to sort through and estimate relative proportion of diet components. Bears digest cellulose poorly (Bunnel and Hamilton 1983) often leaving large and identifiable sections of leaves, stems, and seed heads in the scat. We identify genus and species when possible by using microscopes to dissect and identify defining morphological traits of poorly digested plant matter. We did not quantify dirt and debris because we assumed this was byproduct of foraging for other items. We opportunistically collected samples of unique plants species observed at our moth sites to aid in the bear scat content analysis. Plants were identified, pressed, and mounted for reference.

We collected grizzly bear hair samples for DNA analysis using camera-hair snare traps to help understand the population of grizzly bears at these sites and contribute any unknown bears to the existing IGBST grizzly bear DNA database. Hair samples were also contributed to ongoing work by Jennifer Fortin-Noreaus (U.S. Fish and Wildlife Service) to refine the use of stable isotope analysis on assimilated bear foods in the GYE (Dan Tyers, personal communication). We set up two camera-hair snare traps from each primary trailhead, resulting in 6 total camera traps (South site, n= 4; North site, n=2). Camera hair-snare traps consisted of a large treated plank (12” x 48” x 4”) staked into the ground using 4’ rebar rod. Barbed wire was stapled across the plank and the plank was doused with anise (similar to licorice extract). Bears are attracted to the scent, come to rub on the plank, and the barbed wire catches hair samples. Cameras were either mounted on large rocks with a rachet strap or placed inside a rock cairn built near the plank to capture photos of the visiting bears to aid in DNA analysis. Traps were checked every other week to collect hair samples, photos, and re-bait. Hair samples were collected in coin envelopes using sterile nitrile gloves and sterilized forceps. Hair samples were stored in a cool, dry place until they were sent to a laboratory for DNA analysis (Wildlife Genetics International n.d.).

Human Use

We created a human accessibility model to rank the relative accessibility (or remoteness) of all the confirmed moth sites (n=31) in the GYE to hikers and stock users.

To our knowledge, no previous literature describes methods to develop a human-accessibility model applicable to our needs. Methods were developed through conversations with two ArcMap professionals (Stuart Challender and Shannon Pils, personal communication) and multiple personnel with extensive experience with backcountry travel throughout the study area (Dan Tyers, Andrew Pils, and Kerry Murphy, personal communication). Our human-accessibility model was developed in ArcMap 10.6.1 (ESRI 2018) using the following steps.

First, we identified landscape layers that impact access to backcountry destinations, including passenger vehicle and high clearance roads, trails, campsites (particularly ones that attract stock users), slope, ruggedness, trailhead presence, elevation, and landcover. All layers were rasterized to obtain continuous surfaces that could then be standardized. Each layer was then standardized onto 1-10 scale for comparison; see Table 2 for processing details of each layer. All layers were then combined using a weighted overlay where each layer was assigned a weight factor (out of 1, all weights needed to sum to 1) reflecting their relative importance to human access to backcountry sites; this layer represented our ‘cost’ surface.

We then performed two cost-distance analyses where we used the cost surface to calculate cumulative cost of traveling to each moth site area from 1) trailheads and 2) any high-clearance roads. Both start points were considered separately because we recognized that users don’t necessarily depend on established trailheads to access backcountry sites, therefore a high-clearance road might offer equal opportunity for a starting point.

Table 2. Landscape layer processing for human-accessibility model development. Road, trail, trailhead, and campsite layers obtained from the Shoshone National Forest. All other layers obtained through USDA or Wyoming GIS clearing house.

Layer	Layer processing	Layer rescaling*	Assigned weight**
Passenger vehicle roads	• Passenger vehicle roads queried from 2018 road layer • Rasterized by calculating Euclidean distance from each road. • Euclidean distance rescaled	1 = within 25 yards of road 10 = else	0.21
High clearance roads	• High clearance roads queried from 2018 road layer • Rasterized by calculating Euclidean distance from each road. • Euclidean distance rescaled	2 = within 25 yards of road 10 = else	0.15
Trails and Campsites	• Queried all passable trails in 2018 • Buffered trails by 100m to account for spatial error • Buffer campsites by 1000m • Intersect trails and campsites • Rasterize by using Polygon to Raster tool • Results in one layer that accounts for trails with campsites as more 'attractive'	3 = within 500m of campsite/trail intersections 4 = within 500m of trails only 6 = else	0.11
Trailheads	• Query all existing trailheads from 2018 • Rasterize through calculating Euclidean distance from each trailhead	1 = within 1500m from trailhead 10 = else	0.11
Elevation	• Obtained layer, no other processing necessary	1 = valley bottoms, low elevation (<9,000) 10 = high elevation (>9,000ft)	0.15
Slope	• Calculated using Spatial Analyst toolbox in ArcMap from elevation layer	1 = 0°-25° slopes 5 = 26°-50° slopes 10 = 50°+ slopes	0.11
Ruggedness	• Calculated using Spatial Analyst toolbox in ArcMap from elevation layer	1 = no ruggedness 3 = some ruggedness 6 = moderate ruggedness 10 = highly rugged, impassable	0.08
Landcover	• Obtained USDA landcover national data set • Reclassed to indicate forest/no forest	1 = non forested areas 3 = forested areas	0.08

*1= lowest travel cost, 10=impassable

** Weights reflect relative importance to access and must to sum to 1

Finally, we used zonal statistics to calculate average cost of traveling to each moth site area (the average of all cell values within each moth site area polygon). Average cost for each site was rescaled by equal interval onto a 1-5 scale to deal with the otherwise large and cumbersome averages. Relative accessibility of moth sites from our model was evaluated through field reconnaissance and discussions with U.S. Forest Service personnel experienced in accessing these sites by foot and horseback (Dan Tyers and Andrew Pils, personal communication).

At the two most human accessible moth site areas identified from our model, we quantified human use through trailhead surveys, vehicle and trail counters, peak log monitoring and opportunistic documentation. We quantified human use patterns using data collected from GPS tracking units that were distributed during trailhead monitoring efforts, and density analysis. To focus monitoring efforts, we identified a total of three trailheads used as primary access points our study sites; two at the South site and one at the North site. We focused more time at South site trailheads in 2017, but post-season review of our methods led us to increase our efforts at the North site. All human use methods are discussed in greater detail below.

Trailhead monitoring efforts were focused Thursday-Sunday when we anticipated the most human use at these sites. Crew members showed up at least a half-hour before sunrise and remained at the trailhead until 14:00, a time after which we assumed few or no hiking groups would start. Crew members documented time spent at trailheads, all vehicle traffic, human hiking groups, and recorded any other notes of interest during trailhead monitoring efforts. Additionally, verbal and/or written surveys of hiking groups were given to collect data on reason for trip, group size, names, group origin, and how they heard about the area.

Magnetic vehicle counters (TRAFx 2020) were installed along roads used to access the primary trailheads. These roads are also used for other uses (e.g., recreational vehicle use) so counts were reflective of all users, not just those interested in accessing moth sites. The vehicle counters had electromagnetic triggers that consistently documented vehicle passes within 6 meters during the course of the field season. We installed the counters in the center of the dirt roads deep enough to have 4-6 inches of soil cover. Count-lag time was set to reduce count error, particularly multiple counts of the same vehicle. We calculated the average time it took vehicles to completely pass over the vehicle counters (depending on road ruggedness, about 4 seconds) and set the lag time accordingly. Two vehicle counters were set at each trailhead (6 total) in case of malfunction. Vehicle counter data for 2018 was collected from the beginning of July through mid-September in 2018. Vehicle counters were checked every other week to collect data and replace batteries. We adjusted all count data to account for crew travel.

Infrared trail counters (TRAFx 2020) were installed along trails (animal and/or man-made) at points that seemed the most likely to draw concentrated human traffic. The infrared counters did not require a reflective surface so we were able to set them up in cairn-like rock piles throughout our study sites. We installed 6 infrared trail counters across both sites which were checked every other week to collect data and replace batteries.

Peak logs (a notebook in some sort of waterproof vessel) are often established at prominent high points so visitors can record their presence. We assumed peak logs would be used by most climbers, providing us with a useful data source to compare to our trailhead efforts and capture use we might not have otherwise. Since both of our study sites are associated with a peak or high point we took advantage of existing peak logs (South site) or established a new peak log (North site) to document human use at high points. Peak logs were check every two weeks to take pictures of entries and document human access. At minimum, all entries gave a name and date of access. In addition to the peak logs, we installed surveys to gather additional information about users we may not have documented during our trailhead monitoring efforts. The surveys asked users to provide the following information: date, name, time, reason for trip, trail head, group size, and general route to peak/high point.

Any human use in the moth sites observed outside the methods listed above were also recorded. These observations included people seen with binoculars or spotting scopes too far away to talk to, blog entries on peak climbing websites (summitpost.org, peakbagger.com), and human groups on game cameras intended to capture grizzly bear use.

As an addition to our trailhead monitoring efforts, GPS tracking units were passed out to hiking groups to collect route data. The GPS tracking units were small, key chained sized units programmed to log location data every minute for up to about 12 hours (Qstarz 2013). The route data was then easily downloaded for further analysis. In order to get the GPS units back from users, we installed retired mail drop-boxes at each trailhead for people to leave the GPS units after their trip if we were no longer present. To further maximize our chances of getting the units back, we gave GPS carriers a prelabelled and posted envelope for return via post if they forgot leave the GPS in the drop box.

Using the route data obtained from the GPS tracking units, we performed a density analysis to identify if there were areas of concentrated human use. The density analysis was performed by using the ‘line density’ tool in the spatial analyst toolbox in ArcMap (ESRI 2018). The resulting raster was rescaled onto a 0-1 scale using the ‘rescale by function’ tool in the spatial analyst toolbox in ArcMap for later comparisons with the predictive bear surface.

Human and Bear Use Overlap and Interactions

The human use density and the predictive bear use surfaces were compared to identify areas of overlap. The two layers were added together and averaged using the raster algebra tool in ArcMap (ESRI 2018). The resulting layers was rescaled into four, equal interval bins to indicate level of overlap: none, low, medium, and high. Our overlap surface was validated by comparing it to documented human-bear interactions. We assumed that areas with repeated human-bear interactions would be directly related to level of overlap.

Interaction data was collected through paper and/or verbal surveys during trailhead monitoring efforts and with a survey established with the peak log. Surveys gathered information from groups on number of bears observed, number of interactions, character of interactions, and location of interactions.

The crew also documented any interactions we experienced while out doing field work. Interactions were defined as any perceived reaction to our presence by bears. We did as much as possible to reduce the likelihood of interactions and travelled in groups to increase our safety. Location of crew and bear(s), date, time, bear activity prior to interaction, and bear response was recorded for all opportunistic crew interactions.

Results

Season Efforts

Field efforts spanned July 10 – September 21 in 2017 and June 26 – September 16 in 2018. Field season length was determined by snow conditions that limited our access to the alpine terrain. We had four crew members both seasons to help complete our field work. We spent a total of 27- and 39-days conducting occupancy surveys throughout 2017 and 2018, respectively. We spent 20 and 86 crew-days monitoring trailheads throughout 2017 and 2018, respectively. Field work was based out of a ranger station central to our study sites. From the ranger station, it took 1-1.5 hours driving on rough dirt roads to access trailheads. Field efforts were completed primarily through day hikes, although one area necessitated a 3-day backpacking trip to accomplish field efforts. Field efforts were focused during morning hours (0400 – 1300) for safety reasons. Across both seasons, crew members cumulatively hiked 989 miles and gained 851,800 feet in elevation.

Bear Use

We conducted a total of 293 paired surveys; 233 at the South site and 60 at the North site. We observed grizzly bears in 76 surveys. We documented a total of 266 distinct bear units during our surveys; 227 at the South site and 39 at the North site (Figures 5 and 6). Our observations included 62 sows with cubs, 29 sub adults, and 175 lone adults (2 confirmed female, 23 confirmed male). We documented a minimum of 11 distinct family groups (i.e., sows with dependent young) between the two summers. A total of 22 bears went undetected by an observer during 16 surveys. Non-detections most commonly occurred with new crew members or volunteers during their first surveys

We documented 220 opportunistic bear locations throughout both seasons; 200 at South site and 20 at North site. Our opportunistic sightings included 61 sows with cubs, 31 sub adults, and 128 lone adults (28 confirmed male). Across all survey and opportunistic sightings, we saw anywhere from 0 to 20 bear units (0-37 bears considering individual cubs) in one day. Most observations occurred during the second half of July through the first half of August (Figure 7).

Surveys were conducted at 35 different survey extents (26 at the South site and 9 at the North site). Bears were observed in all but four survey extents. We were able to survey 83% of the South site study area extent and 39% of the North site. Area surveyed was limited by terrain features that affected access, crew safety, and bear disturbance. The South site is a large massif with terrain that offered distant vantage points to observe bears throughout the area. At the North site, the northern half of the study area was less accessible due to extreme terrain ruggedness and we were not able to safely conduct surveys from distant vantage points throughout the area.

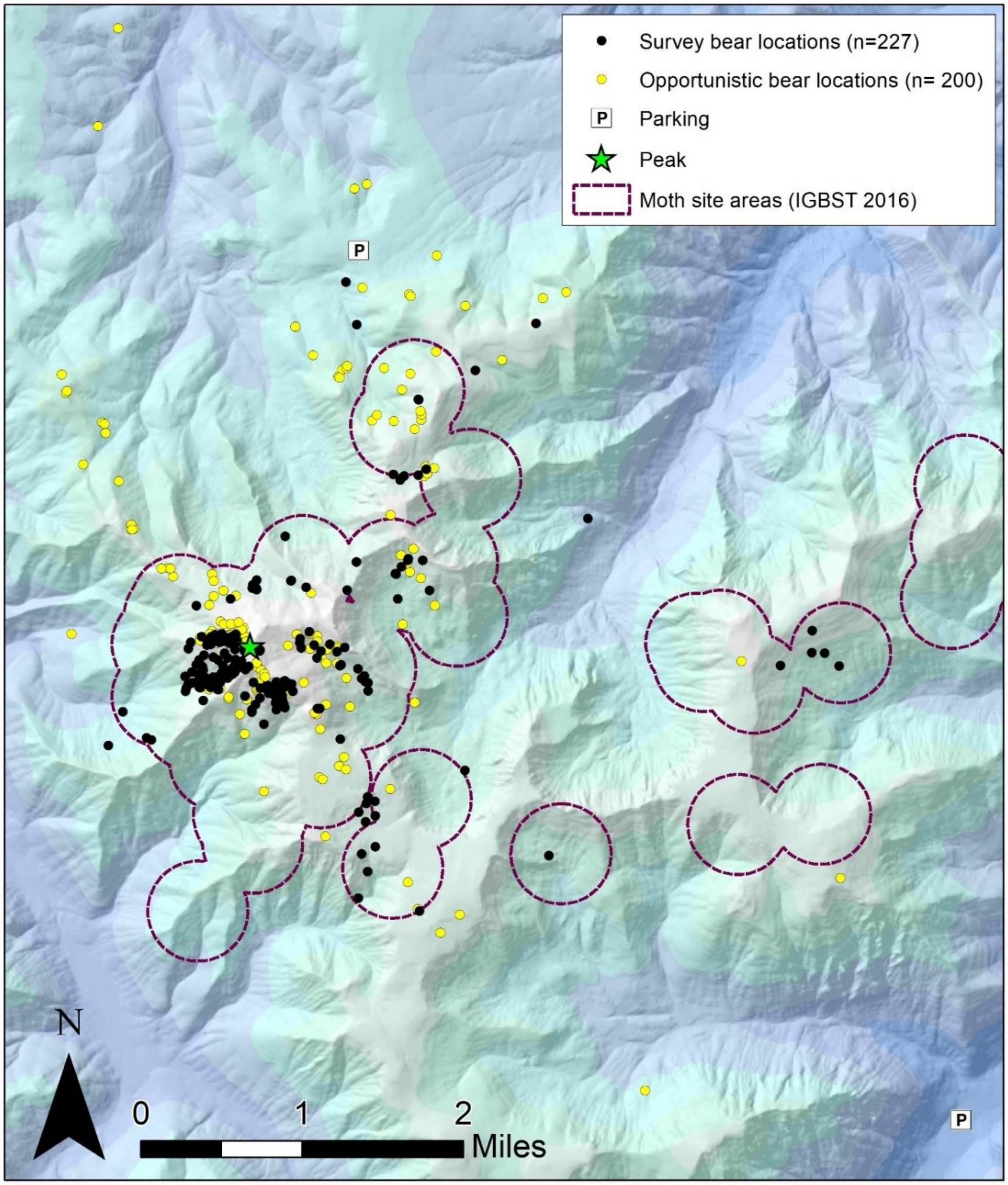

Figure 5. All of our bear location data (survey and opportunistic) collected at the South site in 2017 and 2018

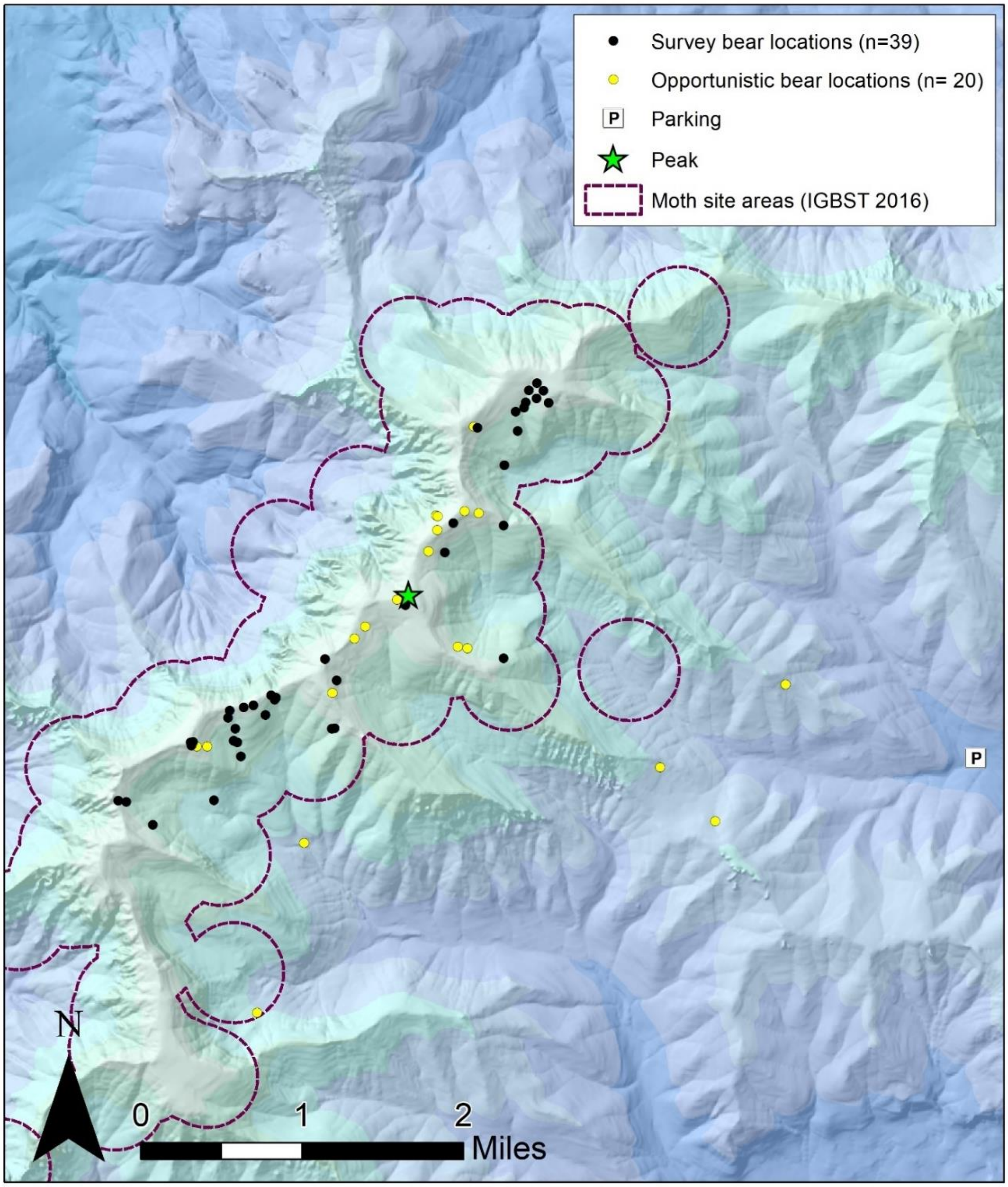

Figure 6. All of our bear location data (survey and opportunistic) collected at the North site in 2017 and 2018

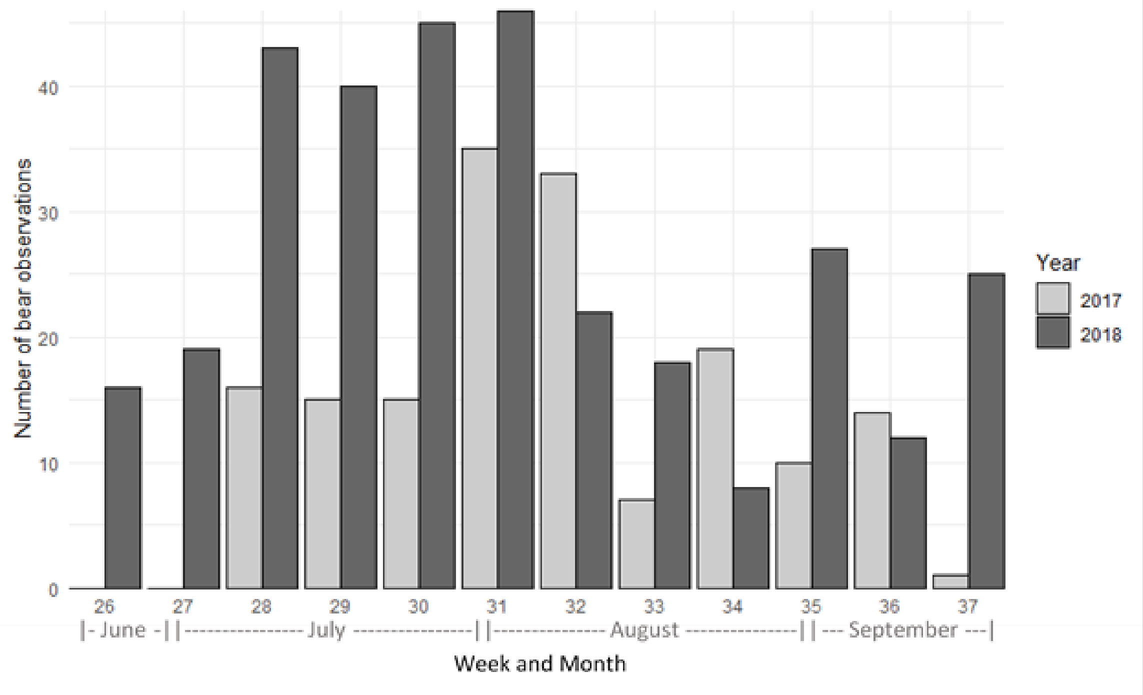

Figure 7. Total number of bear observations by week and month across study sites in 2017 and 2018

Across all survey locations, the most common bear activity documented during surveys was moth foraging (67%). The remaining activities observed included: foraging vegetation (16%), moving/traveling (10%), sleeping (5%), defense (1%), nursing (<0.05%), and playing (<0.05%). Across all opportunistic sightings, the most common bear activity in our opportunistic sightings was moth foraging (46%). The remaining activities observed included: foraging vegetation (31%), moving/traveling (19%), sleeping (<0.05%), defense (<0.05%), and playing (<0.05%).

Bear activity across all observations appeared to vary as the season progressed. We documented proportionally more bears foraging on vegetation early in the season until about mid-July when moth foraging became the primary activity (Figure 8). This

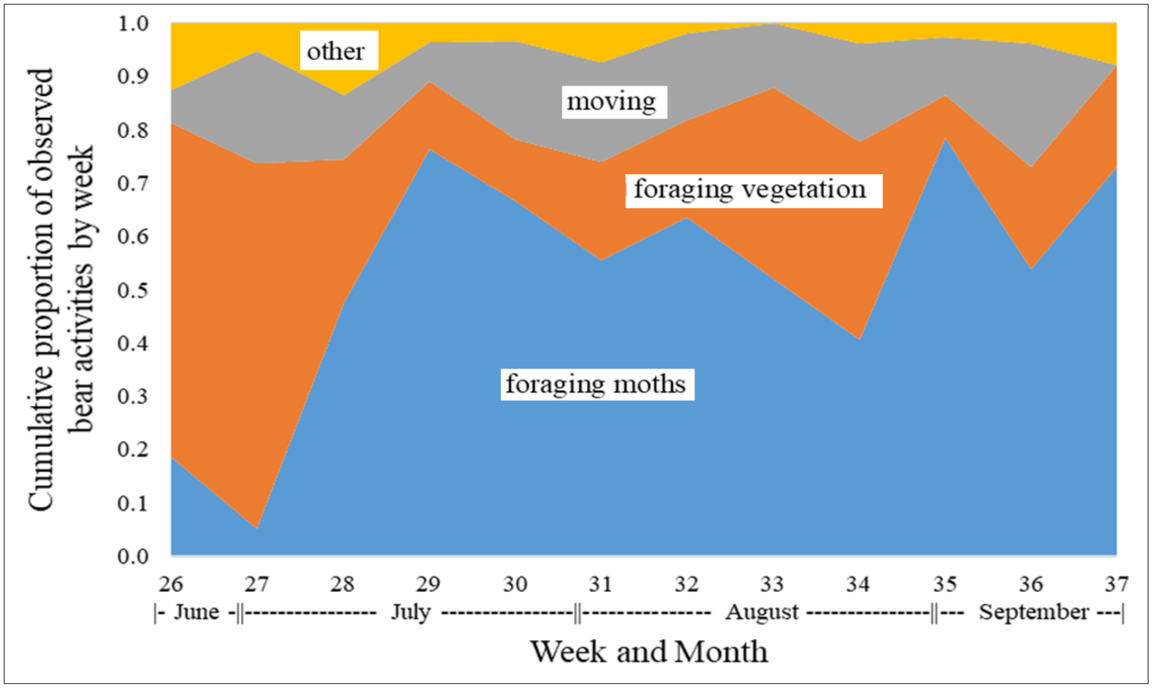

Figure 8. Cumulative proportion of bear activities by week and month across study sites in 2017 and 2018

pattern reflects the relative availability of food resources throughout the summer season: newly emerged and palatable vegetation in June and July until the peak moth occurrence in late July through mid-August, varying by year (Servheen 1983, French et al. 1994, White et al. 1998*a*).

At the South site, we observed the highest concentrations of bears on three slopes immediately below the peak on westerly slopes ranging from south-southwest to northwest. We observed all cohorts foraging in close proximity at times, but primary composition of observed cohort use varied across the three primary slopes (Figure 9). We saw the highest concentration of lone bears on a prominent west facing slope almost entirely visible from the summit. We saw a similar concentration of lone bears on an adjacent south-southwest facing slope, visible by walking about 400 m south of the

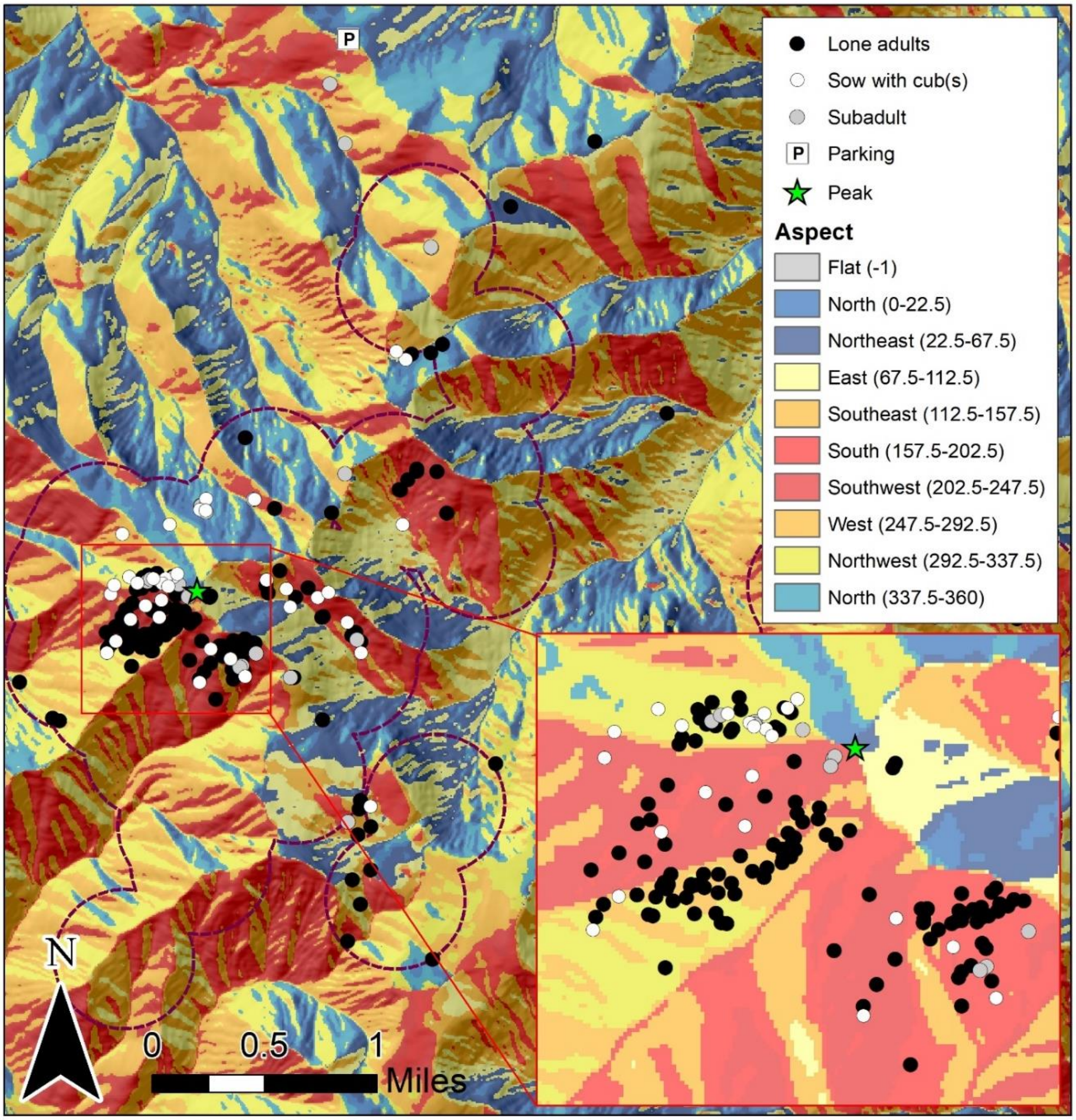

Figure 9. Bear location data distinguished by cohort and compared to aspect from surveys in 2017 and 2018 at the South site. The inset represents concentrated locations on three westerly slopes near the peak.

summit. We saw the highest proportion of family groups and subadults on the northwest slope, visible by walking about 100m northwest of the summit. At the North site, we observed less concentrated use and no distinct areas of higher use by cohort (Figure 10).

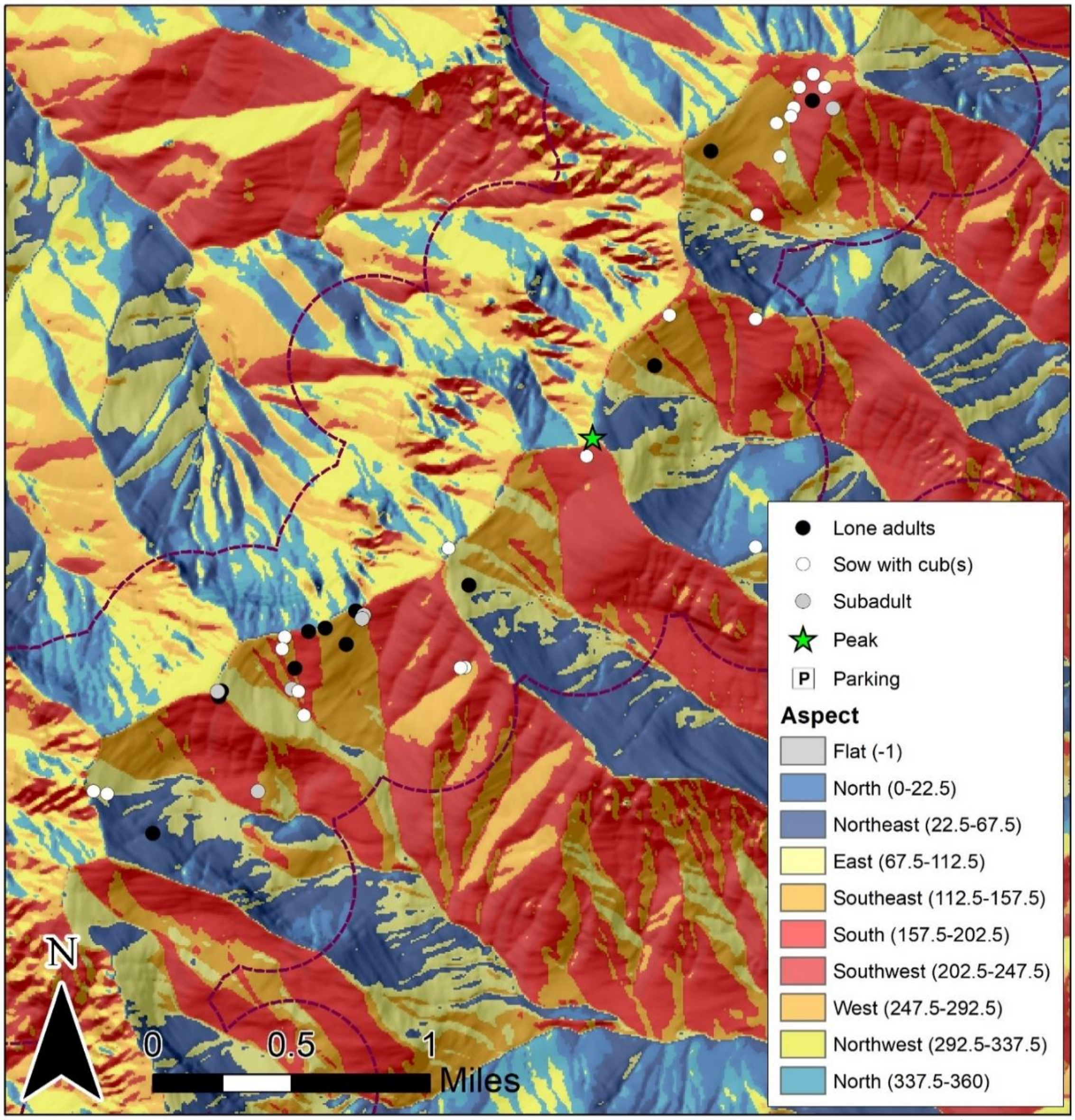

Figure 10. Bear location data distinguished by cohort and compared to aspect from surveys in 2017 and 2018 at the North site.

Observed use locations at the North site appeared to be on more southerly aspects compared to the South site. However, this observation was heavily influenced by the fact that the proportion (39%) of the North site we were able to survey was primarily south and east facing. Reports from SNF personnel indicate that bear use is much different, and often greater, on the more north facing slopes that we were not able to survey (Andy Pils, personal communication).

The first set of kernel density plots showed differences in mean elevation, aspect, and slope between bear activities (moth foraging vs. all other locations), study sites, and compared to averages reported in literature specific to the GYE (Figure 11; Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994). Differences that stand out include use of higher average elevation at both sites and use of shallower slopes at the North site compared to averages reported in three previous studies. The use of higher elevation is not too surprising considering both sites have higher average elevation than most other moth sites in the GYE (Table 3). We suspect that the use of shallower slopes observed at the North site is largely due to sampling bias because the portions we were not able to survey have much steeper slopes and reportedly more bear use (Andy Pils, personal communication).

The second set of kernel density plots showed general similarities in observed use across curvature, ruggedness, moisture potential, and greenness covariates between sites (Figure 12). The plots suggest differences in aspect and heat load index between sites, which we believe is almost entirely due to the fact that safety concerns precluded surveying most of the north and west facing slopes where there is reportedly more bear use (Andy Pils, personal communication). The plots also show a difference in elevation, which is consistent with a difference in mean elevation of about 200 m between the sites. Due to the general similarities observed in these plots between sites, and differences almost entirely from sampling bias at the North site, we decided that pooling data was reasonable.

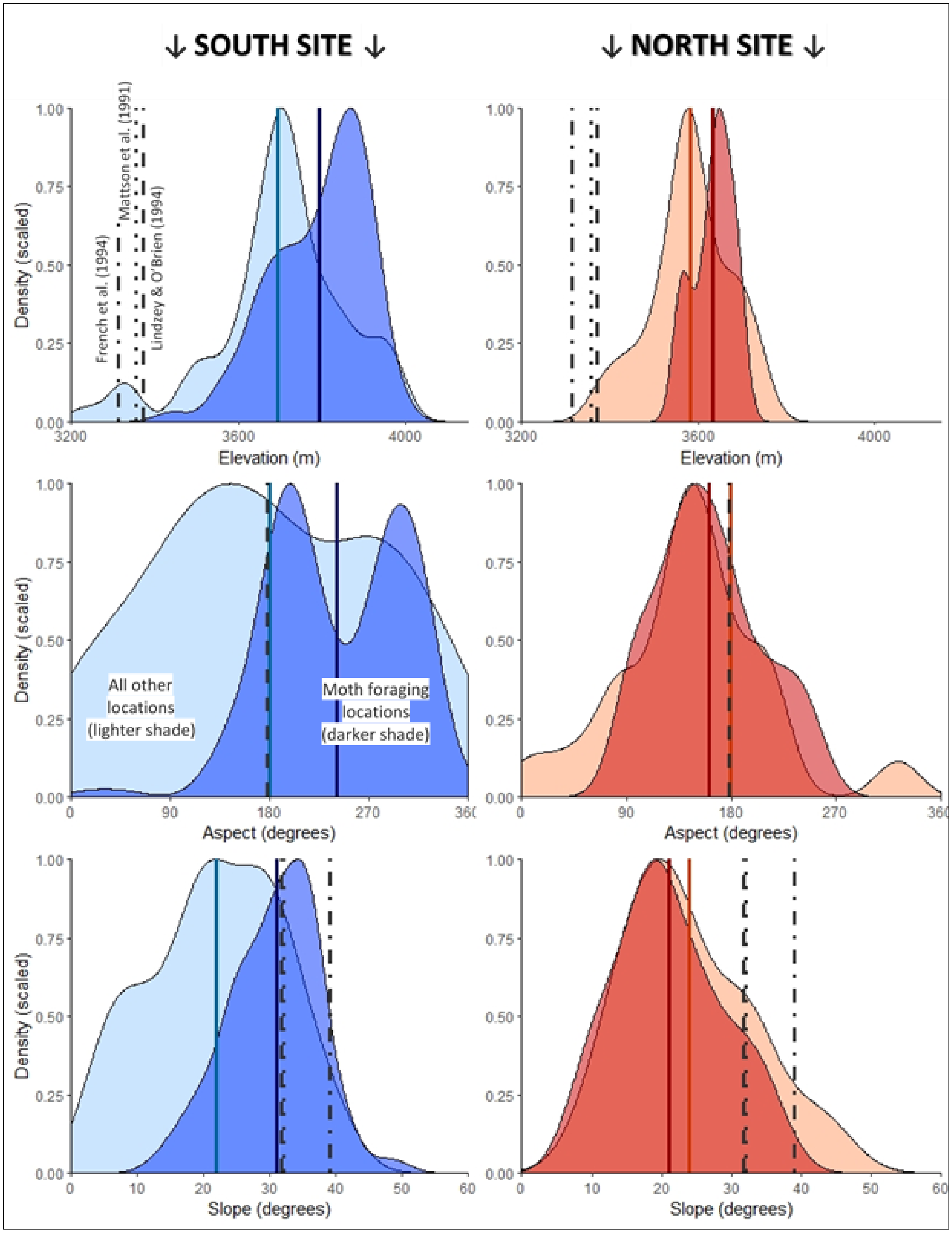

Figure 11. Kernel density plots (e.g., smoothed histograms) showing the distributions and means (solid lines) of elevation, aspect, and slope observed in our survey location data from 2017 and 2018, delineated by site and bear activity. Means from previous studies (dashed lines) are included for comparison.

Table 3. Mean elevation and standard deviation (SD) of all confirmed moth sites in the GYE

Moth site	Mean Elevation (m)	SD
1	3128	115
2	3172	169
3	3204	169
4	3235	137
5	3238	154
6	3245	138
7	3250	130
8	3281	133
9	3285	114
10	3300	155
11	3303	130
12	3313	83
13	3331	133
14	3334	139
15	3341	176
16	3344	182
17	3359	138
18	3360	113
19	3385	98
20	3387	146
21	3409	142
North site	3428	189
22	3443	155
23	3461	128
24	3468	140
25	3477	92
26	3484	121
27	3489	92
28	3523	86
29	3552	101
South site	3601	156

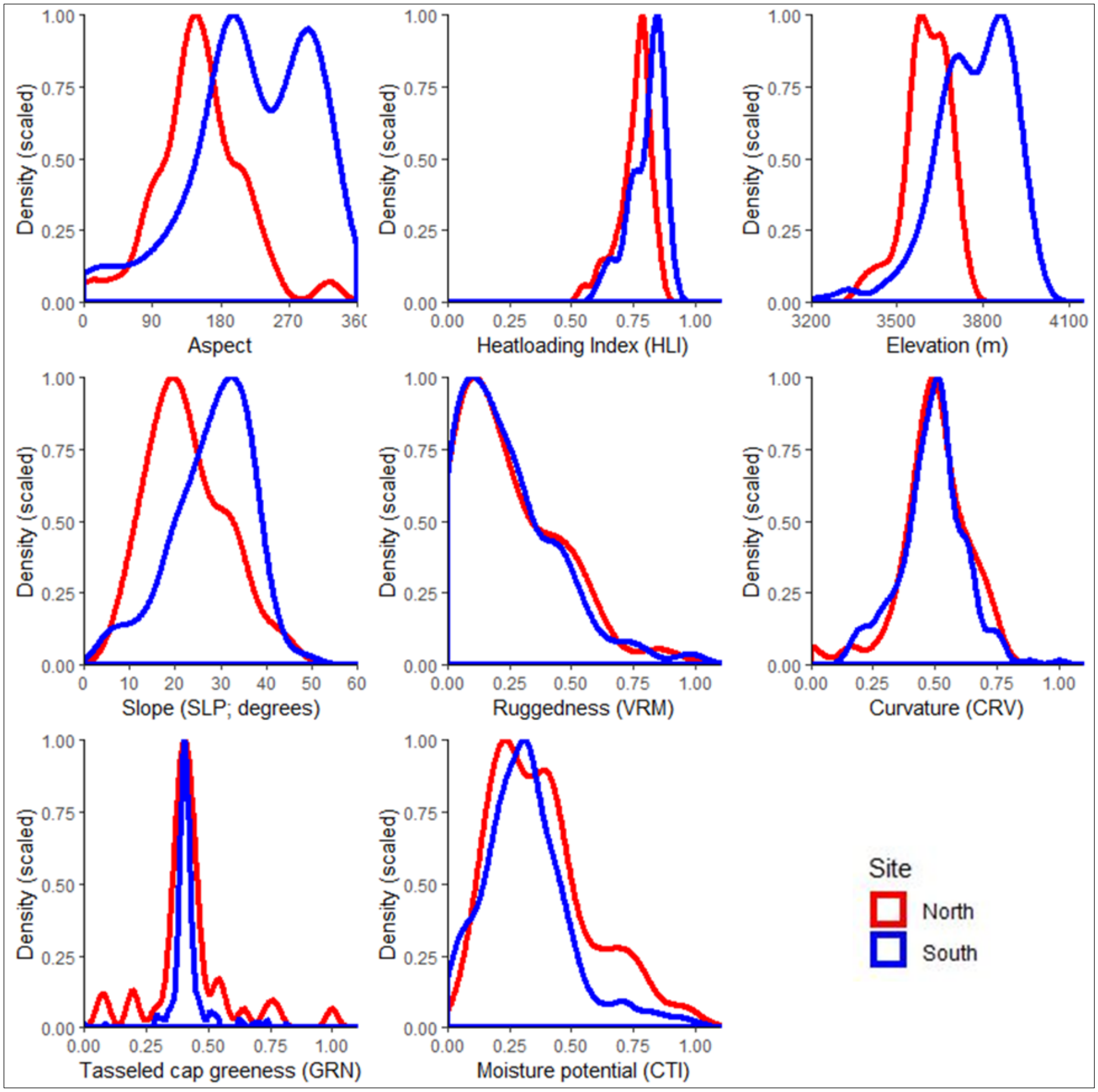

Figure 12. Kernel density plots (e.g., smoothed histograms) showing the distribution of descriptive landscape covariate values observed in our survey location data from 2017 and 2018, delineated by site. The covariates depicted represent the landscape covariates we considered in our RSF model selection; detailed descriptions of each covariate are listed in Table 1.

In the first model selection tier, selection was generally greater for lager spatial grains and quadratic relationships across all covariates (Table 4). There was a clear top spatial grain and functional form for VRM, CRV, CTI, GRN, and NDVI. Model selection uncertainty existed for functional forms of HLI and COSASP and for functional forms and spatial grains of SLP.

Table 4. Results from our first RSF model selection tier of univariate models. Spatial grain(s) and functional form(s) ranked <4 ΔAICc for each covariate are listed. See Table 1 for covariate descriptions

Covariate (abv.)	Spatial grain	Functional form*
CRV	400	sq
SLP	400,100	li, sq
VRM	400	sq
CTI	400	sq
GRN	400	sq
NDVI	400	sq
HLI	100	li, sq
COSASP	200	li, sq

*sq = quadratic, li = linear

In the second model selection tier, HLI was selected over COSASP in the temperature suite and GRN was selected over NDVI in the landcover suite (Table 5). In the terrain suite, the two most supported models included CRV, SLP, and VRM at the 400 m spatial grain and differed only by the functional form of SLP, with the linear form top ranked. There was no additional selection performed in the moisture suite in the second tier because we saw clear support for one CTI model in the first tier. The landcover suite received the most support between suites based on ΔAICc model

Table 5. Results from our second RSF model selection tier of competing univariate models and top within-suite models. Models ranked <4 ΔAICc within each suite are listed. Within and across suite model results are listed. Results are arranged by within suite AICc ranking. The number of parameters (K) and AICc weight (*wt_i*) are also presented. See Table 1 for covariate descriptions

			Within suite		Across suites	
Model	K	AICc	ΔAICc	wt_i	ΔAICc	wt_i
Terrain						
$CRV400 + CRV400^2 + SLP400 + VRM400 + VRM400^2$	6	4124.39	0.00	0.61	111.84	0.00
$CRV400 + CRV400^2 + SLP400 + SLP400^2 + VRM400 + VRM400^2$	7	4125.80	1.41	0.30	113.26	0.00
Moisture						
$CTI400 + CTI400^2$	3	4129.31	0.00	1.00	113.77	0.00
Landcover						
$GRN400 + GRN400^2$	3	4012.50	0.00	1.00	0.00	1.00
Temperature						
HLI100	2	4086.80	0.00	0.65	74.29	0.00
$HLI100 + HLI100^2$	3	4088.20	1.32	0.33	75.61	0.00

selection, following our hypotheses. All other suites were >74 ΔAICc units from the landcover suite, suggesting overwhelming support for landcover as the most informative suite (Burnham et al. 2011). We saw support for all of our covariate-specific hypotheses except SLP based on the point estimates and bootstrapped 95% confidence intervals from the top-ranked model (Figure 13). The biggest difference across all hypotheses was functional form with more quadratic relationships than expected suggesting optimal values for most covariates. Slope was the only estimate whose confidence interval overlapped zero in all functional forms; thus, we cannot confidently say that we observed a difference in used and available locations across slopes. This could be due to sample variation in our location data; particularly from combining locations across sites as we observed a difference in slope means of about 10 degrees between the two sites. Alternatively, it could be variation introduced from the proportion of bears we observed foraging on vegetation or traveling to and from moth foraging areas which typically occurred on shallower slopes. We saw increased error in GRN compared to other covariates, as expected, which we believe is also be due to the proportion of bears we observed foraging on vegetation and traveling.

The final model selection tier resulted in four models that each were comprised of covariates from all suites, indicating that all suites were informative (Table 6). Model selection uncertainty between the top models was a result of covariates considered at different functional forms, particularly SLP and HLI. The top model was considered adequate for inference due to general similarities in covariates, as well as the consistency

Table 6. Results from our final RSF model selection tier of top models. Models ranked <4 ΔAICc reported and arranged by AICc ranking. The number of parameters (K) and AICc weight (wt_i) are also presented. See Table 1 for covariate descriptions

ID	Model	K	AICc	ΔAICc	wt_i
1	$CRV400 + CRV400^2 + SLP400 + VRM400 + VRM400^2 + CTI400 + CTI400^2 + GRN400 + GRN400^2 + HLI100 + HLI100^2$	12	3857.32	0.00	0.48
2	$CRV400 + CRV400^2 + SLP400 + SLP400^2 + VRM400 + VRM400^2 + CTI400 + CTI400^2 + GRN400 + GRN400^2 + HLI100 + HLI100^2$	13	3858.90	1.58	0.22
3	$CRV400 + CRV400^2 + SLP400 + VRM400 + VRM400^2 + CTI400 + CTI400^2 + GRN400 + GRN400^2 + HLI100$	11	3859.00	1.68	0.21
4	$CRV400 + CRV400^2 + SLP400 + SLP400^2 + VRM400 + VRM400^2 + CTI400 + CTI400^2 + GRN400 + GRN400^2 + HLI100$	12	3876.06	3.27	0.09

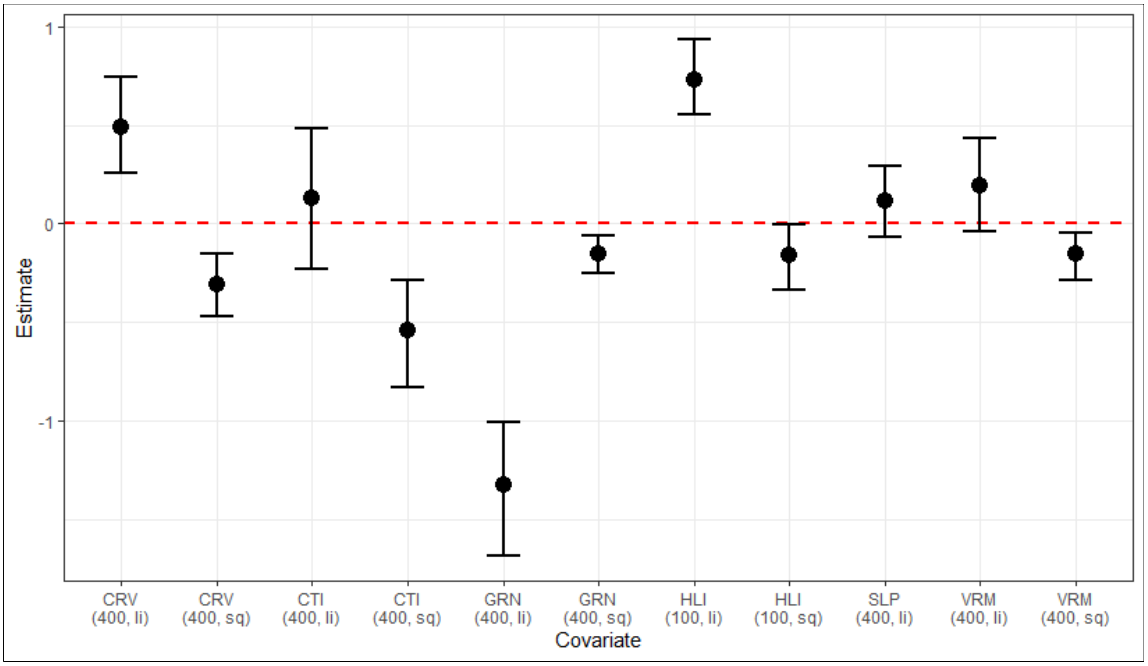

Figure 13. Point estimates with 95% confidence intervals for coefficients in our top RSF model. Parentheses below covariate names on x-axis indicate spatial grain (m^2) and functional form (sq = quadratic, li = linear). Covariate abbreviations and descriptions are listed in Table 1.

in coefficient estimates, among competitive models. Our top ranked model included quadratic forms of CRV, VRM, CTI, GRN at the 400m scale, the quadratic form of HLI at the 100m scale, and the linear form of SLP at the 400m scale. Point estimates and bootstrapped 95% confidence intervals from the top-ranked model (Figure 13) indicated that covariates characterizing terrain, moisture, heat, and landcover were important to grizzly bear resource selection at moth sites, as expected based on our hypotheses (Table 1).

Coefficient estimates from the top model (Figure 13 and 14) indicated that the probability of grizzly bear selection increased: 1) to a maximum at moderately concave-

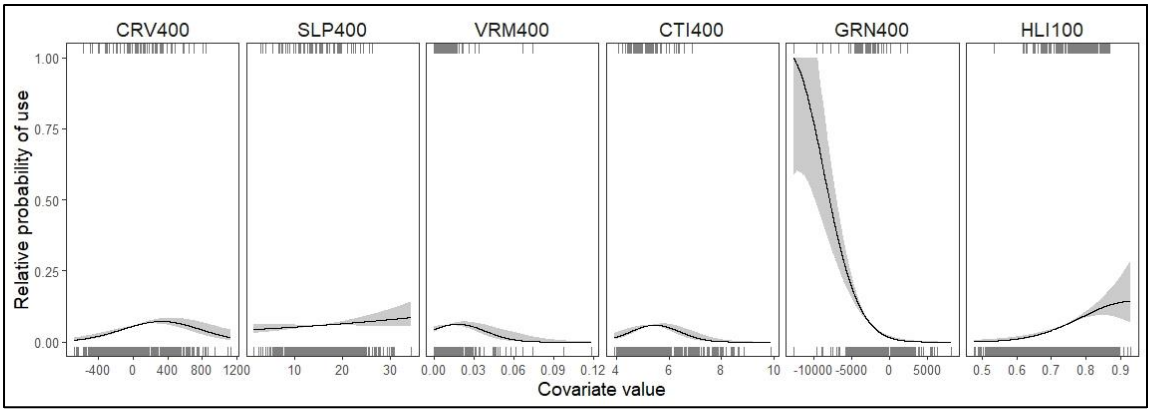

Figure 14. Predictive plots from the top RSF model indicating the relative probability of bear use for each covariate. The bands on the top and bottom of each facet represent the distribution of 'used' and 'available' data, respectively. The number after the description indicates spatial grain (m^2). All covariates had a quadratic functional form except HLI, which was linear. Covariate abbreviations and descriptions are listed in Table 1

up areas, 2) as slope increased, 3) to a maximum at moderately low levels of ruggedness, 4) to a maximum in areas with low-medium levels of moisture potential, 5) to a maximum on slopes without vegetation, and 6) to a maximum on the warmest slopes (i.e. between south and southwest). Figures 15 and 16 show our predictive surface with all our survey and opportunistic bear location data. Anecdotally, many of the bear locations in low predicted use areas were bears foraging on vegetation or traveling between foraging areas. We suspect this introduced realistic error into our RSF that signifies a more dynamic relationship of how bears are using these sites: bears are foraging on moths and vegetation and traveling between foraging areas.

The *k*-fold cross validation procedure to assess our final RSF model indicated similar variation in the predictive output across folds. We saw no concerning variation being introduced into our model from sample variations. Our spearman rank correlation between the RSF bins and the frequency of used locations was high (r_s mean = 0.74, r_s

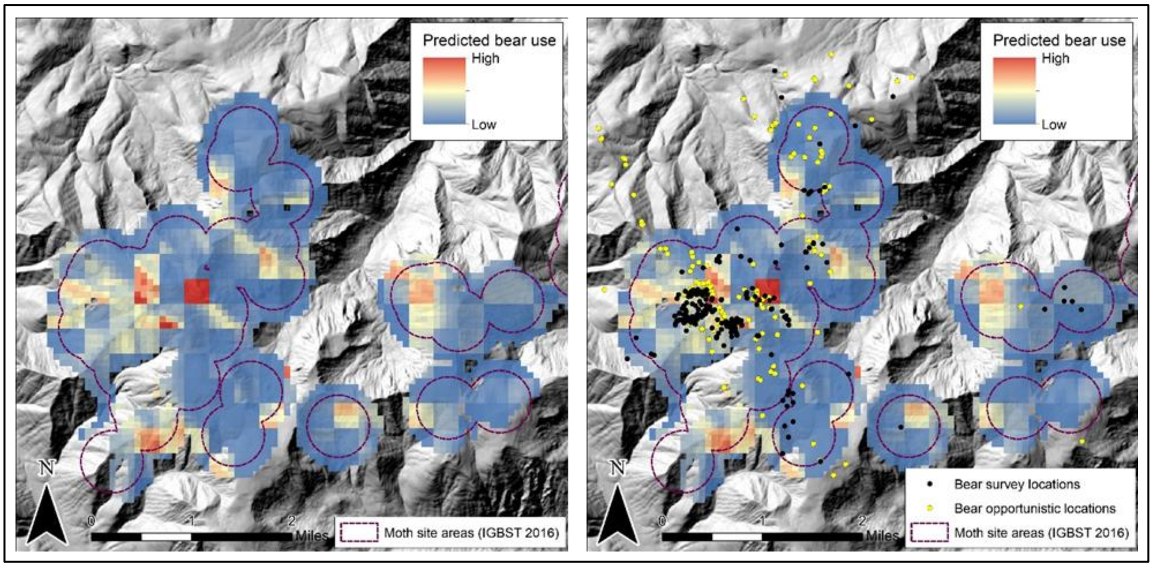

Figure 15. Two maps illustrating the cumulative probability of bear use throughout the South site derived from our top RSF model with and without bear location data (survey and opportunistic) from 2017 and 2018 for comparison.

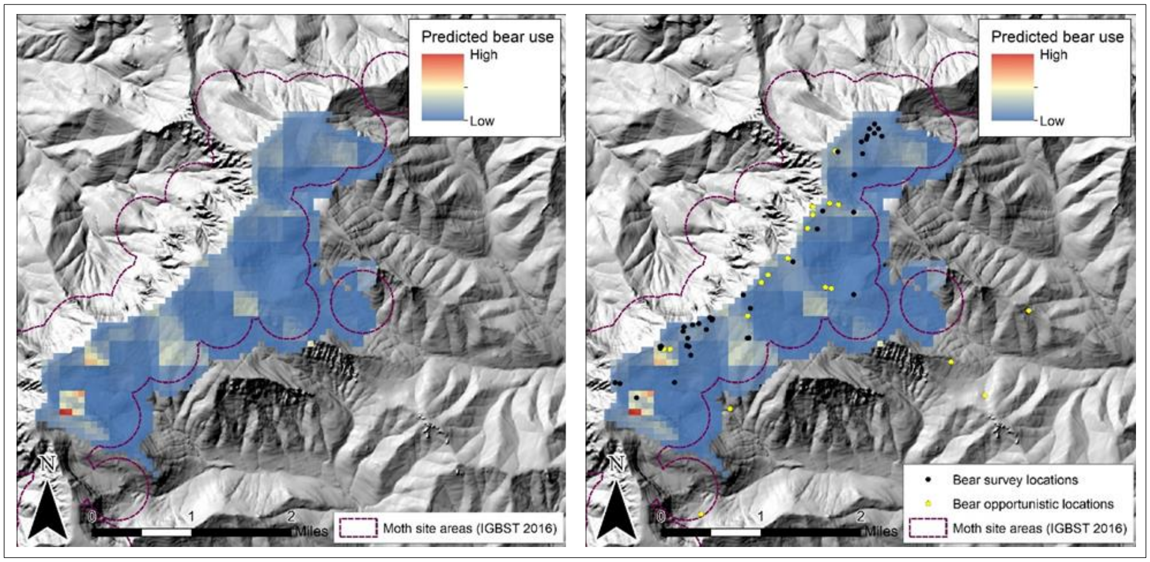

Figure 16. Two maps illustrating the cumulative probability of bear use throughout the North site derived from our top RSF model with and without bear location data (survey and opportunistic) from 2017 and 2018 for comparison

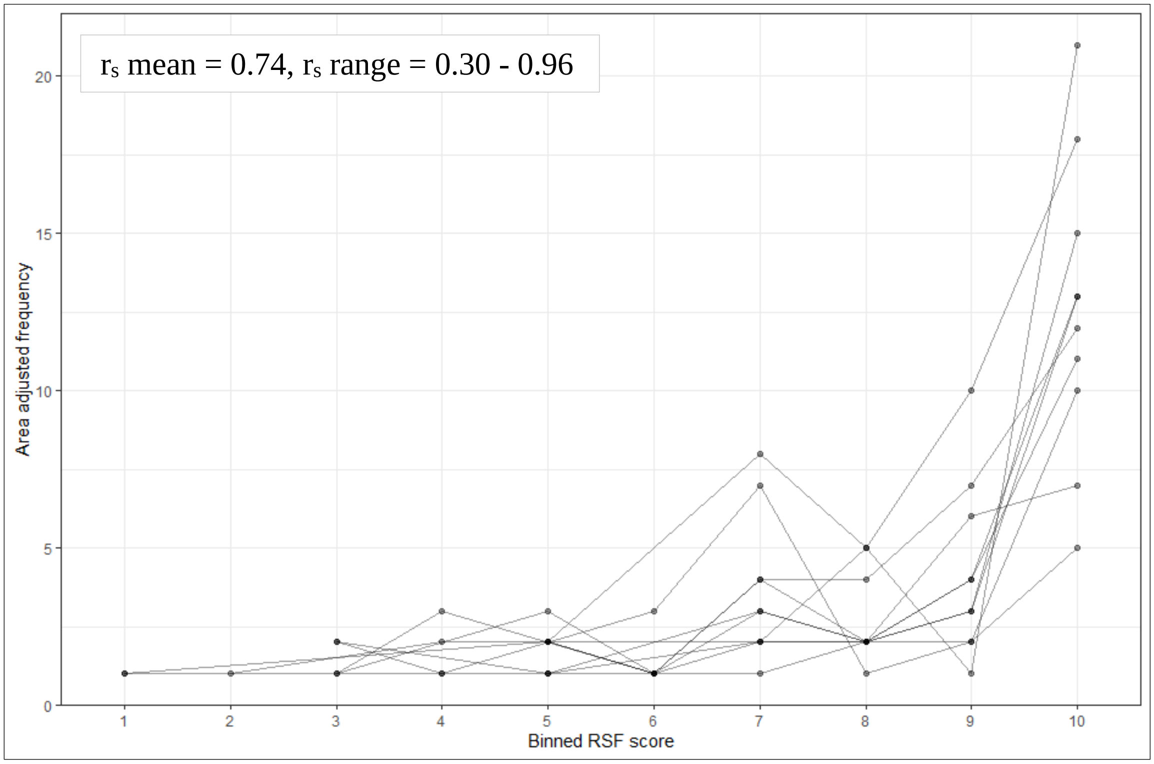

Figure 17. The k-fold cross validation results showing the frequency of RSF scores occurring in 10 equal area bins with each line representing the withheld data in each fold.

range = 0.30 - 0.96) indicating strong correlation and good predictive performance (Figure 17).

We collected a total of 376 bear scats (North site 22; South site 354) opportunistically while we were conducting field work (Figures 18 and 19). Scats were only collected if they looked relatively fresh (<2 weeks old). Table 7 lists the scat content frequency and percent volume of diet items. Because we opportunistically collected scats on the periphery of moth sites, our samples probably underrepresent moth- foraging bear scats. We collected, identified, and pressed 34 plant samples from our study sites in 2018 to aid with scat analysis plant identification (see Appendix B).

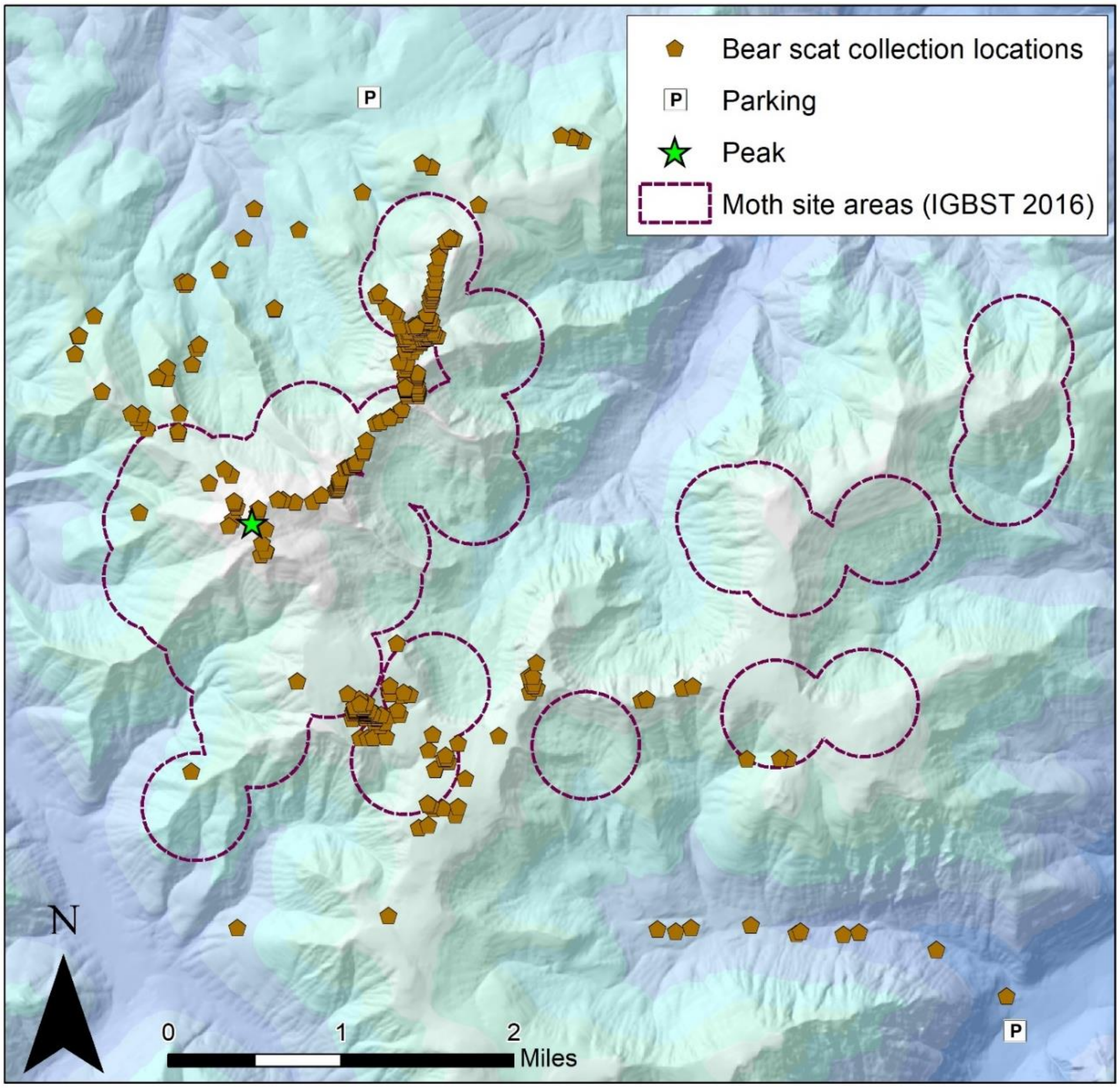

Figure 18. Opportunistically collected bear scat locations at the South site in 2017 and 2018

Major diet items included *Euxoa auxiliaris*, roots and tubers, *Poa* spp., *Trifolium* spp., and *Carex* spp. We were not able to confidently differentiate root and tubers species in all scats. From our field observations of dig areas, however, it appeared that bears were eating primarily *Lomatium* spp. roots. Other roots and tubers we saw foraging evidence of included *Claytonia megarhiza, Trifolium* spp., *Oxytropis* spp., and *Astragalus* spp.

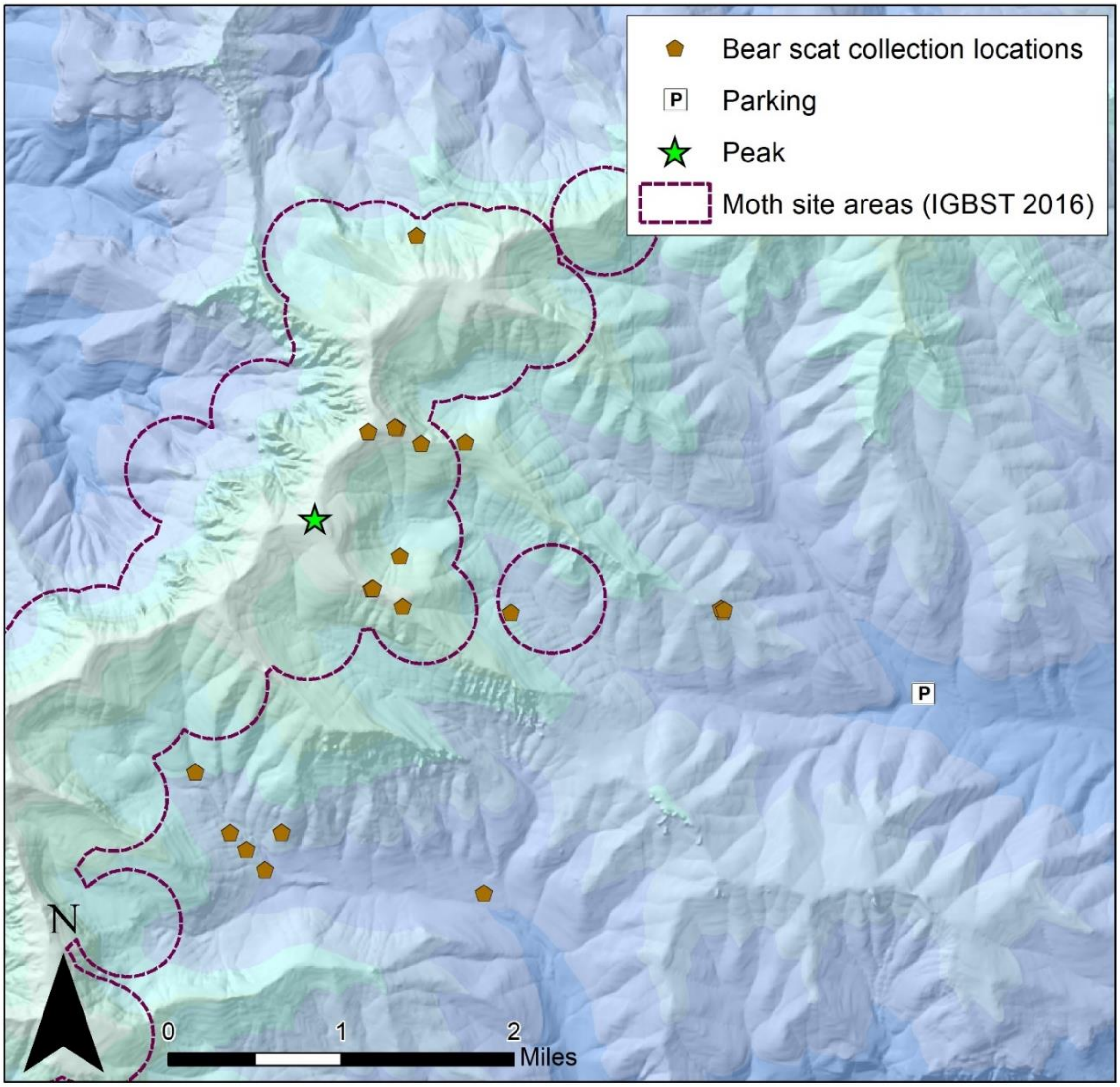

Figure 19. Opportunistically collected bear scat locations at the North site in 2017 and 2018.

We set two camera-hair snare traps at the northern site and 4 camera traps at the southern site. We collected hair from the camera-trap planks on 29 different occasions (2 from the North site and 27 from the South site). We counted a total of 87 bear visits from pictures accompanying hair collections; it is likely many of these bears were repeat visitors. Hair samples were sent in for DNA analysis where they were able to identify

Table 7. Bear scat diet analysis of scats collected at the North and South sites in 2017 and 2018. Frequency (%) and volume (%) of each diet item across all scats are listed

	% Frequency	% Volume
Insects	50.2	20.3
Euxoa auxiliaris	39.2	19.6
Formicidae	6.3	0.27
Coleoptera	3.5	0.03
Orthoptera	0.8	0.36
Other	3.5	0.04
Graminoids	94.1	33.3
Carex spp.	41.2	10.5
Poa spp.	65.9	16.1
Festuca spp.	5.9	0.40
Trisetum spp.	37.6	5.8
Other	18.0	1.5
Forbs	74.5	18.9
Trifolium spp.	51.8	14.0
Lomatium spp. (leafy material)	42.4	3.9
Mertensia spp.	1.2	<0.01
Mysotis spp.	3.1	0.03
Oxytropis or *astragulus* spp.	3.9	0.25
Cerastium spp.	0.78	<0.01
Other	14.1	0.73
Roots and tubers	77.6	26.6
Mammals	5.5	0.6
Rodentia	2.4	2.3
Other	3.1	3.1
Debris	4.3	0.06
Needles	3.1	3.1
Other	3.6	1.28
Pine nuts	1.6	0.02
Fleshy fruits	2.7	0.05

DNA from 11 individual grizzly bears (4 male, 7 female), 10 of which were new to the GYE known grizzly bear DNA database.

Human Use

From our human-accessibility model, we identified 6 moth sites (of 31) that were most accessible to human use (Figures 20 and 21). We identified two moth sites to focus our field efforts based on our model output and discussions with SNF personnel where they identified areas perceived to have the highest potential for immediate concern (Andrew Pils, personal communication). These sites are referred to as “North site” and “South site”.

Across all methods, we documented a total of 34 and 36 hiking groups (79, 93 people) at the South site in 2017 and 2018, respectively. At the North site, we documented a total of 3 and 3 hiking groups (7,3 people) in 2017 and 2018, respectively. Across all hiking group observations, we documented a mean group size of 2.4 people (range 1-12 people/group). Human use was concentrated in August both years, but hiking groups were documented throughout both field seasons (Figure 22). We documented an average of 3.2 hiking groups per week (range 0-7 groups/week).

We recorded a total of 54 groups (77% of all observed hiking use) accessing the southern moth site across both summers. Of these, we documented a total of 38 groups

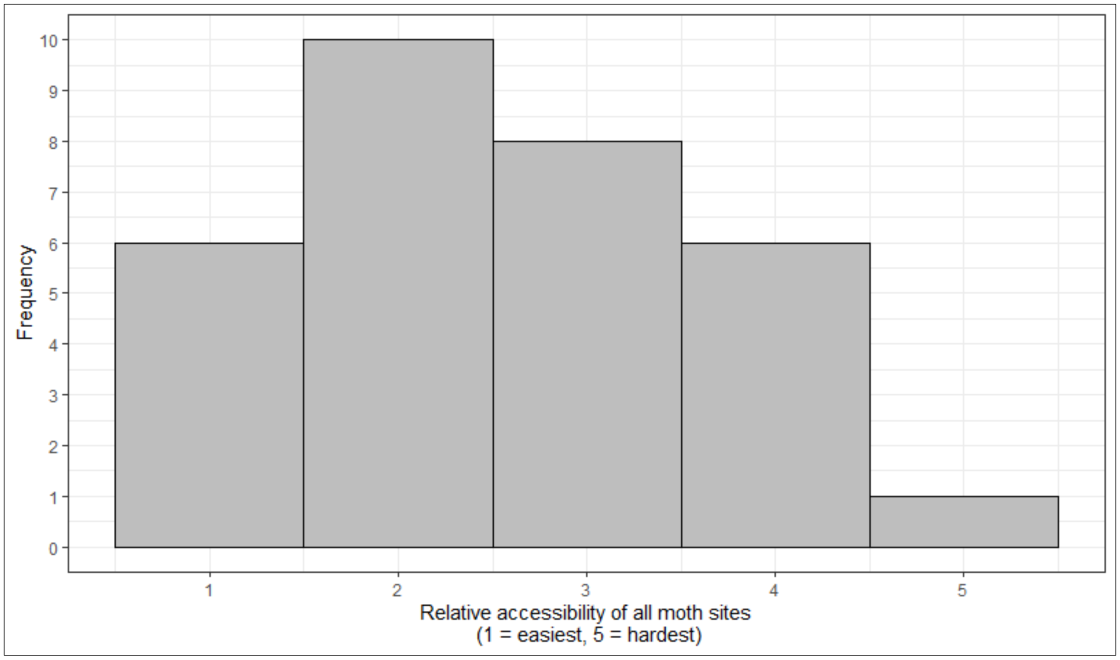

Figure 20. Frequency of relative accessibility for all moth sites in the GYE (n = 31).

(54% of all documented hiking use) accessing the peak area. We documented no groups accessing the moth site area or peak at the northern site

Our human use monitoring efforts varied in success at documenting human use associated with moth sites. Trailhead monitoring was the most successful documenting 61% of all human use followed by peak log entries (38%), and opportunistic documentation (11%).

Trailhead monitoring efforts and results are listed in Table 8. Most vehicle traffic documented (80-90%) was associated with recreational ATV travel only. This was particularly true at the southern trailhead at the South site where most groups were traveling past the trailhead to access other areas of interest.

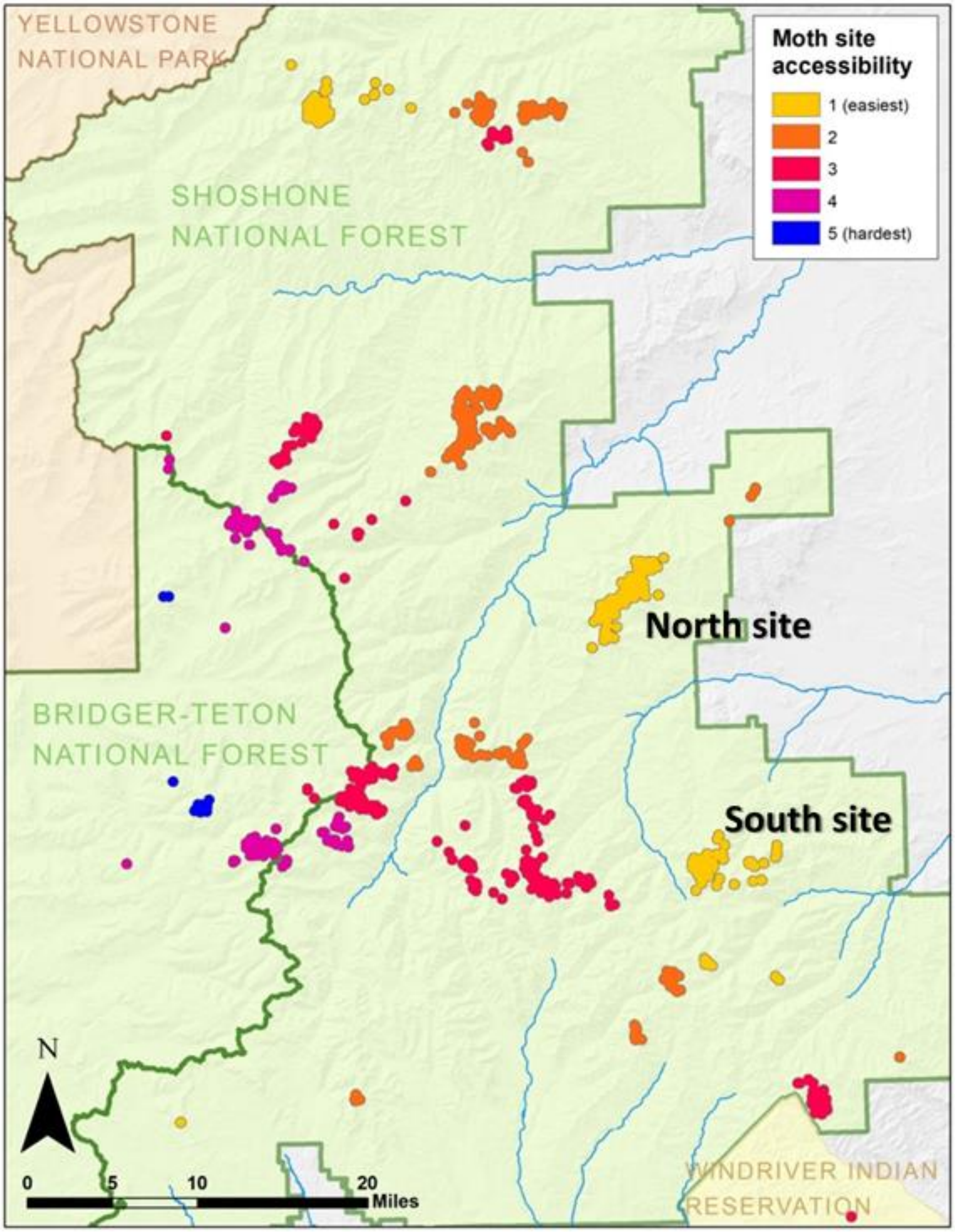

Figure 21. Human accessibility model indicating relative accessibility (e.g., remoteness) from trailheads for all confirmed moth site complexes in Greater Yellowstone Ecosystem (Bjornlie and Haroldson 2018). Spatial data for moth site boundaries was provided by the IGBST. This study focused its efforts on the “North” and “South” sites

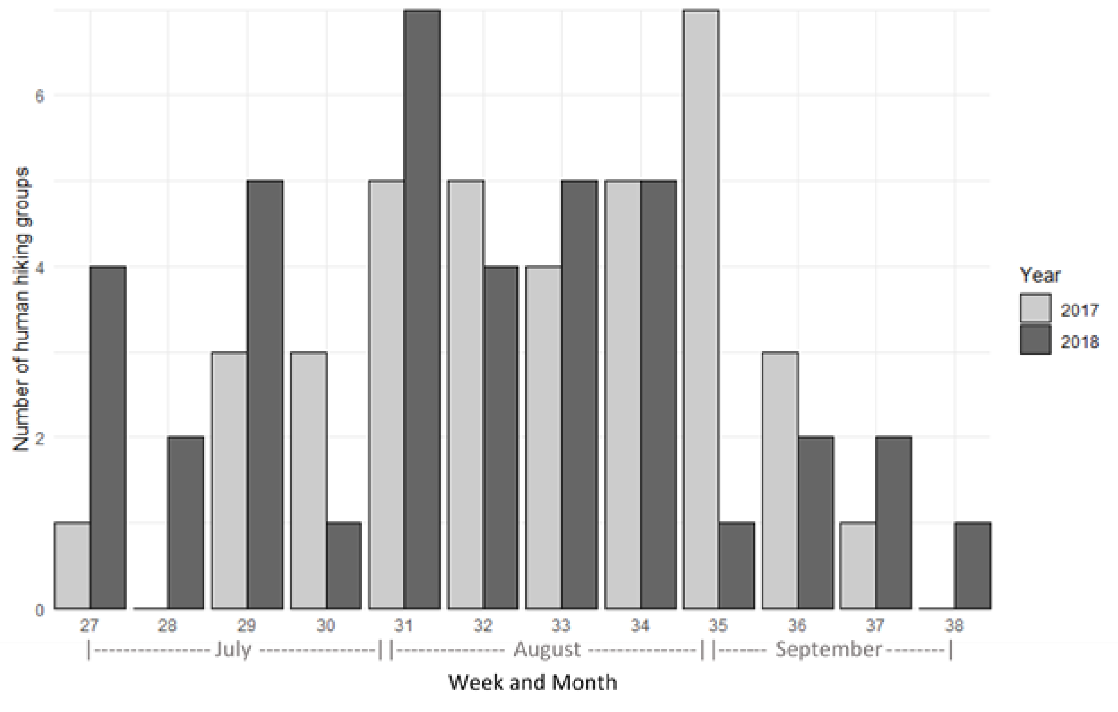

Figure 22. Number of hiking groups recorded by week and month at the South Site in 2017 and 2018.

Table 8. Trailhead monitoring efforts and observed vehicle and hiking activity at the North and South sites in 2017 and 2018

	Number of days spent trailhead monitoring		Vehicles documented		Hiking groups documented	
	2017	2018	2017	2018	2017	2018
North site	0	21	0	15	3	3
South site						
Northern trailhead	15	38	65	129	14	18
Southern trailhead	5	27	66	687	3	8

We recorded a total of 2 post-trip surveys at the North site and 38 surveys at the South site across both years. Reason for visitation for both sites is listed in Table 9; visitation was often dual purpose (i.e. climbing and bear viewing). We documented both

Table 9. Primary reason(s) for visitation for hiking groups at the North and South site in 2017 and 2018

Reason for visitation	North site	South site
Peak climbing	0%	59%
Bear viewing	0%	34%
Photography & film	0%	24%
Hunting	83%	29%
Day hiking	0%	12%
Other or unknown	17%	5%

local and non-local groups utilizing the peak. Local groups were from the Big Horn Basin of Wyoming and non-local groups were documented from California, Utah, Illinois, Idaho, Montana, Colorado, and Nevada. Source of information for groups visiting these sites often included word of mouth for local groups but also online climbing websites such as summitpost.org and peakbagger.com for non-local groups.

We were only able to obtain reliable vehicle counter data from 2018; however, observations from our field efforts indicated similar vehicle use occurred during both years across all trailheads. At the northern site, vehicle counters documented 31 vehicles in 2018. At the South site, northern trailhead, vehicle counters documented 180 vehicles in 2018. At the South site, southern trailhead, vehicle counters documented 90 vehicles in 2018. At this last site, we ended up installing the vehicle counters in the parking lot (small lot, room for about 4 vehicles) rather than the access road. This was because most traffic on the access road was associated with recreational vehicle travel or commercial logging with vehicles passing by the trailhead to access other areas and was not associated with access to moth sites. Instead, we recorded vehicles parked for more than an hour at this trailhead.

After post-season review of our trail counter data in 2017, we eliminated this method for the remainder of the study due to their ineffectiveness in accurately counting human use. Reasons for ineffectiveness for this study include 1) lack of established trails and dispersed human use resulting in high likelihood of missing human users, 2) frequent wildlife (e.g., elk, bears, and coyotes) use at these sites and our inability to confidently separate human from animal use. Future studies should consider these complications if using infrared trail counters in high elevation areas with no established hiking routes.

We documented peak log entries from 14 and 12 climbing groups at the South site in 2017 and 2018, respectively. We documented only one peak log entry at the North site, but it was associated with USFS radio repeater maintenance with access via helicopter. Our peak log surveys collected group data from 6 and 8 groups at the South site in 2017 and 2018, respectively. Of the 48 groups we documented making it to the South site peak across all methods, only 29 (60%) were documented in the peak log or peak log survey.

We documented a total of 6 and 0 groups opportunistically at the South site in 2017 and 2018, respectively. We documented a total of 2 and 0 groups opportunistically at the North site in 2017 and 2018, respectively. Opportunistic groups were typically documented while we were conducting bear occupancy surveys. We also documented one group with a game camera set up on a bear hair snare trap.

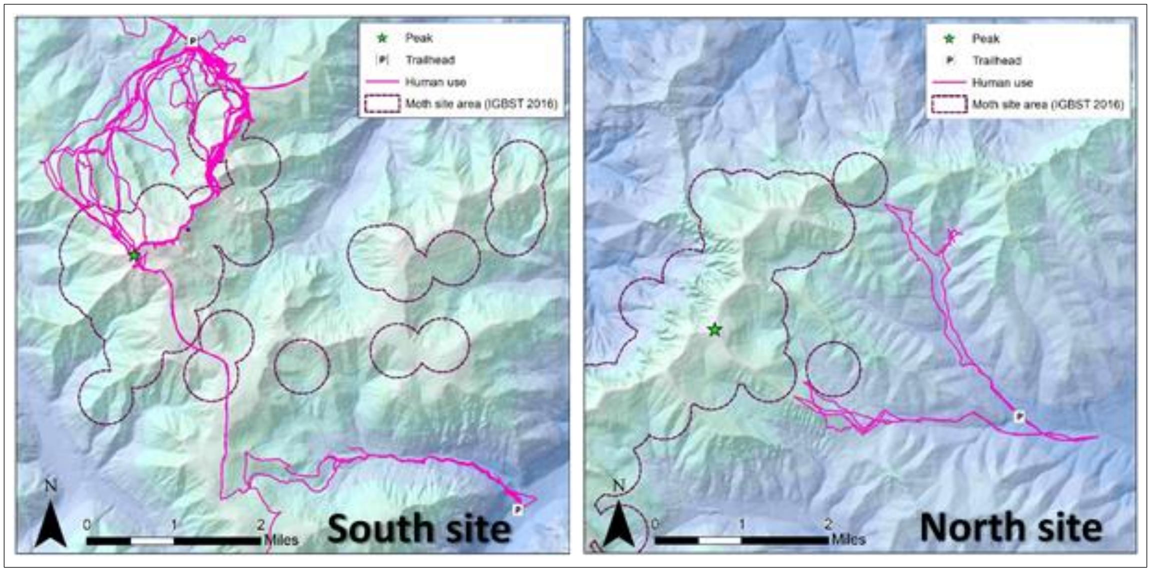

Figure 23. Hiking route data from 2017 and 2018 at the North and South sites.

We obtained a total of 47 routes from human hiking groups at the South site across both years and 3 routes at the North site (Figure 23). Routes were mostly collected using GPS units (68%), but in some cases (i.e. GPS malfunction) routes were digitized (32%) based on verbal and visual descriptions from hiking groups.

All route data collected was combined and used to perform a density analysis on the human use routes. At the South site, one route from the northern trailhead indicated high density of use. All other routes were dispersed or had so little use that they either resulted in low to no use density (Figure 24).

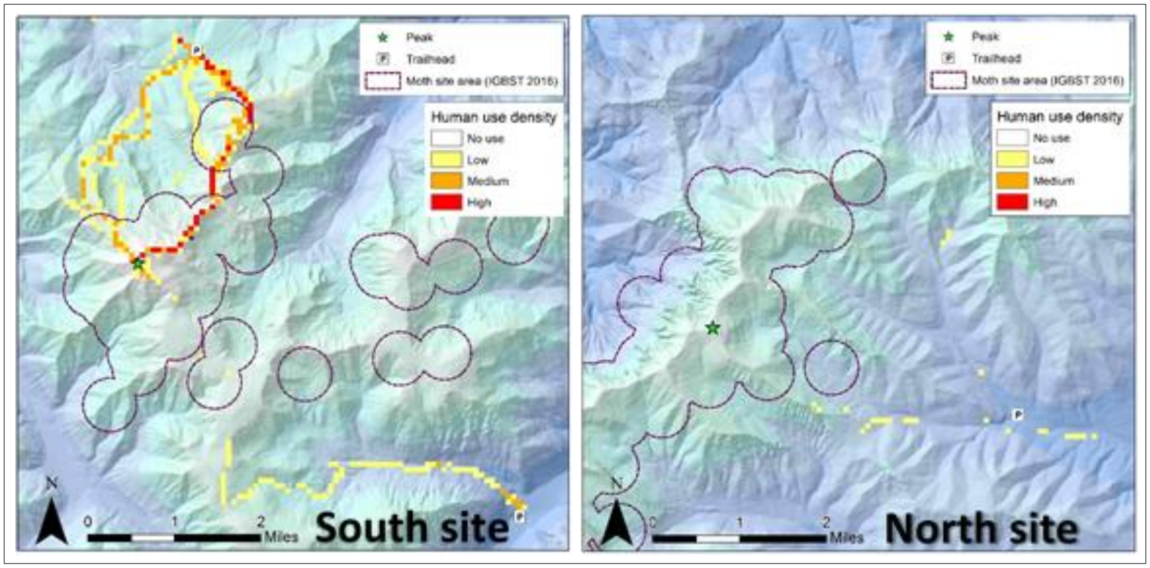

Figure 24. Density of hiking route use in 2017 and 2018 at the North and South sites

<u>Human and Bear Use Overlap and Interactions</u>

The additive bear and human use surface estimated high human and bear use overlap along the primary climbing route and immediately around the peak at the South site (Figure 25). We identified no human and bear use overlap at the North site

We found very similar overlap patterns from our interaction data, validating the additive surface. We recorded a total of 43 interactions between humans and bears at the South site and no interactions at the North site We were able to collect approximate human location data for 29 of the interactions. Of the known locations, most interactions occurred around the peak (14/29) or along the primary route (12/29) (Figure 26).

No interactions resulted in immediate physical harm to humans or bears. Our surveys indicated that around 80% of the interactions resulting in grizzly bears running or walking away from humans and the other 20% resulted in bears obviously noticing

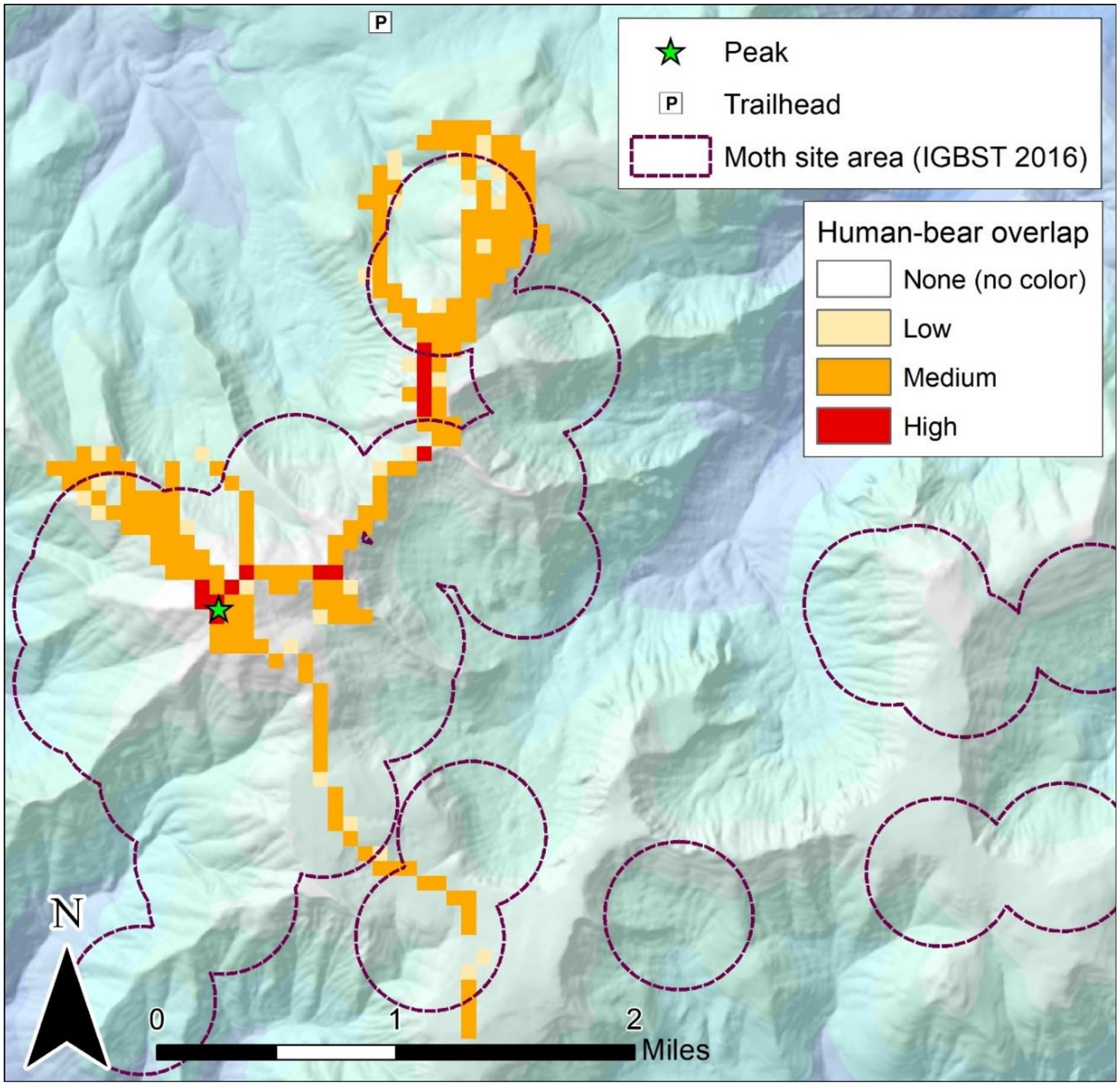

Figure 25. Additive human and bear use surface divided into four equal-quantile bins to estimate the level of overlap at the South site

humans but returning to prior activity. Across all interactions, 44% (19/43) involved sows with cubs. Lone adults were involved in 21% (9/43), subadults were involved in 19% (8/43) of the interactions, and bear cohort was unknown in 16% (7/43) of the interactions. Interactions were reported to occur at an average distance of 171 meters but ranged from 9 to 1000 meters.

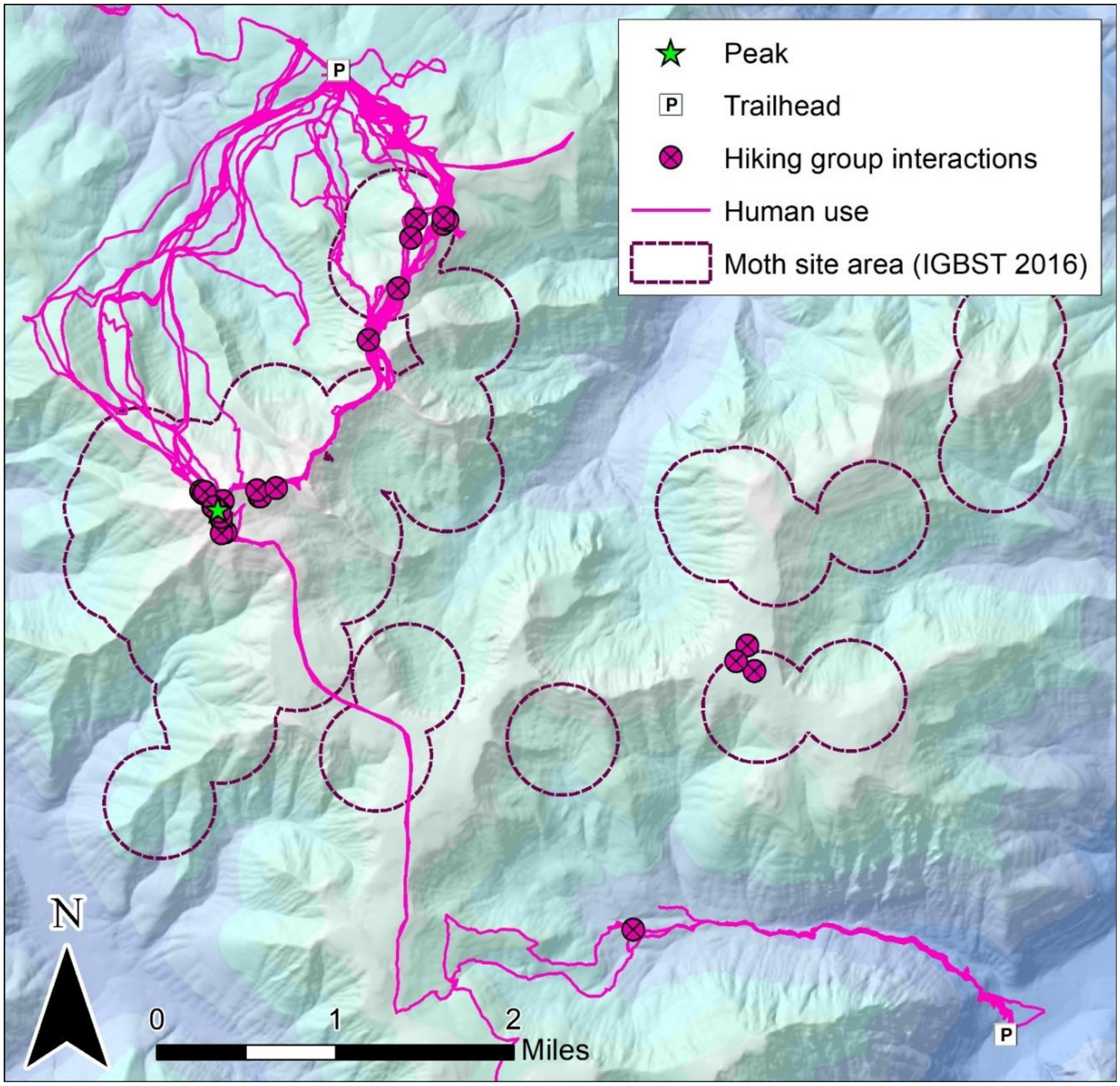

Figure 26. Approximate human locations for 29 human and bear interactions at the South site in 2017 and 2918. No interactions were documented at the North site

Although avoiding bear disturbance and maximizing crew safety was paramount, interactions were unavoidable while working in such an exposed environment with high grizzly bear density. We experienced a total of 25 interactions with bears during 2017 and 2018 (Figure 27). Interactions occurred at an average distance of 269 meters but ranged from 40 to more than 1000 meters. Bears typically ran as soon as they sensed us,

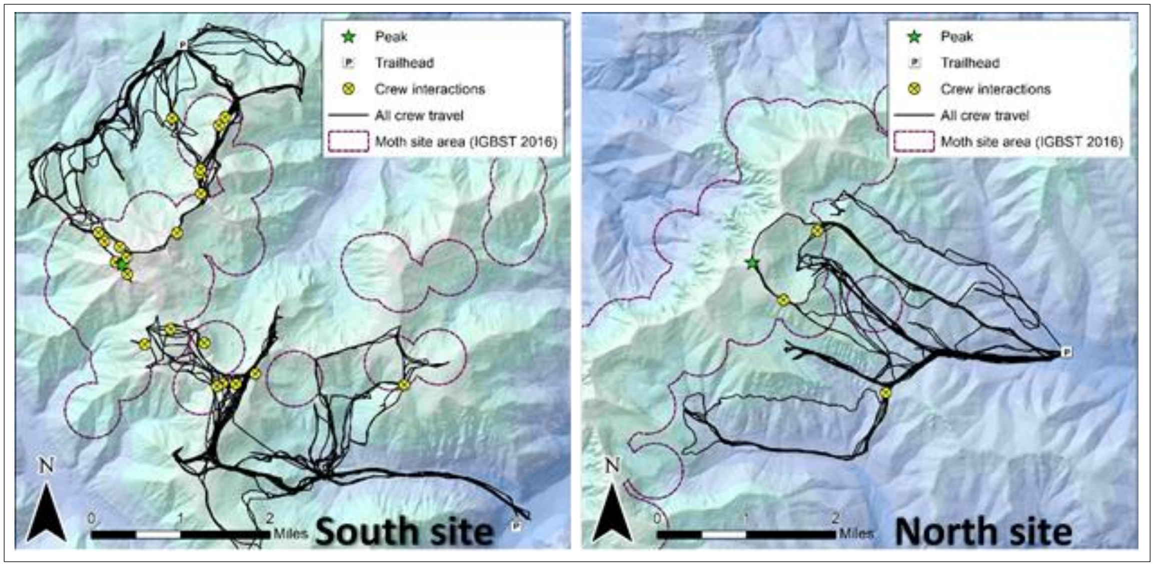

Figure 27. Crew locations for 25 human and bear interactions experienced at the North and South sites in 2017 and 2018

but in several instances they walked away unconcerned. Bears most often reacted to our presence after seeing us but we documented three cases where bears scented our tracks, from up to an hour prior, and took off running without ever seeing us.

Our interactions were more widespread than what we documented in public hiking groups. Because we knew the interaction 'hot-spots' near the South site peak, we were able to avoid many of the interactions with bear family groups observed from the public hiking groups. Instead, our interactions tended to be with bears on the periphery of the moth sites, in less predictable areas, with individuals foraging on vegetation or travelling to or from the moth site. Of the 25 total interactions, the majority (60%; n=15) of interactions were with lone adults followed by family groups (20%; n = 5) and subadults (20%; n=5).

DISCUSSION

Bear Use

We observed grizzly bears at moth sites from late June through mid-September in 2017 and 2018. We observed the most bear use from the second week of July through the second week of August both seasons. Peak bear use was very similar to timing of peak moth captures in O'Brien and Lindzey (1994) which was reported to be between 26 July – 6 August in 1991 and 1992 in the GYE.

We documented far more bear use at the South site compared to the North site. However, we believe the differences we observed were almost entirely due to sampling bias because the portions of the North site that we did not survey (north and west slopes, steeper and more talus) reportedly see more concentrated bear use (Andy Pils, personal communication). Aerial observations from routine flights indicate that the North site is consistently one of the highest bear use sites in the GYE (Andrew Pils, personal communication).

With our sampling bias in mind, it was apparent that differences in topography across surveyed areas contributed to variation in the bear use we observed. The areas at the North site that we surveyed were almost entirely shallow cirque-like basins perpendicular to a continuous ridgeline. These slopes did not lend to optimal (> 15cm deep) talus formation for moth foraging and included the presence of stabilizing vegetation on slopes too shallow (<20°), both inhibiting active talus formation (O'Brien and Lindzey 1994). Consequently, we suspect that most of the bear use we observed on the shallower talus slopes at the North site was associated with vegetation foraging activity rather than moth foraging as we initially thought. This became apparent after finding a total lack of moth evidence (e.g., old moth carcasses typically present at moth aggregations) while digging on several slopes that we had primarily recorded moth foraging bear activity. Instead, we found evidence of vegetation foraging for biscuit root (*Lomatium* sp.) and several clover (*Trifoliuim* sp.) species growing intermittently throughout the talus.

In contrast, the South site is one large massif with consistently steep (~30°) drainages running from the peak down to low elevations in almost all directions resulting in more consistent and widespread active talus formation throughout the site (O'Brien and Lindzey 1994). This apparently contributed to increased foraging opportunity assuming bear concentration is reflective of moth abundance and foraging cost-efficiency, particularly on three slopes directly below the South site peak where we observed concentrated use (up to 22 bears on one slope). Although it was common to see all cohorts feeding in close proximity, without social tension, on these slopes, our surveys did show some pattern in cohort use between these three primary slopes. We believe differences in use reflect a social hierarchy associated with primary foraging opportunities. All three slopes were similar in elevation (~3,800 m) and slope degree (~30°) but ranged in aspect (south-southwest, east, and northwest). We observed more concentrated use by lone bears on the west and south-southwest slopes and more concentrated use by family groups on the northwest slope. Previous literature indicates that moths show an apparent preference for warmer south to southwest facing slopes, which were the slopes where most lone bears observed (Mattson et al. 1991, O'Brien and

Lindzey 1994). From this we infer that the west slope held the highest abundance of moths followed by the south-southwest and northwest slopes, respectively.

We did not conduct surveys throughout the day and bear activities we reported are only reflective dawn to early afternoon bear activities. For this time period, we observed moth foraging to be the most common activity, similar to what has been reported in previous studies (French et al. 1994, O'Brien and Lindzey 1994, White et al. 1998*b*). If we had been able to conduct surveys throughout the day and at night, we expect that we would have seen a shift in daily patterns following the availability and cost-efficiency of foraging moths. For example, previous studies have reported that moth foraging activity almost completely subsides by mid-afternoon reflective of moths becoming harder and less efficient to forage on because moths crawl deeper into the slopes in response to warmer midday temperatures or, if they are near the surface, they are more mobile and can take flight quickly (White et al. 1998*b*). This was a shift we also observed when trying to capture moths out of the talus after about 11:00 am, a time after which collection became notably less efficient. Previous studies also report a second moth foraging period early-to-late evening when moths are near the surface staging for nocturnal activity; this is reportedly a less active foraging period and again, probably reflective of the moths being less available due to their mobility (French et al. 1994, O'Brien and Lindzey 1994, White et al. 1998*b*). To our knowledge, no one has quantified bear activities at night, although O'Brien and Lindzey (1994) speculated that there could be increased vegetation foraging in response to moth unavailability based on the number of bears they observed on or returning from adjacent vegetation areas at dawn. We observed this pattern as well particularly on the plateau south of the South site peak. Also supportive of this concept is that bear visits to our camera traps (all in vegetation areas) occurred most from late afternoon (16:00) through early morning (04:00)

At night and throughout the season, diet shifts from moth foraging to vegetation foraging based on moth availability would make intuitive sense based on grizzly bears dietary plasticity and ability to adapt to resource availability (Gunther et al. 2014). Although previous work has documented grizzly bears using vegetative resources adjacent to moth sites(French et al. 1994, O'Brien and Lindzey 1994), it was a much more important aspect of the moth-site ecology than we initially expected. From our observations, use of vegetation was observed across all cohorts and we suspect that it is a secondary food item that contributes to a dual-economy resource system. We think that bears are primarily at high elevations for the moth resource but take advantage of abundant vegetation when moths are less abundant or unavailable. This includes early season before peak moth abundance and periods when moths are out foraging on nectar or are harder to catch.

For vegetation foraging bears, roots and tubers, especially biscuit root (*Lomatium* sp.), were observed to be of particular importance from our field observations and scat analysis. Biscuitroot can have up to 30% starch and are highly digestible, making them a good food source (Mattson 1997). While collecting our plant samples, we found biscuit root masses up to 8-10 inches long with a diameter slightly larger than a quarter. Other species that we suspected grizzly bears were digging for included several clover species

(*Trifolium* sp.) and Alpine Spring Beauty (*Claytonia megarhiza*). We documented areas similar in size to a football field (plateau south of South site peak) that were extensively excavated by bears for roots and tubers (Figures 28 and 29). These sites typically appeared to receive persistent snow melt-off which contributed to forming less compacted soils due to the persistent soil moisture being susceptible to frequent frost-heave action (Nagy and Grabherr 2009). In turn, the softer soil and moisture contributed to more efficient excavation by grizzly bears and the ability for the plants to develop larger root masses. This ultimately led to ideal microsites for biscuit root excavation, as discussed previously by Mattson (1997).

Our RSF analysis followed our hypotheses based on previous literature and our observations in the field (Mattson et al. 1991, French et al. 1994, O'Brien and Lindzey 1994, Robison 2009). Although we referred to our final predictive surface as the relative probability of bear use, it important to restate that it was really a moth-bear surface because we selected covariates based on their expected influence on moth selection and abundance (i.e. talus depth, moisture, temperature, landcover) as well as their expected influence on bear-foraging efficiency (i.e. talus depth and slope degree). With this in mind, we saw increased probability of bear use in areas with: talus, higher heat loading potential (south to southwest slopes), mid-slope areas with some moisture, moderately sloped (20-30°), low-moderate ruggedness, and concave up drainages. Collectively, these relationships generally described areas of talus formation suitable for moth aggregation and cost-efficient terrain for moth foraging. To our knowledge, there are no previously published studies that have examined different spatial extents during a RSF analysis of

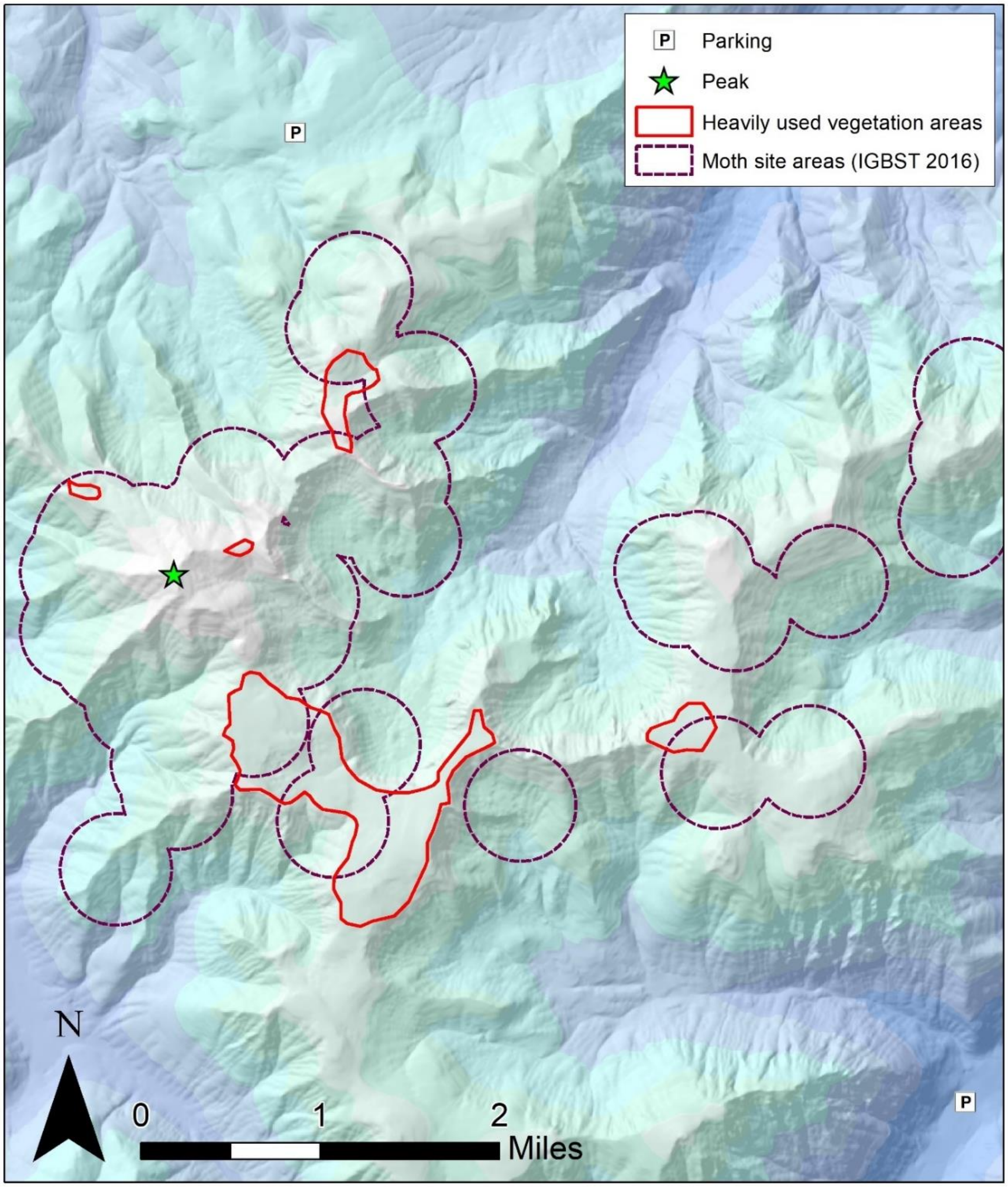

Figure 28. Vegetation areas opportunistically observed to be heavily used by bears, evident from extensive excavation and observed bear use, at the South site in 2017 and 2018.

Figure 29. A photo example of an area heavily excavated for roots and tubers by grizzly bears on the southern plateau at the South site in 2017. Note the density of excavations and bear scats.

bear use at moth sites. We believed exploration on this topic was important to get a better sense on how bears are using these sites. We generally saw selection for larger spatial extents ($400m^2$ vs. $100m^2$ or $200m^2$) suggesting that bears are selecting foraging areas on more of a drainage-wide scale rather than specific slopes or areas. If we continue to assume that bear selection is directly reflective of moth availability this could mean a number of things. For example, this could suggest that moths are more dispersed and foraging opportunity for bears is drainage specific over slope specific. Although our predictive model of bear use performed relatively well based on internal validation, there were some bear locations (both survey and opportunistic) that occurred in low predicted use areas. It is likely that our small sample size (n=266), as well as grizzly bear use of adjacent vegetative areas, introduced some uncertainty into the model.

We considered our camera hair snare traps a success at alpine moth sites. Notably, the majority of the DNA samples (10/11) were from new individuals to the GYE database. Future work building off of this initial data set will help us understand the importance of these sites to the GYE grizzly bear population (Dan Tyers, personal communication). Overall, our methodology worked and attracted a lot of bear-attention and provided some great pictures (Figures 30, 31, 32). The plank set-up proved mostly bear-proof (i.e., bears were not able to destroy or move it) but we had persistent problems securing the camera in a spot that did not attract grizzly bear investigation. This proved very hard to do in the rocky terrain. Rock cairns were most commonly used to ‘hide’ the camera but were often tampered with. Boulders tall enough to get the camera at least 7-8 feet off ground while still providing a way to use the ratchet strap to secure the camera were uncommon but worked well for one of our camera setups. Another method with potential that we did not consider until field work was completed is to directly secure a camera to a rock by drilling and installing gear on which the camera can be mounted and should be considered in future work.

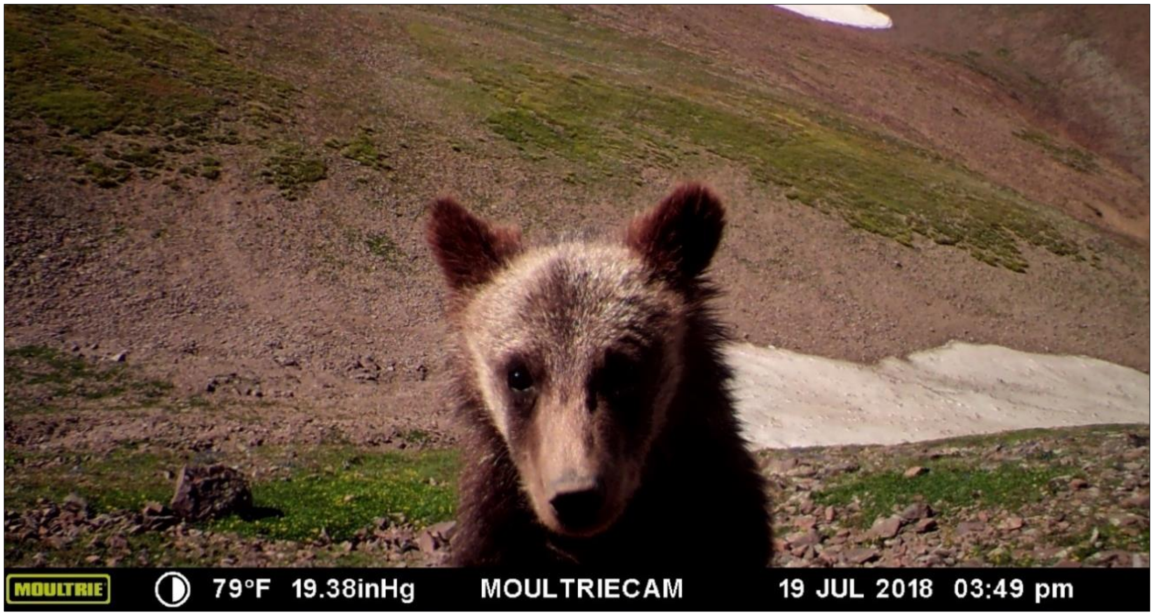

Figure 30. Camera trap picture of a young lone bear noticing the camera and approaching for closer investigation, July 19, 2018.

Figure 31. Camera trap picture of a family group consisting of a female with three cubs of the year in, July 28, 2018.0

Figure 32. Camera trap picture of a ‘bear pile’; a family group consisting of a female with three cubs of the year that are fat, furry, and almost ready for hibernation, September 6, 2018.

Human Use

Our human accessibility model provided useful insight for prioritizing human use monitoring at moth sites in the GYE. We identified six moth sites (out of the 31) that were most accessible to human users. Based on our field efforts, access to the most accessible sites requires a minimum of about 1-1.5 hours on a rough dirt road and at least 1-1.5 hours hiking to reach the moth site boundary. An additional 1-2 hours of highway travel was typical (for visitors from the Big Horn Basin) resulting in a full day or overnight trip for most groups. With these travel times in mind for the most accessible sites, we believe that all other, less accessible, moth sites in the GYE require a minimum 2-3-day trip to access rendering them fairly inaccessible to most visitors.

Creating a human-accessibility model may be useful for others interested in quantifying relative human accessibility, but a few things should be kept in mind. First, field reconnaissance is highly recommended to validate the accessibility model results given that site-specific factors not considered in the model may be important. For example, discussions with SNF personnel revealed that one of the most accessible moth sites we identified (but did not focus on) had an access road that is impassable most of the year and the site is realistically not as accessible as our model suggested (Andy Pils, personal communication). Second, anticipated use-type should be taken into consideration (i.e. hiking, horseback, biking) because access will look different to different user groups. Because the SNF experiences heavy horse use, we tried to design our accessibility model to account for both hiking and horse use, including campsites suitable for stock users along trails. Regardless, because our concerns were more heavily focused on hiking groups, our accessibility model became more representative of access to hiking groups. The accessibility model should be user-group specific for management utility. Finally, established models should be reevaluated with any major changes to trails, roads, or trailheads. Improvements, degradations, or closures to any of the above could have significant changes to human-accessibility and should be incorporated.

Although both of our sites had similar human accessibility, we saw very different levels of human use between sites (South site: 35 groups/year; North site: 3 groups/year). At the South site, this level of use translated to about 3.2 groups a week, with up to 7 groups a week on two occasions, or about a group every other day. We suspect this is a conservative estimate of human use because we likely missed some human use in our efforts. This estimate will likely become increasingly conservative considering that human use associated with the South site is expected to continue rising with increasing popularity of outdoor recreation (Fortin et al. 2016, Penteriani et al. 2017). The level of use observed at the South site may initially seem low but human impact is likely amplified considering the terrain exposure of these sites (O'Brien and Lindzey 1994, White et al. 1999). This was readily apparent from some of our interaction data where we recorded bear displacement from far distances (~1km), displacement from human scent (urine or tracks from hours prior), and strong avoidance reactions (bears running across drainages for >1km until out of sight).

Differences in observed human use levels between sites was largely due to reasons for visitation. At the North site, the only documented reason for visitation was big horn sheep (*Ovis canadensis*) hunting. In contrast, the South site generated interest for many different reasons. Use was primarily associated with peak climbing and/or bear viewing, but also photography, day hiking, and hunting for mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*) and big horn sheep. Because we saw so much human interest in peak climbing, we found climbing websites (peakbagger.com, summitpost.com) to be very helpful in providing initial insight on human use. In particular, summitpost.com reported the number of views of the peak information webpage and contained comments from visitors, providing a great indicator of public interest. Any future work concerned with human use at moth sites should review climbing websites.

There were no established routes or trails at either of our study sites. As a result, human use routes were affected by reason for visitation. At the North site, use was associated with hunting and people did not access the moth site area. Similarly, at the South site when human use was associated with hunting we saw dispersed use that typically did not overlap with the moth site area. However, when use was associated with peak climbing and/or bear viewing we saw concentrated use on one primary route (henceforth ‘ridge route’) from the northern trailhead.

Although there are several routes to the South site peak, use was concentrated on the ridge route because many groups were obtaining access information from climbing websites (peakbagger.com, summitpost.com) where this route is recommended. The ridge route is popular because it is the most scenic, straightforward, and efficient route to the South site peak. However, it is not necessarily the safest when considering grizzly bears. The route takes hikers along a game trail (we called it the ‘bear-highway’ due to the number of scats observed along the trail) on a relatively narrow ridge almost the entire time with little opportunity to escape in the event of an encounter. There are also numerous blind corners around rocky outcrops and blind hill crests as hikers travel along the ridge’s undulations. Furthermore, the ridge route requires travel into the wind the entire time to access the peak which reduces the chance of a grizzly bear smelling and avoiding hikers. To exacerbate the concerns associated with human travel along the ridge route, we observed that the climbing websites provided little warning about the grizzly bear density other than the generally applied ‘food storage requirements’ and ‘traveling in bear country warnings' tags. If climbing websites are a group's only information source, uneducated and unprepared human use through the moth site area will probably occur.

Human and Bear Use Overlap and Interactions

We saw high human and bear use overlap on the primary human use route at the southern site and immediately around the peak, reflective of the human use patterns discussed previously. We saw medium human and bear overlap on two alternate, less used routes at the South site. We saw no human and bear overlap at the North site. We observed peak use by humans and bears around the same time, late-July through mid-August. This happens to be an ideal time for peak climbing because of the warm weather and minimal snowpack but it is also when the most moths are available to bears.

Our predictions of human and bear overlap at the South site are probably conservative for several reasons. For one, it is unlikely that we documented all human use because we were not able to conduct trailhead monitoring all the time. Although our other human use methods captured use on the days we were not at trailheads (e.g., peak logs), we doubt all use was documented. For example, we documented that at least 8 (of 38) groups that made it to the peak did not sign the peak log. Additionally, human use is projected to increase and will likely contribute to increased overlap along the primary route and potentially more widespread overlap including areas currently seeing little or no use. Finally, our RSF model predicting the relative probability of bear use throughout our study sites was not able to capture the importance of the vegetation foraging areas and travel routes because the high concentrations of moth foraging bears was over-powering. This was especially apparent on two of the routes used to access the South site peak. The primary route and southern plateau routes pass through heavily used vegetation sites and overlap bear routes used to travel between moth and vegetative resources. Even though our overlap estimates only indicated patches of high overlap on the primary route, it was apparent that concerning levels of overlap probably exist along the entire route from the copious amount of bear sign (tracks, scat, observations). Similarly, little human use (1-2 groups a summer) documented on the southern plateau route resulted in apparently low overlap, but realistically, heavy bear use indicated that almost any human use is probably concerning. This latter observation became distinctly apparent during our field work. We ended up avoiding most of the southern plateau area because we found that bear disturbance was nearly unavoidable, even for our experienced crew. Similar observations were noted by O'Brien and Lindzey (1994) at other moth sites in the GYE.

Interactions observed from public users were predominantly in areas we estimated to have high human and bear overlap (e.g., the peak and primary route), lending confidence to our additive modeling approach. Crew interactions were more dispersed throughout the site, largely due to our more dispersed travel patterns. Although highest overlap currently exists along the ridge route where public use is concentrated, our experiences demonstrate that there is high potential for human and bear interactions anywhere in or near moth sites.

Several differences between public and crew interactions highlighted the advantage of being educated about bear use patterns at these sites. Most public interactions occurred with bear family groups near the peak. We routinely observed these family groups (1 in 2017, 3 in 2018) and learned how best to avoid them (i.e. avoid the peak). Unfortunately, climbing groups did not have this similar insight and in several cases experienced unanticipated interactions near the peak. Several groups reported reactions like ‘we immediately turned around and left before reaching the peak’. Because of our crew’s bear-awareness, our average interaction distance (269 m) was nearly 100m greater than average distance reported in public users (171 m). Our closest encounters (40 m) were in areas on the periphery of the moth sites at blind hillcrests that would suddenly put us in close proximity to a bear. The closest encounters reported by public users (9 m) were also associated with blind hillcrests, but immediately around the peak area.

There are a number of management concerns related to human and bear use patterns we observed, predominately at the South site. Human safety and bear disturbance were the prevailing management concerns, although potential for human-habituation also exists. Human safety concerns were most apparent in climbing groups with a general lack of awareness or preparedness due to lack of education presented in climbing resources. Specifically, this led to several groups with no bear deterrent (bear spray or firearms) and most groups consisting of less than 4 people (64/70) which is the recommended group size when travelling through grizzly bear country (Parks Canada 2017). This included many groups (24/70) consisting of only 1 person. For some visitors, we were able to provide education at the trailheads which resulted in groups changing plans and leaving in several cases. In one case, however, a single man from Chicago visiting to climb the peak was unaware of the bear presence until he was at the peak and able to read the peak log and noted how many people mentioned grizzly bears. Subsequently, he looked down and saw 3 bears below him. The clouds were low that day resulting in poor visibility, he was alone, and unaware of the bear density with no bear spray. This anecdote is provided to illustrate the real concerns associated with human use at this site.

Bear disturbance was acutely apparent in most human and bear interactions (80%) where we observed bears strongly avoiding human presence by running away. In some cases, disturbance resulted in bears running for more than a kilometer. Additionally, bears were disturbed not only when they saw humans but even the scent of urine or human tracks was documented to send bears running in three cases. Disturbance can result in loss of calories from time spent not foraging and from the movements to avoid human presence. Considering grizzly bears have been estimated to eat up to 2500 calories an hour, even a short period of disturbance could have a negative impact (White 1996; White et al. 1999). Anecdotally, many of the interactions we documented with public groups appeared to be with the same subadult pair or family group near the South site peak. If disturbance occurs repeatedly for the same individuals, as we documented, the calories lost over the course of a season are even more likely to have negative impacts.

In 20% of the interactions we documented, grizzly bears clearly noticed but did not react to human presence bringing up potential habituation concerns (Klaver et al. 1985). Habituation is typically associated with much higher and consistent levels of human presence (i.e. along roadways) and we are uncertain whether or not the non-reactions we observed was actually human-habituated behavior or just a general display of apathy due to the abundant food source. Regardless, habituation is certainly a management concern to be considered associated with human use at moth sites because it can lead to human-bear conflict and eventually bear removal or mortality.

CHAPTER THREE

SUMMARY AND MANAGEMENT RECOMMENDATIONS

Summary

The purpose of this project was to obtain the information needed to help guide management efforts associated with human use at moth sites in the GYE. Our objectives were to quantify bear and human use at the most accessible moth sites in the GYE and assess human and bear use overlap concerns. We identified 6 (of 31) moth sites in the GYE that were most accessible to human use. Based on discussions with SNF personnel (Andrew Pils, personal communication), we selected two of the most accessible sites perceived to have the highest potential for concern (referred to as the “North site” and “South site”). Both sites took about the same amount of time to access, although we quickly realized that only one of the sites had human use levels of potential concern.

We observed much higher levels of grizzly bear use at the South site than the North site, which we believe was mostly due to sampling bias in our surveys. We only surveyed 39% of the North site and safety concerns precluded surveying areas reported to have concentrated bear use (Andrew Pils, personal communication). From our observations and RSF analysis, bear use associated with moth foraging was generally focused on warmer (S- SW aspects), moderately angled (20-30°), talus slopes with terrain features that lent to talus accumulation and moisture retention.

We also documented heavy use of vegetative resources immediately adjacent to moth sites. The dual use of vegetative and moth resources affected the overall use of moth sites by grizzly bears.

We saw very little human use at the North site (3 groups/summer), none of it overlapping the moth site area. The South site had much higher levels of human use (35 groups/summer) with high levels of overlap along one primary route. The difference for use levels between sites was due to the favorable peak climbing opportunity associated with the South site, a large and scenic massif. We saw 59% of human use associated with peak climbing which lead to concentrated use on the primary route due to advertisement of the route on online climbing websites such as peakbagger.com or summitpost.org.

Comparison of the high human and bear use areas indicated high overlap along the primary human-use route and immediately around the peak (<100m). High overlap in these areas was validated after comparison with human-bear interaction locations where we recorded 48% (14/29) occurring on or near the peak and 41% (12/29) occurring along the primary route. Importantly, no interactions resulted in human or bear injury.

The human and bear use overlap and interactions that we documented at our South site present human safety, bear disturbance, and habituation management concerns, consistent with concerns identified in previous studies (Klaver et al. 1985, O'Brien and Lindzey 1994, White et al. 1999). The greatest human safety concern was associated with peak climbers who are unaware of the presence of grizzly bears due to lack of bear education and warnings in climbing resources. In some cases, this resulted in groups with no bear deterrents (bear spray or firearms) and often resulted in groups consisting of less than 4 people (64/70), which is the recommended group when travelling through grizzly bear country. Human safety concerns were most apparent on the primary route to the peak due to blind corners and high overlap with bears moving between vegetative and moth resources.

Bear disturbance concerns were very apparent from the human-bear interactions we recorded. Bears were very sensitive to human presence and ran away from human presence in 80% of human-bear interactions. In some cases, bears were disturbed from more than a kilometer away or from human scent from hours prior. The resulting caloric loss for disturbed grizzly bears is potentially concerning, especially if the same bears are repeatedly disturbed. We suspected this was happening with at least one family group near the South site peak.

We observed no reaction to human presence in 20% of our human-bear interactions, bringing up our final bear management concern: human habituation. Habituation is typically associated much higher and consistent levels of human presence (i.e. along roadways) and we are uncertain whether or not the non-reactions we observed was actually human-habituated behavior or just a general display of apathy due to the abundant food source. Regardless, habituation is certainly a management concern to be considered associated with human use at moth sites because it can lead to human-bear conflict and eventually bear removal or mortality.

Overall, when moth sites overlap areas that provide good mountain climbing opportunity or attract increased human use for other reasons, human and bear interactions become inevitable. Management concerns associated with high levels of overlap include human safety, bear disturbance, and habituation potential. We saw very different levels of human use between our study sites and subsequently recognized very different levels of concern. The differences we observed between sites in this study suggest that management concerns vary by site and each site should be considered individually. Accordingly, we provide different management recommendations for our two study sites.

Management Recommendations

At the North site, we documented 3 visitor groups a year. Most of this use was later in the season and involved bighorn sheep hunting. Furthermore, we did not record human use close to areas where bears were foraging for moths. Consequently, there is no apparent need for management intervention at this site. However, because it is one of the most human-accessible moth sites in the GYE, we recommend continued human use monitoring using magnetic vehicle counters.

By contrast, we documented 35 hiking groups a year at the South site. Most of this use was associated with the northern trailhead. We identified human safety, bear disturbance, and habituation concerns which managers should consider mitigating. We recommend increased public education to inform visitors of the risks inherent to traveling through the moth site. This could be accomplished by an information kiosk at the northern trailhead with site-specific educational material. It should warn visitors about bear densities and the potential for surprise encounters, and also recommend a travel route to the peak that minimizes bear disturbance and human risk. Climbing guides and other online resources are another mechanism for describing safe practices for traveling in bear country. However, this information should be crafted to avoid attracting bear viewing interest. This combination of strategies should increase the awareness of visitors traveling through the moth site. We also recommend continued human use monitoring at the South site. At minimum, this should include checking the peak log once a year. Installing vehicle counters at the northern trailhead and trailhead monitoring on weekends in July and August should also be considered.

In addition to these site-specific recommendations, we advocate that other moth sites be similarly assessed for risk of bear-human interactions. Our model indicated that 6 of 31 sites are comparatively more accessible, which gives focus to this effort. This initial analysis also demonstrates that justification for more immediate and directed management concern potentially involves only a subset of sites. The 2 sites of greatest interest to SNF managers were addressed in this thesis. A systematic assessment of the remaining sites is warranted using concepts developed here. Online climbing resources (e.g., peakbagger.com and summitpost.org) should be reviewed to measure public interest. Sites with more associated management concerns should be visited to check peak logs and identify issues and management options. In this exercise, it needs to be acknowledged that our human-accessibility model may be useful to prioritize hiker access but may not be as functional to assess horse accessibility. Finally, we recommend that managers consider areas where bears are foraging on vegetation adjacent to moth sites. Our findings demonstrate the importance of vegetative resources in combination with moth sites for bears foraging at high-elevation; a phenomenon that has been previously underestimated.

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APPENDICES

APPENDIX A

EVALUATION OF POOLED RSF MODEL

To determine if a single model that included data pooled across study sites was appropriate, we used the same *k*-fold cross-validation procedure described in the methods section but trained the model only on the South site locations and assessed its predictive performance on the withheld North site locations. We could not evaluate the performance of a model trained on the North site locations to predict South site locations due to sample size limitations. We also performed a post hoc analysis following the model selection described for the South site to assess if model performance and coefficient point estimates were affected by data from the North site.

Our evaluation of pooling the data resulted in great predictive performance for the North site (r_s mean = 0.84), indicating that pooling data was justified for these sites (Figure A1). Results from the post hoc analysis indicated that predictive performance did not change when model selection was performed only using the South site locations (r_s mean = 0.74, r_s range = 0.32 - 0.97). We did see increased certainty in the top model estimate and 95% confidence interval for slope with it no longer overlapping zero (Figure A2). Ultimately, pooling sites appears to have introduced some uncertainty into at least the slope covariate, but overall predictive performance did not change. We determined that the pooled RSF model was appropriate for further analysis.

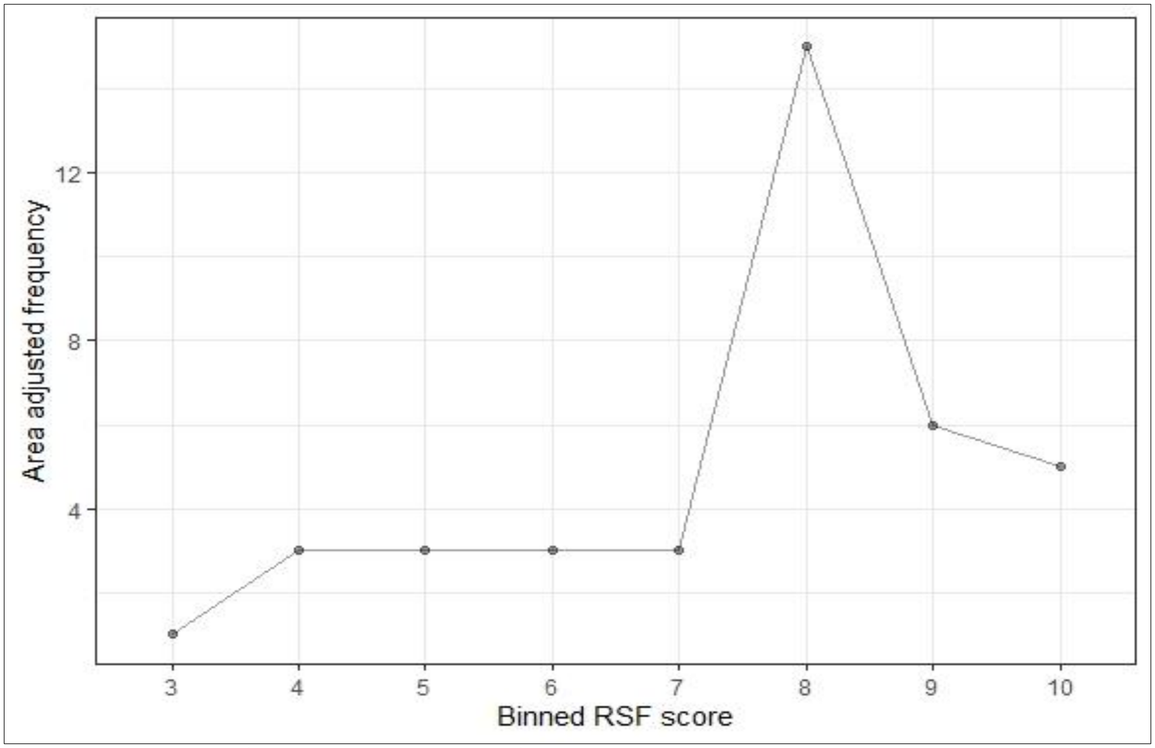

Figure A1. The k-fold cross-validation for the North site locations on the South site trained model. The figure depicts the frequency of RSF scores occurring in 10 equal area bins in withheld data. Our spearman correlation coefficient was 0.84 indicating very strong correlation and great predictive performance

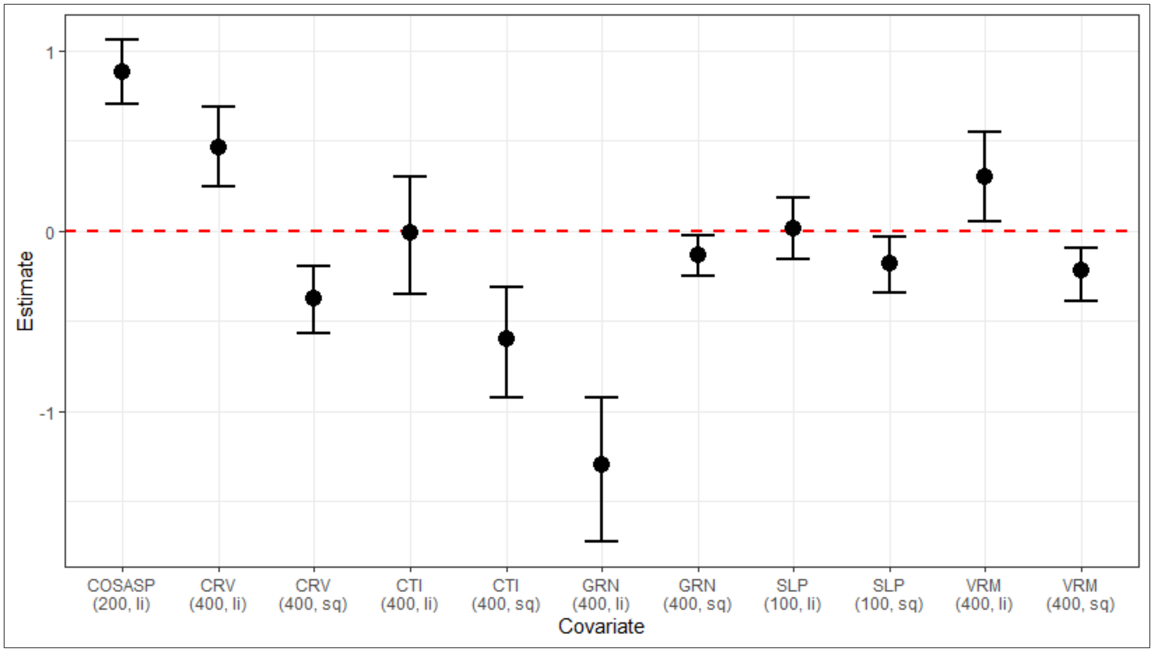

Figure A2. Point estimates with 95% for coefficient estimates in the top South site model. Parentheses below covariate names on x-axis indicate spatial scale and functional form (sq = squared, li = linear). Abbreviation descriptions are listed in Table 2.

APPENDIX B

PLANT SAMPLES COLLECTED OPPORTUNISTICALLY IN 2018

We collected and identified 34 plant species from our alpine study sites in 2018 to help with bear scat content analysis (Table B1). All samples were collected above 3650 m (~12,000 ft). Samples were collected opportunistically and should not be considered a comprehensive species list for our study sites.

Table B1. Opportunistically collected plant species at our alpine study sites, 2018.

	Scientific name	Common name	Family
Forbs			
	Lomatium cous	Biscuitroot	Apiaceae
	Achillea millefolium	Yarrow	Asteraceae
	Antennaria umbrinella	Umber Pussytoes	Asteraceae
	Chaenactis douglasii var. *alpine*	Alpine Dustymaidens	Asteraceae
*	*Erigeron compositus*	Dwarf Mountain Fleabane	Asteraceae
*	*Packera* spp.	Packera	Asteraceae
*	*Packera streptanthifolia*	Rocky Mountain Packera	Asteraceae
*	*Senecio megacaphalus*	Large-headed Groundsel	Asteraceae
	Townsendia condensate	Cushion Easter Daisy	Asteraceae
	Townsendia parryi	Parry’s Easter Daisy	Asteraceae
	Mertensia viridis	Greenleaf Bluebells	Boraginaceae
	Myosotis alpestris spp. *asiatica*	Mountain forget-me-not	Boraginaceae
	Smelowskia americana	Alpine skycress	Brassicaceae
	Cerastium beeringianum	Bering Chickweed	Caryophyllaceae
*	*Silene drummondii* spp. *striata*	Drummond’s catchfly	Caryophyllaceae
	Sedum lanceolatum	Lance-leaved Stonecrop	Crassulaceae
	Trifolium dasyphyllum	Whip-root clover	Fabaceae
	Trifolium nanum	Dwarf clover	Fabaceae
	Trifolium parryi	Parry’s Clover	Fabaceae
*	*Gentiana spp.*	Gentian	Gentianaceae
	Papaver radicatum	Artic Poppy	Papaveraceae
*	*Phlox* spp.	Phlox	Polemoniaceae
	Polemonium viscosum	Sky Pilot	Polemoniaceae
	Erigeron flavum	Golden Alpine Wild-buckwheat	Polygonaceae
	Oxyria digyna	Mountain-sorrel	Polygonaceae
	Claytonia megarhiza	Fellfield Springbeauty	Portulacaceae
	Ranunculus spp.	Buttercup	Ranunculaceae
	Potentilla ovina	Sheep Cinquefoil	Rosaceae
*	*Castillega* spp.	Paintbrush	Scrophulariaceae
Graminoids			
*	*Carex* spp.	Sedge	Cyperaceae
*	*Carex* spp.	Sedge	Cyperaceae
	Danthonia intermedia	Timber Oatgrass	Poaceae
	Poa abbreviata	Dwarf Bluegrass	Poaceae
	Trisetum spicatum	Downy Oatgrass	Poaceae

* Tentative identifications.