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Risk Analysis of Disease Transmission between Domestic Sheep and Goats and Rocky Mountain Bighorn Sheep

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Acronyms and Abbreviations

BIA – Bureau of Indian Affairs
BLM – Bureau of Land Management
BTNF – Bridger-Teton National Forest
CFR – Code of Federal Regulations
FSM – Forest Service Manual
KCS -- keratoconjunctivitis
MOU – Memorandum of Understanding
NEPA – National Environmental Policy Act
NFMA – National Forest Management Act
NFS – National Forest System
RADT – Risk Assessment of Disease Transmission
SNF – Shoshone National Forest
WGFD – Wyoming Game and Fish Department

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Background

The 1982 planning regulations (36 CFR 219.19) that interpreted the National Forest Management Act (NFMA) imposed requirements that forest plans include provisions to manage habitats to support viable populations of native and desired non-native vertebrate species on national forests and grasslands. For planning purposes, a viable population is regarded as one that has the estimated numbers and distribution of reproductive individuals to ensure its continued existence is well distributed in the planning area.

Rocky Mountain bighorn sheep (*Ovis canadensis*) are designated by the Forest Service Rocky Mountain Region (Region 2) as a sensitive species on National Forest System lands within the Region (USDA Forest Service 2016a). The sensitive species designation implies there is concern for the long-term viability and/or conservation status of bighorn sheep on National Forest System (NFS) lands in the Region (Forest Service Manual 2670.5, Beecham et. al 2007). For this reason, Forest Service Manual (FSM) sections 2670.32 and 2672.1 direct the National Forests to avoid or minimize impacts to species listed by the Regional Forester as a sensitive species. The Shoshone National Forest (SNF) supports one of the largest metapopulations of bighorn sheep in the lower 48 (the Absaroka metapopulation). On a statewide basis, the SNF is key to maintaining bighorn sheep in Wyoming (McWhirter, WGFD, pers. comm. 2017).

The primary issue of concern for bighorn sheep on the SNF is the risk of contact with, and the potential for disease transmission from, domestic sheep (*Ovis aries*) and domestic goats (*Capra aegagrus hircus*), including pack goats. Although habitat degradation from fire suppression, highways, non-native invasive weeds, and human disturbance are also concerns, the susceptibility of bighorn sheep to population declines or extirpation due to respiratory diseases, which can be transmitted by domestic sheep or goats (Besser et al. 2012b, Cassirer et al. 2013), is the greatest concern. Therefore, analyzing and disclosing the potential effects of domestic sheep grazing and domestic goat use on bighorn sheep is needed to meet Forest Service direction for sensitive species management, as described in FSM 2672.4.

In order to maintain viable populations of bighorn sheep on the SNF, there must be sufficient habitat where there is not a substantial risk for disease transmission from domestic sheep and goats. In effect, areas of domestic sheep and goat use can create “sink” habitats – habitats that are otherwise suitable for bighorn sheep, but in which bighorn sheep populations may be subject to disease transmission from domestics. In addition, once disease is introduced into bighorn sheep populations, they can transmit these diseases to other wild sheep populations. As a result, identifying areas of domestic sheep and goat use that pose a risk of interspecies contact and disease transmission, and identifying options to reduce this risk, are key aspects of bighorn sheep management on national forests.

In addition to direction provided in FSM 2670, the Forest Service Washington Office has issued several letters regarding bighorn sheep analysis for National Environmental Policy Act (NEPA) documents, which form the basis of this Risk Assessment for Disease Transmission (RADT). An August 2011 letter from the Deputy Chief of the Forest Service directs National Forest units considering projects with the potential for physical contact between bighorn and domestic sheep, with subsequent potential for disease transmission, to conduct a Risk Assessment analysis. The letter states “Forests that have necessary data, issue complexity, and the ability to conduct a quantitative bighorn sheep viability analysis may do so.

However, a qualitative approach to NEPA analysis for bighorn sheep viability is sufficient as long as clear and reasonable rationale for the decision is displayed" (USDA Forest Service 2011b).

The analysis process outlined in the letter consists of four steps:

1. Gather applicable data and information from appropriate sources.
2. Assess spatial and temporal overlap of bighorn sheep core herd home ranges with domestic livestock allotments, use areas, and driveways.
3. Assess likelihood of contact (low, moderate, high) based on spatial and temporal overlap between domestic livestock use areas and bighorn sheep herds.
4. Identify management practices with the goal of separation between domestic livestock and bighorn sheep where necessary to provide for Forestwide bighorn sheep viability.

Subsequent guidance letters were provided to (1) describe availability of products to accomplish the first two steps of the process (USDA Forest Service 2012), and (2) clarify the role of best management practices in the overall balance of multiple-use demands and management practices to support viable populations (USDA Forest Service 2014). Although these guidance letters focus on bighorn sheep and domestic sheep, the approach is also applicable to domestic goats. This RADT utilizes the four-step process outlined above and uses a qualitative approach to determine the risk of contact between bighorn and domestic sheep and goats on the SNF (see *Methods* for the rationale).

The goal of this RADT is to assess the potential risk of physical contact between bighorn sheep and domestic sheep or goats on the SNF and the subsequent possibility of disease transmission to bighorn sheep. This RADT has been developed on the basis of existing Forest Service direction, policy, and guidance and relies on the best available science regarding disease transmission and potential impacts to bighorn sheep, status of bighorn sheep on the SNF, and current information on domestic sheep and goat use of the SNF. This RADT replaces the previous version developed in support of the SNF's 2015 Record of Decision for the Land Management Plan Revision.

Key Concepts

The documents described below provide suggestions that land management agencies can consider when evaluating domestic sheep or goat activities in proximity to bighorn sheep habitat. These documents provide recommendations that can help land management agencies achieve conservation goals while also meeting multiple use mandates.

- **Master Memorandum of Understanding for the Management of Bighorn Sheep on National Forest System (NFS) Lands in Wyoming (2016)**: signed in January of 2016 by Forest Service Rocky Mountain Region and the Wyoming Game and Fish Department (WGFD). The purpose of this Memorandum of Understanding (MOU) is to document the cooperative efforts to manage bighorn sheep herds and their habitats on NFS lands in the State of Wyoming to be undertaken by WGFD and the Forest Service. Specifically, the parties agree to collaborate to implement the "2004 Final Report and Recommendations

from the Wyoming State-wide Bighorn/Domestic Sheep Interaction Working Group" (see below) on NFS lands.

- Wild Sheep Working Group, Recommendations for Domestic Sheep and Goat Management in Wild Sheep Habitat, Western Association of Fish and Wildlife Agencies (2012): A report published by 23 state and provincial wildlife management agencies. This group seeks to work collaboratively with the livestock industry to reduce the potential for bighorn sheep die-offs. The report articulates concerns about the potential for disease transmission between domestic sheep and goats and bighorn sheep, and suggests management approaches to minimize such risks.
- **Final Report and Recommendations from the Wyoming State-wide Bighorn/Domestic Sheep Interaction Working Group (2004)**: This Working Group includes Federal and state agencies, livestock producers, non-governmental organizations, and others with an interest in bighorn and domestic sheep management, and was initiated in response to concerns over bighorn and domestic sheep interactions. The group implemented a statewide approach to developing collaborative recommendations culminating in a final report in 2004. The recommendations included the need to minimize the risk of disease transmission, and to optimize preventive management procedures to ensure healthy populations of bighorn and domestic sheep. Additionally, the group mapped statewide bighorn sheep management areas and delineated them into core native herds, cooperative review areas, and bighorn sheep non-emphasis areas. Core native bighorn herds are those populations that have never been extirpated and repopulated. The group agreed that core native herds were the highest priority areas for bighorn sheep, where all efforts would be made to prevent contact between bighorn and domestic sheep within the Terms of Agreement put forth in the Wyoming Plan. Cooperative review areas encompass suitable bighorn sheep range where proposed changes in bighorn sheep management or domestic sheep use will be cooperatively evaluated.

Introduction

Historical Bighorn Sheep Distribution and Abundance

Bighorn sheep were once one of the most abundant wild ungulates in the West. Population estimates range from 1.5 million to 2 million at the onset of the 19th century (Lawrence et al. 2010, WAFWA 2012). Populations declined with the westward expansion of human populations due to overhunting, introduction of domestic sheep and goats, and overgrazing of rangelands. Bighorn populations began to decline dramatically in most areas about 1880. By 1900, many populations were eliminated (Buechner 1960).

Disease contributed to the decline of bighorn sheep populations (Beecham et al. 2007, CAST 2008), and many native herds declined to less than 10% of their historical size. According to historical accounts, such declines coincided with the advent of domestic livestock grazing on ranges occupied by bighorn sheep (Grinnell 1928, Schillinger 1937, Honess and Frost 1942, CAST 2008). Epizootics among native bighorn herds were reported in various locations following European settlement and establishment of domestic livestock grazing, with reports from Colorado as early as 1885 (Coggins 2010). These observations may reflect the introduction of novel bacterial pathogens (including some strains of *Pasteurella*

[*Mannheimia*] spp.) to naïve bighorn populations beginning in the late 1800s (Grinnell 1928, Marsh 1938, Honess and Frost 1942, Miller 2001).

By 1950, bighorn sheep were extirpated from a large portion of their range. Restoration and protection efforts have allowed populations of bighorn sheep to grow from an estimated 25,000 in 1955 (Buechner 1960) to 70,000 in the 1990s (Valdez and Krausman, 1999), but growth has stagnated despite continued efforts. Many extant populations of bighorn sheep consist of fewer than100 individuals in a fragmented distribution across the landscape (Singer et. al 2000b). Even with ongoing recovery efforts, current bighorn sheep numbers in the Western United States are estimated to be less than 10% of pre-settlement populations (Schommer and Woolever 2001).

Rocky Mountain bighorn sheep are native to Wyoming and, historically, bighorns ranged across most of the state within suitable habitat. The SNF has the largest number of bighorn sheep of any national forest within National Forest System lands, with nearly 5,000 of the estimated 6,000 bighorn sheep in Wyoming. Northwestern Wyoming contains eight core native bighorn sheep herds (WGFD 2010), which are herds that have never been extirpated and re-populated with transplanted bighorn sheep (Wyoming State-wide Bighorn/Domestic Sheep Interaction Working Group 2004). These are Wyoming's largest and most robust bighorn sheep populations and are the highest priorities for bighorn sheep management in Wyoming (Wyoming State-wide Bighorn/Domestic Sheep Interaction Working Group 2004). Core native herds include the Clarks Fork, Trout Peak, Wapiti Ridge, Younts Peak, Francs Peak, Targhee, Jackson, and Whiskey Mountain Herds, which account for more than 90% of the bighorn sheep in the state. Two of these core native herds have suffered significant die-offs in the past due to bacterial pneumonia. The Jackson herd, on the Bridger-Teton National Forest (BTNF), experienced a significant die-off in 2002 and the Whiskey Mountain herd (SNF) has suffered through several outbreaks of the disease (WGFD 2011). Managers also suspect that disease played a role in a population decline in the southern Absaroka Mountains during 2011–2013, which coincided with a particularly severe late-winter/spring in 2011 (McWhirter, WGFD, pers. comm., 2017).

Bacterial Pneumonia

The main obstacle to restoring bighorn sheep populations is polymicrobial bacterial pneumonia (George et al. 2008, Cahn et al. 2011), primarily bacteria of the family Pasteurellaceae (*Pasteurella multocida*, *Mannheimia haemolytica,* and *Bibersteinia trehalosi*), and *Mycoplasma ovipneumoniae* (Martin et al. 1996, Schommer and Woolever 2001, Herndon et al. 2011, Wood et al. 2017). *Mycoplasma ovipneumoniae*, a primary pathogen that triggers bighorn sheep pneumonia (Besser et al. 2008, Besser et al. 2013, Wood et al. 2017), has a host range limited to the subfamily *Caprinae* (primarily sheep and goats) (Nicholas et al. 2008) and is frequently carried asymptomatically by domestic sheep and goats (Martin and Aitken 2000). When *M*. *ovipneumoniae* is introduced into naïve bighorn sheep populations, outbreaks of polymicrobial pneumonia ensue, sometimes resulting in high mortality in all age classes (Besser et al. 2008, 2014). During disease outbreaks in bighorn sheep, members of the genera *Mannheimia*, *Bibersteinia*, and *Pasteurella*, including *Mannheimia* (*Pasteurella*) *haemolytica*, *Bibersteinia* (*Pasteurella*) *trehalosi*, and *Pasteurella multocida*, have commonly been isolated from pneumonic lungs (Herndon et al. 2011, Wood et al. 2017). (It should be noted that the organism called *Pasteurella haemolytica* has been renamed *Mannheimia haemolytica*, but because much of the scientific literature uses the old

nomenclature, the names should be considered synonymous). Of the numerous pathogens affecting bighorn sheep, *Mannheimia haemolytica* consistently causes fatal bronchopneumonia in bighorn sheep under natural and experimental conditions (Foreyt 1993, Herndon et al. 2011). Some pathogens, such as *Pasteurellaceae* and *Mycoplasma,* are endemic in some wild sheep populations (CAST 2008).

In some bighorn epidemics, endemic respiratory pathogens including parainfluenza-3 (PI-3) virus, respiratory syncytial viruses (RSV), *Mycoplasma ovipneumoniae*, and lungworms (*Protostrongylus* spp.) are believed to have contributed to disease (Rudolph et al. 2007; Spraker et al. 1986). Besser et al. (2008) analyzed diagnostic specimens taken from nine pneumonic bighorn sheep and *M. ovipneumoniae* was detected as a predominant member of the pneumonic flora in lambs with early lesions of bronchopneumonia. *M. ovipneumoniae* was the only agent detected at significantly higher prevalence in animals from outbreaks than in animals from unaffected healthy populations, and was the most consistently detected agent within each outbreak (Besser et al. 2012b). These data provide evidence that *M. ovipneumoniae* plays a primary role in the cause of widespread pneumonia in bighorn sheep; however, it must be stressed that bronchopneumonia is a polymicrobial disease and, at least in some areas, a combination of pathogens is most significant at the herd level.

The interaction of disease outbreaks in bighorn sheep populations with other stressors (both disease and otherwise) is poorly understood. Recent research suggests that the complex interactions of disease agents themselves increases uncertainty in diagnosis and may also predispose bighorn sheep to secondary disease events (Cassirer et al. 2016). Additional research is needed on the interactions of disease pathogens, but it is reasonable to expect bighorn sheep are susceptible to diseases caused by multiple pathogens that result in multiple disease cycles (e.g., *Mycoplasma ovieneumoniae,* viruses, internal and external parasites, and other bacterial taxa). Additional stressors, which can reduce the resistance of bighorn sheep to disease organisms, include overcrowding on limited range; harassment by dogs; encroachment by humans; heavy snowfall and other weather events (Bunch et al. 1999); poor nutrition; predation; other human disturbances such as roads, habitat degradation, and noise; breeding behavior; and the presence of other wildlife (Festa-Bianchet 1988, Foreyt 1989, Monello et al. 2001, Garde et al. 2005, USDA Forest Service 2010a).

Causes of Disease Outbreaks in Bighorn Sheep

Domestic sheep and goats are the cause of many disease outbreaks in bighorn sheep. Bighorn sheep are closely related to domestic sheep but did not evolve with them, and thus are more vulnerable to many infectious diseases commonly carried by domestic sheep, particularly to *M. haemolytica* (Jessup and Boyce 1993). In contrast, domestic sheep, originally from Europe, have evolved resistance to several forms of respiratory diseases and are able to carry the disease-causing bacteria without clinical symptoms (Foreyt et al. 1994, George et al. 2008, Besser et al. 2012a, b; WAFWA 2012, Cassirer et al. 2013). Several studies have shown that these bacteria are highly virulent in wild bighorn sheep and prove lethal after transmission from domestic sheep herds (Foreyt et al. 1994, Beecham et al. 2007, Lawrence et al. 2010, Herndon et al. 2011, Besser et al. 2012b).

A large body of evidence underscores the risk of disease transmission from domestic sheep (e.g., McQuivey 1978, Hunt 1980, Jessup 1982, Foreyt and Jessup 1982, Onderka and Wishart 1984, Jessup 1985, Black et al.1988, Coggins 1988, Festa-Bianchet 1988, Callan et al.1991, Coggins and Matthews 1992, Foreyt 1994, Martin et al. 1996, Coggins 2002, George

et al. 2008, Jeffress 2008, Lawrence et al. 2010, Miller et al. 2011, 2012; Besser et al. 2012a, WAFWA 2012) and goats (e.g., Foreyt 1994, Coggins 2002, Rudolph et al. 2003, Miller et al. 2011, WAFWA 2012) to wild sheep. The central role of domestic sheep and goats in bighorn sheep exposure to pathogens is well documented; pathogen transmission from domestics to bighorn sheep is the only supported hypothesis in experimental trials (Wehausen et al. 2011). The literature includes both circumstantial evidence linking bighorn die-offs in the wild to contact with domestic animals, and controlled experiments where healthy bighorn sheep exposed to domestic sheep and goats subsequently displayed high mortality rates (e.g., Goodson 1982, Foreyt 1989, 1990, 1992a, b, 1994; Foreyt et al. 1994; Onderka et al. 1988; Onderka and Wishart 1988; Garde et al. 2005, Lawrence et al. 2010).

Bighorn sheep and domestic sheep and goats are attracted to each other, particularly during rut, which increases the probability that they will make the close contact necessary for disease transmission (Onderka et al. 1988, Foreyt 1989, Ward et al. 1997, Dubay et al. 2002, Borg et al. 2016). For example, one study showed that the odds of a pneumonia epizootic are more than three times greater if domestic sheep or goats are within a 14.5-km buffer of a bighorn sheep herd's distribution (Sells et al. 2015). Miller et al. (2011) compared the infectious agents present in multiple populations of bighorn sheep near to, and distant from, their interface with domestic sheep and domestic goats and provided critical baseline information needed for interpretations of cross-species transmission risks. Bighorn sheep, domestic goats, and domestic sheep had 60, 37, and 135 different *Pasteurellaceae* species or biovariants isolated, respectively. Thirty-six of the bighorn sheep *Pasteurellaceae* species or biovariants were also found in domestic livestock. Bighorn sheep isolates were primarily (73%) *P. (B.) trehalosi* (n = 193), whereas most (60%) domestic sheep isolates were *M*. *haemolytica* (n = 473). Half (50%) of domestic goat isolates were *P. (B.) trehalosi* (n = 102), and 44% were *M. haemolytica* (n = 89). This finding is important due to the fact that bronchopneumonia is a polymicrobial disease, and that domestic sheep and goats carry different suites of pathogens. As a result, any time contact occurs between domestics and bighorn sheep populations, the potential for transmission of novel agents to naïve bighorns exists (Miller et al. 2011).

Between 1994 and 2008, the Idaho Department of Fish and Game Wildlife Health Laboratory received 17 (4 F, 13 M) bighorns with known domestic ruminant contact: domestic sheep (n=9); domestic goats (n=3); domestic sheep and goats (n=1); and cattle (n=4); 28% of the bighorns died with evidence of respiratory disease following domestic ruminant contact. Five bighorns had gross and/or histological evidence of pneumonia. *Pasteurellaceae* were isolated from 17 bighorns. Although the majority of bighorns in this study were males, contact with domestic sheep or goats did not correlate with either the bighorn breeding season or estrus in the domestic species (Drew et al. 2014). One research paper found indications that, under certain circumstances, pathogenic bacteria can be transferred from cattle to wild sheep. The authors caution that intimate interactions between wild sheep and cattle (e.g., shared feed lines or troughs) should be discouraged as part of a comprehensive approach to health management and conservation of North American wild sheep (Wolfe et al. 2010).

Experiments

Controlled research studies have confirmed that both *Mannheimia hemolytica* and *Mycoplasma ovipneumoniae* are transmitted to wild sheep upon contact with, or proximity to,

domestic sheep (Lawrence et al. 2010, Wehausen et al. 2011, Besser et al. 2014). Domestic sheep and goats commonly carry these disease-causing organisms, which typically cause few deaths and little illness in domesticated adults and lambs (Martin et al. 1996, Gilmour and Gilmour 1989). Numerous controlled experiments have shown more than 90% mortality in bighorn populations due to respiratory diseases within 2 months after exposure to domestic sheep (Foreyt 1989, Onderka and Wishart 1988, Drew et al. 2014). Co-mingling of domestic sheep and bighorn sheep under experimental conditions unequivocally results in transmission of bacterial pneumonia (*Mannheimia haemolytica*) from domestic sheep to bighorn sheep (Lawrence et al. 2010). Several co-pasturing studies revealed that 40 of 42 (95%) bighorn sheep died from pneumonia after association with domestic sheep (Foreyt 1995). All domestic sheep remained healthy. Supporting these observations, more than 95% of 90 bighorn sheep in 11 independent accidental (N=2) or experimental (N=9) studies involving contact with domestic sheep suffered fatal pneumonia within 100 days (Besser et al. 2012a).

Field Evidence of Large-scale, Rapid, All-age Die-offs

Pen experiments cannot by themselves determine whether transmission of fatal disease between domestic sheep and bighorn sheep actually occurs in the wild. Given the evidence from pen experiments, it is likely that transmission of pneumophilic bacteria could also occur in the wild. In fact, a long history of large-scale, rapid, all-age die-offs in bighorn sheep has been documented across North America, many of which appeared to be associated with domestic animal contact (Shackleton 1999).

Disease-caused mortality events have been recorded in wild populations immediately after contact with domestic sheep in Oregon, Colorado, Washington, California, Nevada, Montana, the Dakotas, British Columbia, Alberta, and other locations (Foreyt and Jessup 1982, Onderka and Wishart 1984, Coggins 1988, Foreyt 1989, Callan et al. 1991, Garde et al. 2005, George et al. 2008). Martin et al. (1996) summarized more than 30 published cases where bighorn die-offs are believed to have resulted from contact with domestic sheep. In most cases, from 75 to 100% of the bighorn herd died. Domestic sheep always remained healthy. In 1997 in Colorado, George et al. (2008) observed a single domestic ram grazing with a group of bighorn sheep, 14 km from the nearest herd of domestic sheep. It was the first and only time during their 10-year study that the authors saw domestic sheep with bighorn sheep, and it coincided with the beginning of a disease outbreak that eventually spread to two additional herds.

These observations are consistent with the hypothesis that disease transmitted by domestic sheep cause die-offs of bighorn sheep herds. However, the complete range of mechanisms and/or causal agents that lead to disease events in bighorn sheep is still debated, and not all bighorn sheep disease events can be attributed to contact with domestic sheep or goats (Onderka and Wishart 1984, Aune et al. 1998, Besser et al. 2012b). However, no studies report any bighorn sheep herds, fenced or free ranging, that have come into contact with domestic sheep and remained healthy (Schommer and Woolever 2001). When contact between bighorn sheep and domestic sheep or goats is documented, the severity of the bighorn sheep die-off is typically greater (Onderka and Wishart 1984, Martin et al. 1996, Aune et al. 1998, George et al. 2008).

Attempts to quantitatively test whether contact with domestic sheep poses a risk of die-off or extirpation of bighorn sheep populations have examined the correlation between population

performance and distance from domestic sheep. Monello et al. (2001) analyzed population records of 99 bighorn sheep herds in western North America in an investigation of the ecological correlates of pneumonia epizootics. They found that bighorn sheep populations that had suffered a pneumonia-induced die-off were located, on average, significantly closer to domestic sheep allotments (24.1 ± 11.5 km) than either those that had not suffered a die-off or those that had suffered a die-off not induced by pneumonia (39.6 ± 8.5 km).

Singer et al. (2000c) analyzed factors contributing to the success of 100 translocations of bighorn sheep and found that the 30 unsuccessful translocations were on average significantly closer to domestic sheep (6 ± km) than either modestly successful or successful translocations. Finally, based on an analysis of 24 herds, Singer et al. (2001) found that the persistence of bighorn sheep populations was significantly correlated with the presence of domestic sheep: populations located closer to domestic sheep were smaller and had lower population growth rates than bighorn populations located farther from domestic sheep.

Although these analyses indicate that bighorn sheep populations perform more poorly when they are closer to domestic sheep, they typically don't include observations of contact, let alone the transmission of a pathogen from domestic sheep to bighorn sheep (USDA Forest Service 2010b).

Evidence for Disease Transmission from Domestic Goats

Although there is no direct experimental evidence of domestic goats, and specifically pack goats, infecting wild sheep with life threatening diseases, there is an abundance of connected evidence that leads to a reasonable conclusion that domestic goats are a vector. Domestic goats are physiologically capable of carrying and spreading several of the bacteria that are implicated in wild sheep die-offs. Domestic goats may approach bighorn sheep as stray animals from farmsteads, when used for weed control, when commercial operations graze on public or private lands, or when used as pack animals supporting back-country recreation. Although there have been all-age die-offs following observed contact between domestic goats and wild sheep, many of them occurred prior to the technology that allows for DNA strain typing to positively identify the source of the bacteria.

The body of literature linking disease transmission from domestic goats to bighorn sheep is not as extensive as that of domestic sheep. The literature that does exist indicates a connection between contact between domestic goats and bighorn sheep and disease transmission. For example, the cause of a bighorn die-off in the winter of 1995–96 in Hells Canyon was traced by DNA fingerprinting to a domestic goat that had been recently released in the wild. Prior to release, the goat had recently been exposed to domestic sheep at a county fair (Schommer and Woolever 2001, Rudolph et al. 2003). The subsequent die-off resulted in the death of more than 260 bighorn sheep in an 8-week period. The disease spread more than 30 air miles and affected six bighorn sheep herds. Contact with feral goats also appears to result in bighorn sheep exposure to pathogens (Rudolph et al. 2003).

As in domestic and bighorn sheep, strains of *Mannheimia haemolytica* are the organisms most frequently isolated from the lungs of pneumonic domestic goats. *Mannheimia haemolytica* A1 is infrequently isolated from the upper respiratory tract of healthy bighorn sheep, and is thought to act as an opportunistic invader in much the same way as other strains of *Pasteurella* spp. *Mannheimia haemolytica* A2 has been found in the upper respiratory tract

of healthy domestic sheep and goats, but has not been isolated from healthy wild sheep (Garde et al. 2005). It is thought that bighorn sheep are infected with *M. haemolytica* A2 through contact with domestic sheep or goats (Foreyt and Lagerquist 1996, Martin et al. 1996, Schommer and Woolever 2001). This bacteria has the potential to act as a primary pathogen in bighorn sheep, resulting in all-age die-offs (Garde et al. 2005). In addition, *Pasteurella* spp. were isolated from feral goats and bighorn sheep in the Hells Canyon National Recreation Area. Although the direction of transmission could not be established, evidence suggests transmission of strains from goats to bighorn sheep (Rudolph et al. 2003, Foreyt et. al 2009, Cassirer et al. 2016).

In a recent Washington state survey of goat farms adjacent to bighorn sheep habitat, active *Mycoplasma ovipneumoniae* was carried asymptomatically by animals on 7 of 16 goat farms, and by 58% of individual goats on positive farms (Heinse et al. 2016). Recently, a series of experimental exposure studies were conducted to investigate the virulence of *Mycoplasma ovipneumoniae* carried by domestic goats to naïve bighorn sheep. The results indicate that the goat-origin *M. ovipneumoniae* strains used in these experiments were capable of causing respiratory disease symptoms and pneumonia lesions in susceptible bighorn sheep. However, the disease observed was notably milder than that reported in previous experiments conducted with domestic sheep-origin strains of *M. ovipneumoniae* (Besser and Cassirer 2016).

In contrast, Cassirer et al. (2016) found that introduction of a new genotype (strain) of *M. ovipneumoniae* into a chronically infected bighorn sheep population in the Hells Canyon region of Washington and Oregon was accompanied by adult morbidity (100%) and pneumonia-induced mortality (33%) similar to that reported in epizootics following exposure of naïve bighorn sheep. Phylogenetic analysis showed that the strain associated with the outbreak was likely of domestic goat origin. The authors conclude that the lack of cross-strain immunity in the face of recurrent spillovers from reservoir hosts may account for a significant proportion of the disease outbreaks in bighorn sheep that continue to happen regularly despite a century of exposure to domestic sheep and goats (Cassirer et al. 2016).

Domestic goats can also carry other disease organisms with serious consequences for bighorn sheep (Jansen et al. 2006). In late 2003 and 2004, the Silver Bell bighorn herd in Arizona was infected with keratoconjunctivitis (KCS) caused by *Mycoplasma conjunctivae*. This is a highly contagious eye infection common in domestic sheep and goats (Whithear 2001). This disease is thought to spread via insect vectors or direct contact (Whithear 2001). Infection is characterized by redness of the eyes, squinting, pain, and ocular discharge (Janovsky et al. 2002). This disease typically causes temporary blindness but in advanced stages can lead to permanent blindness (Janovsky et al. 2002). As a result of genetic investigation, the source of the Silver Bell infection was believed to be direct contact with 4,800 domestic goats released into bighorn habitat (Jansen et al. 2006).

In a pen experiment, lungworms (*Muellerius capillaris*) from co-pastured domestic goats infected bighorn sheep (Foreyt et al. 2009). Lungworm larvae deposited in animal feces are hosted by several species of land snails and remain in the snail until accidentally ingested by bighorn sheep. Lungworms inhabit the air passages of the lungs and can make wild sheep more susceptible to bacterial pneumonia (Colorado Division of Wildlife 1981). On the basis of the results of this experimental study, bighorn sheep that occupy habitat with domestic goats are at potential risk of acquiring *Muellerius* infections, thus increasing the potential risk of pneumonia (Foreyt et al. 2009).

Contagious ecthyma, commonly called sore mouth, is endemic in domestic herds of sheep, goats, and llamas in western Canada (Fowler 1998, Wenger and Tait 2001). Lesions are typically restricted to the lips and muzzle on domestics while they can cover the entire body of bighorn sheep (Fowler 1998, Merwin and Brundage 2000). The condition can be very painful, interfering with chewing of food (Samuel et al. 1975), and resulting in loss of body condition (Fowler 1998, Kimberling 1988). Although bighorn lambs can be impacted the most by this disease, it appears that contagious ecthyma rarely leads to population declines (Clark et al. 1993, L'Heureux et al. 1996). Contagious ecthyma was reported from the Silver Bell bighorn sheep herd incident previously discussed. The bighorns initially suffered from keratoconjunctivitis, which was followed by a large-scale and severe contagious ecthyma outbreak (Jansen et al. 2006).

Long-term Implications of Die-offs

In contrast to most other wild and domesticated mammal species, bighorn sheep are notable in their extreme susceptibility to some strains of *Pasteurella* spp. (Miller 2001). In some cases, bighorn sheep disease events can have devastating population-limiting effects with die-offs affecting animals of all age classes, and resulting in prolonged periods of low lamb survival (Coggins 1988; Foreyt 1990; Coggins and Matthews 1992; Cassirer and Sinclair 2007; George et al. 2008; Besser et al. 2012a, b; Cassirer et al. 2013). It is hypothesized that once *Pasteurella* spp. have been introduced to bighorn sheep populations, they may become endemic and continue cycling for decades (Miller et al. 1991; Hobbs and Miller 1992, Miller et al. 1995). The disease persists following mortality events and reduces reproductive success, preventing regrowth of the population (George et al. 2008).

When bighorn sheep experience a pneumonia episode, all-age mortality normally occurs. Low lamb survival rates typically continue after the initial die-off, delaying population recovery for years to decades (Foreyt 1990, Coggins and Matthews 1992, Ward et al. 1992, Foreyt 1995, Schommer and Woolever 2001, George et al. 2008; Cassirer et al. 2013, Manlove et al. 2016). Research indicates that lambs born in bighorn sheep herds that experienced a pneumonia episode typically die before 3 months of age (Foreyt 1990, Herndon et al. 2011, Wood et al. 2017). It is likely that surviving ewes remain carriers of pathogens for several years and transfer the bacteria to their lambs (Herndon et al. 2011, Wood et al. 2017). Lambs are protected by passive colostrum immunity early in life, but when this immunity wanes at 6 to 8 weeks of age, they die from pneumonia.

As a result, full population recovery following a die-off may require decades. Loss of genetic diversity and herd memory of historical migration routes may be irreplaceable. Economically, the loss of potential hunting and wildlife viewing and photography may represent hundreds of thousands of dollars lost in State wildlife agency revenue, as well as lost revenue to local economies associated with these uses. In extreme cases, such as Sierra Nevada bighorn sheep, there is even the potential of federal listing under the Endangered Species Act (Schommer and Woolever 2001).

Vaccines

Experimental trials to develop and test vaccines have been conducted, but are far from conclusive. In a pen experiment, four bighorn sheep repeatedly immunized with multivalent *Mannheimia-Bibersteinia* vaccine were protected from induced *Mannheimia haemolytica* pneumonia, while four non-vaccinated control bighorn sheep died within 48 hours of being

infected (Subramaniam et al. 2011). However, strain-specific immunity could complicate efforts to develop vaccines (Cassirer et al. 2016). So far no vaccine has completely protected wild sheep commingled with domestic sheep or goats in captive settings or shown potential for efficacy in free-ranging animals (Callan et al. 1991, Kraabel et al. 1998, Cassirer et al. 2001, Subramaniam et al. 2011, Sirochman et al. 2012). If successfully developed, vaccinations would be logistically difficult and expensive to administer (Wehausen et al. 2011); therefore, repeated vaccination in the wild would likely not be practical.

Forays

Bighorn sheep make occasional long-distance exploratory movements beyond their core home range (Singer et al. 2001, O'Brien et al. 2014). Singer et al. (2001) called these movements forays, and defined them as any short-term movement of an animal away from, and back to, its herd's core home range. This life-history trait places bighorn sheep at risk of contact with domestic sheep and goats. The risk of contact between foraying bighorn sheep (mostly rams) and domestic sheep is related to the extent of bighorn sheep source habitat, proximity to domestic sheep or goats, distance of bighorn forays outside their core home range, and the frequency of bighorn forays outside their core home range.

The foray behavior of wild sheep, where individuals can travel up to 50 km, facilitates the spread of disease (O'Brien et al. 2014). Survivors of disease outbreaks become carriers of the disease and serve as a source of infection for other animals in the same herd, or other populations, through natural movements, forays, or translocations. Domestic sheep strays are also common and increase the potential for interaction. When forays result in contact with domestic sheep, there is the potential for disease transmission to bighorn sheep that in turn can be transmitted to and infect an entire bighorn sheep herd. As discussed above, disease events can result in the deaths of 25–100% of animals in a population and long-term reduction of fecundity (Singer et al. 2000a).

Because disease events in bighorn populations often have severe repercussions that can last for decades, an understanding of bighorn forays is instructive for addressing the potential risks of interspecies contact. Data analyzed for the Hells Canyon bighorn population in Idaho found that 14.1% of rams and 1.5% of ewes forayed during the summer months (O'Brien et al. 2014). Of rams that made forays, 50% traveled at least 8.1 km and 10% of foraying rams traveled 21.7 km beyond their home range boundaries. However, forays exceeding 50 km have been documented (O'Brien et al. 2014).

Domestic Sheep Grazing on the Shoshone National Forest

Domestic sheep grazing on the SNF reached its highest point in the early 1900s and has been on a steady decline since. The initial decline was primarily due to stocking rate adjustments to achieve a more sustainable use of the rangeland. From the 1960s to 1980s, many sheep allotments were converted to cattle. Since then, all commercial sheep grazing permits on the SNF, except for one, have been removed.

Three allotments (Table 1) on the southern end of the SNF comprise the extent of domestic sheep grazing on the SNF. Two allotments, with a total of 1,150 ewe/lambs, are active and one allotment is vacant. No domestic sheep grazing is authorized within core native bighorn sheep range on the SNF.

Table 1. Domestic sheep grazing allotments on the Shoshone National Forest

Allotment	Stocking Rate	Grazing Dates	Allotment Status
Atlantic City	1,000 ewe/lamb	7/16 – 8/25	Vacant
Pine-Willow[1]	1,150 ewe/lamb[1]	7/20 – 8/15	Active
Slate Creek[1]	1,150 ewe/lamb[1]	8/16 – 9/10	Active

[1] Pine-Willow and Slate Creek domestic sheep are grazed by the same permittee.

Domestic Goat Use on the Shoshone National Forest

There are no active commercial domestic goat allotments on the SNF, and goats are not used for vegetation management, but recreational domestic goat packing is allowed on the Washakie Ranger District. In contrast to domestic sheep grazing, little is known about the extent, magnitude, and characteristics of pack goat use in this area.

On November 14, 2011, a temporary area closure order was signed and implemented restricting domestic goat use on the Clarks Fork, Wapiti, Greybull, and Wind River Ranger Districts. Six of the eight core native bighorn sheep herds in Wyoming have their ranges in this area. This closure was implemented to reduce the risk of disease transmission from pack goats to core native bighorn sheep herds (USDA Forest Service 2011a). The pack goat closure order was issued again in June 2016 and will be in effect until December 31, 2019, or until rescinded (Appendix A). Under this temporary closure, domestic goat use is only authorized on the Washakie Ranger District, inhabited by the Temple Peak herd, which is not a core native herd. However, as currently written, the closure order still allows pack goat use in the Fitzpatrick Wilderness on the Washakie Ranger District, which encompasses the southern portion of the Whiskey Mountain herd's home range, which is a core native herd (Appendix A).

Pack goat use for back country trips into the Wind River Range occurred in recent years. The primary destinations for goat pack trips have been in the Fitzpatrick Wilderness on both the Wind River and Washakie Ranger Districts. Specific trails (about 38 miles) used by goat packing enthusiasts in this area in the past have been identified (North American Packgoat Association 2011). About 33 miles of the trails identified are within currently occupied bighorn sheep habitat within the Whiskey Mountain herd range (Figure 1).

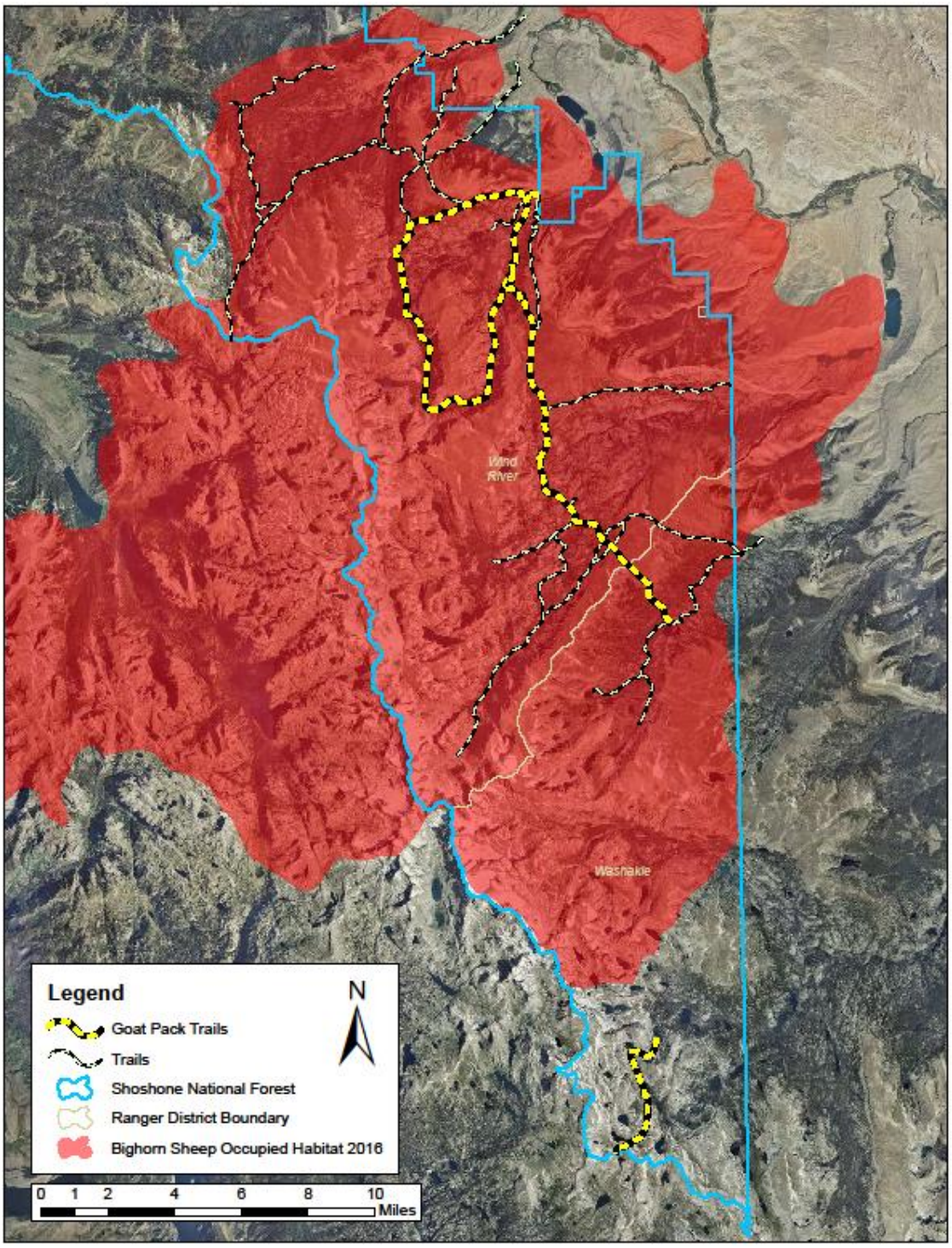

Figure 1. Trails used for goat packing prior to the 2011 and 2016 closure orders within the Whiskey Mountain bighorn sheep herd's occupied habitat on the Wind River and Washakie Ranger Districts.

Bighorn Sheep Status on the Shoshone National Forest

The SNF has the largest number of bighorn sheep of any forest within the National Forest System, with nearly 5,000 of the estimated 6,000 bighorn sheep in Wyoming (Table 2). Six of the eight core native bighorn sheep herds in Wyoming reside on the SNF. These core native herds include: Clarks Fork, Trout Peak, Wapiti Ridge, Younts Peak, Francs Peak, and Whiskey Mountain, which currently occupy 67% (1.65 million acres) of the SNF (Figure 2).

Table 2. Population estimates and demographic characteristics of six bighorn sheep populations on the Shoshone National Forest

[Source: WGFD 2016 a, b; –, no data]

Herd	Population Estimate	Population Objective	Lambs per 100 Ewes	2010–2014 Average	Rams per 100 Ewes	2010–2014 Average
Clarks Fork	600	500	21	33	43	27
Trout Peak	700	750	25	27	24	38
Wapiti Ridge	850	1000	31	21	27	29
Younts Peak	900	900	27	24	39	41
Francs Peak	841	1350	26	25	55	58
Whiskey Mountain	975	1350	25	30	47	46
Temple Peak[1]	–	–	–	–	–	–

[1] Comparable population data are not currently available for this cooperative review herd.

Five of the six core native herds on the SNF are connected to one another, (the Whiskey Mountain herd being the exception), and together form the Absaroka metapopulation. Natural interchange between these adjacent herds is thought to be greater than 10%. If interchange falls below 10%, WGFD considers the relevant herd units to be isolated from one another and functioning as discrete biological herds rather than as a metapopulation.

An additional bighorn sheep herd occurs on the adjacent Wind River Indian Reservation in the South Fork Little Wind River watershed (Figure 2). This herd is connected to the Temple Peak herd, and altogether the combined herd consists of about 100 sheep (McWhirter, WGFD, pers. comm. 2017).

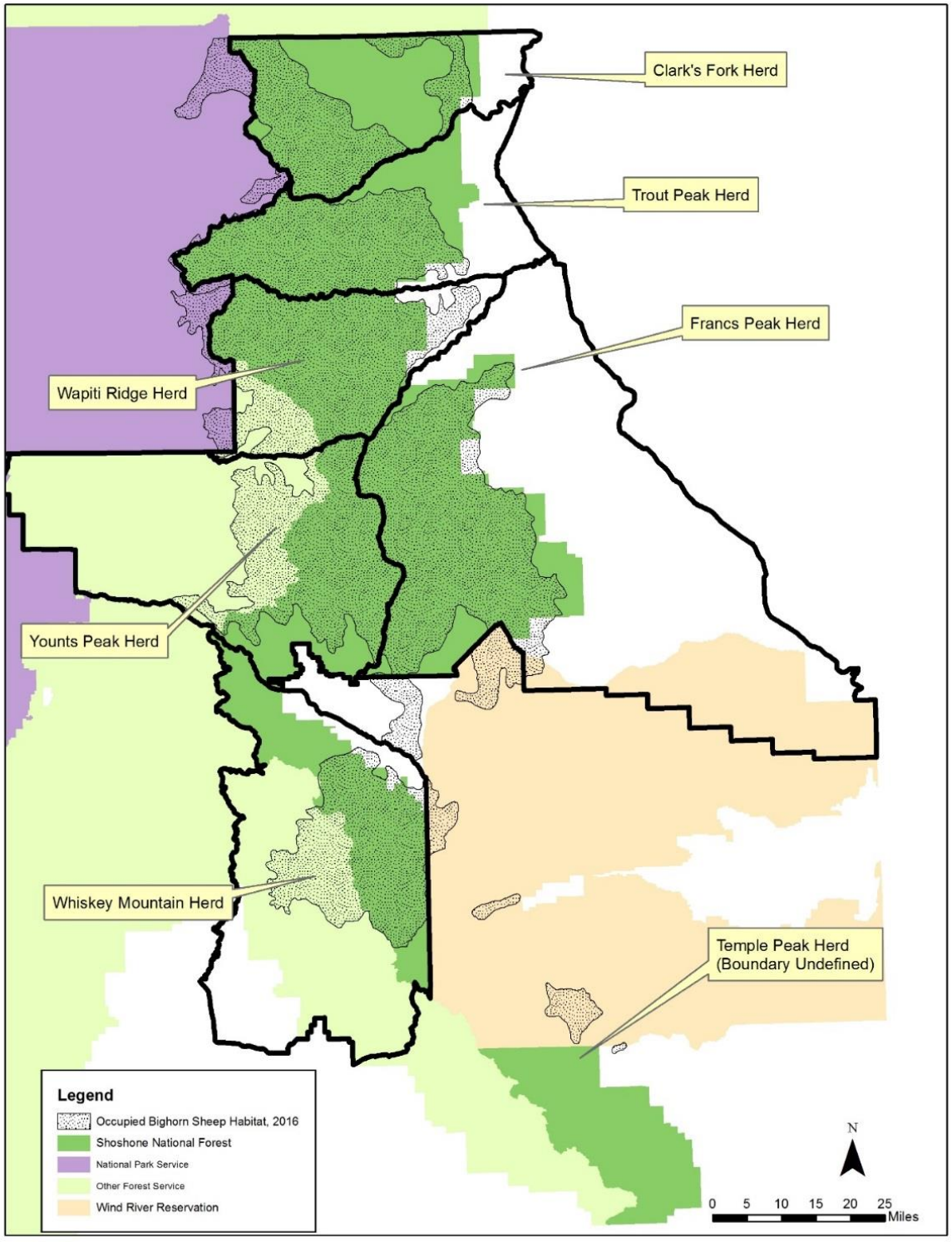

Figure 2. Bighorn sheep herds and occupied habitat on the Shoshone National Forest.

Clarks Fork Bighorn Sheep Herd

This core native herd occupies portions of the SNF and Custer Gallatin National Forest, and ranges across the Absaroka Range and the Beartooth Plateau. The population objective for the Clarks Fork herd is 500 with the present population at 600 (Table 2). The lamb:ewe ratio was 21:100 in 2015.

No domestic sheep grazing occurs within this herd unit. The closest domestic sheep/goat grazing to the Clarks Fork herd is about 2 km (1 mile) east on private lands. The closest domestic sheep/goat grazing on the SNF is about 240 km (150 miles) south of the Clarks Fork herd (Table 3). No pack goat use is known to occur within this core native herd range.

Table 3. Proximity of bighorn sheep herds on the Shoshone National Forest to closest domestic sheep herd by land ownership and herd status

[km, kilometer; BLM, Bureau of Land Management; >, greater than]

Bighorn Sheep Herd	Proximity to Domestic Sheep on Shoshone National Forest (km)	Proximity to Domestic Sheep on adjacent lands (km)	Land Ownership of Adjacent Lands	Herd Status
Clarks Fork	240	2	Private	Core native herd
Trout Peak	221	19	BLM	Core native herd
Wapiti Ridge	179	29	BLM	Core native herd
Younts Peak	137	42	BLM	Core native herd
Francs Peak	113	33	BLM, Private	Core native herd
Whiskey Mountain	81	>60	Bridger-Teton National Forest	Core native herd
Temple Peak	29	Unknown	Unknown	Cooperative review herd

Trout Peak Bighorn Sheep Herd

This core native herd occupies portions of the SNF within the Absaroka Range. The population objective for the Trout Peak herd is 750. The present population is estimated to be about 700 sheep. The lamb:ewe ratio for this herd in 2015 was 25:100. The ram:ewe ratio for this herd in 2015 was 24:100 (Table 2).

No domestic sheep grazing occurs within this herd unit. The closest potential domestic sheep/goat grazing on public lands to the Trout Peak herd is about 19 km (12 miles) east on Bureau of Land Management lands. However, those potential sheep grazing sites are separated from this herd by miles of unsuitable terrain as well as by Highway 120 (Minnick, BLM, pers. comm. 2017; McWhirter, WGFD, pers. comm. 2017). The closest domestic sheep/goat grazing on the SNF is about 221 km (138 miles) south of the Trout Peak herd. No pack goat use is known to occur within this core native herd range.

Wapiti Ridge Bighorn Sheep Herd

This core native herd occupies portions of the SNF and BTNFs within the Absaroka Range. The population objective for the Wapiti Ridge herd is 1,000 sheep with the present population estimated at 850 (Table 2). In 2015, the lamb:ewe ratio was 31:100 which is above the 2010–2014 average of 21:100. The ram:ewe ratio was 27:100 in 2015**.**

No domestic sheep grazing occurs within this herd unit. The closest potential domestic sheep/goat grazing on public lands to the Wapiti Ridge herd is about 29 km (18 miles) east on Bureau of Land Management lands. However, those potential sheep grazing sites are separated from this herd by miles of unsuitable terrain as well as by Highway 120 (Minnick, BLM, pers. comm. 2017; McWhirter, WGFD, pers. comm. 2017). Closest domestic sheep/goat grazing on the SNF is about 179 km (112 miles) south of the Wapiti Ridge herd. No pack goat use is known to occur within this core native herd range.

Younts Peak Bighorn Sheep Herd

This core native herd occupies portions of the SNF and BTNFs, primarily within the Absaroka Range. Younts Peak is the most remote bighorn sheep herd in Wyoming **(**Beecham et al. 2007**)**. While much of the Younts Peak herd is non-migratory and resides year-round on high-elevation ridges, portions of this herd do migrate to low-elevation winter range in the South Fork of the Shoshone and Greybull rivers (WGFD 2009). The large number of sheep wintering at high elevations make this herd prone to periodic high mortality losses from severe winter weather.

The population for this herd is estimated to be 900, which is at objective. The 2015 lamb:ewe ratio was 27:100, and ram:ewe ratio was 39:100 (Table 2). The lamb:ewe ratio was above the 5 year (2010–2014) average of 24:100 for this herd, while the ram:ewe ratio was near average (41:100) (WGFD 2016a).

No domestic sheep grazing occurs within this herd unit. The closest potential domestic sheep/goat grazing on public lands to the Younts Peak herd is about 42 km (26 miles) east on Bureau of Land Management lands (Table 3). However, those potential sheep grazing sites are separated from this herd by miles of unsuitable terrain (Minnick, BLM, pers. comm. 2017; McWhirter, WGFD, pers. comm. 2017). The closest domestic sheep/goat grazing on the SNF is about 137 km (85 miles) southeast of the Younts Peak herd. No pack goat use is known to occur within this core native herd range.

Francs Peak Bighorn Sheep Herd

This core native herd occupies portions of the SNF and the Wind River Indian Reservation within the Absaroka and Owl Creek Ranges. The population objective for this herd is 1,350 sheep. Current model estimates put the population at 841 sheep, well below objective (WGFD 2016a). Lamb:ewe ratios for the herd averaged 25:100 during 2010–2014 (Table 2) . Over the past 10 years the number of sheep observed on average in this herd has declined by 40% (WGFD 2016a).

No domestic sheep grazing occurs within this herd unit. The closest potential domestic sheep/goat grazing to the Francs Peak herd is about 3 km (2 miles) to the east. However, the Wyoming Wild Sheep Foundation and the individual landowner in question have recently cooperated to develop water sources at lower elevations (33 km from occupied sheep habitat, Table 3) to reduce the need to graze domestic sheep in proximity to occupied bighorn sheep habitat (McWhirter, WGFD, pers. comm. 2017). The closest domestic sheep/goat grazing on the SNF is about 113 km (70 miles) south of the Francs Peak herd. No pack goat use is known to occur within this core native herd range.

Whiskey Mountain Bighorn Sheep Herd

This core native herd occupies portions of the SNF and BTNFs and the Wind River Indian Reservation within the Wind River Range (Figure 3).

The population objective for this herd is 1,350 sheep. The current population estimate is about 975 sheep (WGFD 2016b). This was once the largest herd in the country, but after a catastrophic disease-related all-age die-off in 1991, the population has yet to recover and has been below objective for the past 20 years, though it appears to be slowly recovering. In 2015, the lamb:ewe ratio was 25:100 (Table 2). The ram:ewe ratio for this herd has been more stable. In 2015, the ratio was 47:100, above the 2010–2014 average of 46:100 (WGFD 2016b).

In 2010, WGFD personnel spent a significant amount of time observing sheep in early fall as they arrived on winter range. Many lambs were observed coughing violently and showing symptoms of pneumonia. Eleven sheep were euthanized throughout the fall and examined at the Wyoming state veterinary lab to document the presence of disease. Examinations revealed *Mycoplasma ovipneumoniae* in all the sheep that had been seen coughing violently. It appears likely that persistent, low annual recruitment in this population can be traced to chronic bacterial infection resulting in significant lamb mortality as sheep migrate onto winter range in the fall. Despite low recruitment, the population is growing very slowly and it appears a small increase in lamb recruitment will stabilize this population. Unfortunately managers do not have any effective tools to mitigate the persistent presence of bacterial pneumonia in wild sheep; therefore, persistent chronic pneumonia continues to be a problem in this herd (Anderson, WGFD, pers. comm. 2017).

The Whiskey Mountain herd is isolated from other herds on the SNF. The Highway 26 corridor, which is the dividing line between the Whiskey Mountain herd and core native herds to the north, consists of fairly unsuitable bighorn sheep habitat, which limits interchange with the Absaroka metapopulation (Beecham et al. 2007). Furthermore, connectivity between the Whiskey Mountain and Temple Peak herds has not been demonstrated (McWhirter, WGFD, pers. comm. 2017).

No domestic sheep grazing occurs within this herd unit. In the recent past, the closest domestic sheep grazing on public lands to the Whiskey Mountain herd was about 10 km (6 miles) west on the BTNF. However, those allotments were recently closed to sheep grazing (USDA Forest Service 2016b). As a result, no known domestic sheep grazing occurs within 35 km of this herd, either on the SNF or BTNFs. The closest sheep grazing on lands outside of the SNF to this herd is now more than 60 km away on the BTNF (Table 3). Domestic sheep or goats are not known to be present on the Wind River Reservation within

this herd's home range (BIA, pers. comm. 2017) (Figure 3). The closest domestic sheep grazing on the SNF is about 81 km southeast of the Whiskey Mountain herd (Table 3).

In the past, pack goat use occurred on the SNF within the occupied habitat of this core native herd, and it still occurs on adjacent lands on the BTNF (Figure 1). The only pack goat outfitter to operate in this area on the SNF relinquished their permit in 2007, and pack goat use is currently banned within most of this herd's range by forest order. However, as currently written, the closure order still allows pack goat use in the Fitzpatrick Wilderness on the Washakie Ranger District, which encompasses the southern portion of the Whiskey Mountain herd's home range (Appendix A).

Temple Peak Bighorn Sheep Herd

The Temple Peak herd occupies a small portion of the Washakie Ranger District along the Lander Front in the southern end of the Wind River Range. The distribution of bighorns within this unit is scattered, with known wintering areas in the North Fork of the Popo Agie River (Figure 2). This herd no longer has a hunt area assigned to it and is not discussed in the WGFD 2016 Annual Big Game Herd Unit Reports.

The Temple Peak herd is not a core native herd; rather, it is a transplanted herd and is designated a "Cooperative Review Area" (Wyoming State-wide Bighorn/Domestic Sheep Interaction Working Group 2004). Cooperative Review Areas contain suitable bighorn sheep range where proposed changes in bighorn sheep management or domestic sheep use will be cooperatively evaluated.

This herd experienced an all-age pneumonia die-off in 1992 and has never recovered (WGFD 2006). Following the all-age die-off it existed as a remnant herd for many years, although it appears to have increased slightly in recent years. Together with the South Fork Little Wind River herd on the Wind River Indian Reservation, to which it is connected, the Temple Peak herd consists of about 100 sheep (McWhirter, WGFD, pers. comm. 2017). Cassaigne et al. (2010) suggest that a minimum population of 188 bighorn sheep is required to ensure long-term persistence in the presence of epizootic disease. Therefore, this herd may eventually go extinct. The WGFD is not currently considering supplementations into this herd (McWhirter, WGFD, pers. comm. 2017).

Domestic sheep grazing has occurred on both the SNF and BTNFs within this herd's historic summer range, but not within currently occupied range. Suitable bighorn sheep habitat within the domestic sheep allotments on the SNF is very limited due to its forested nature. In addition, a large portion of the land between the allotments and the Temple Peak herd's occupied habitat is forested, which essentially precludes bighorn sheep forays to these allotments.

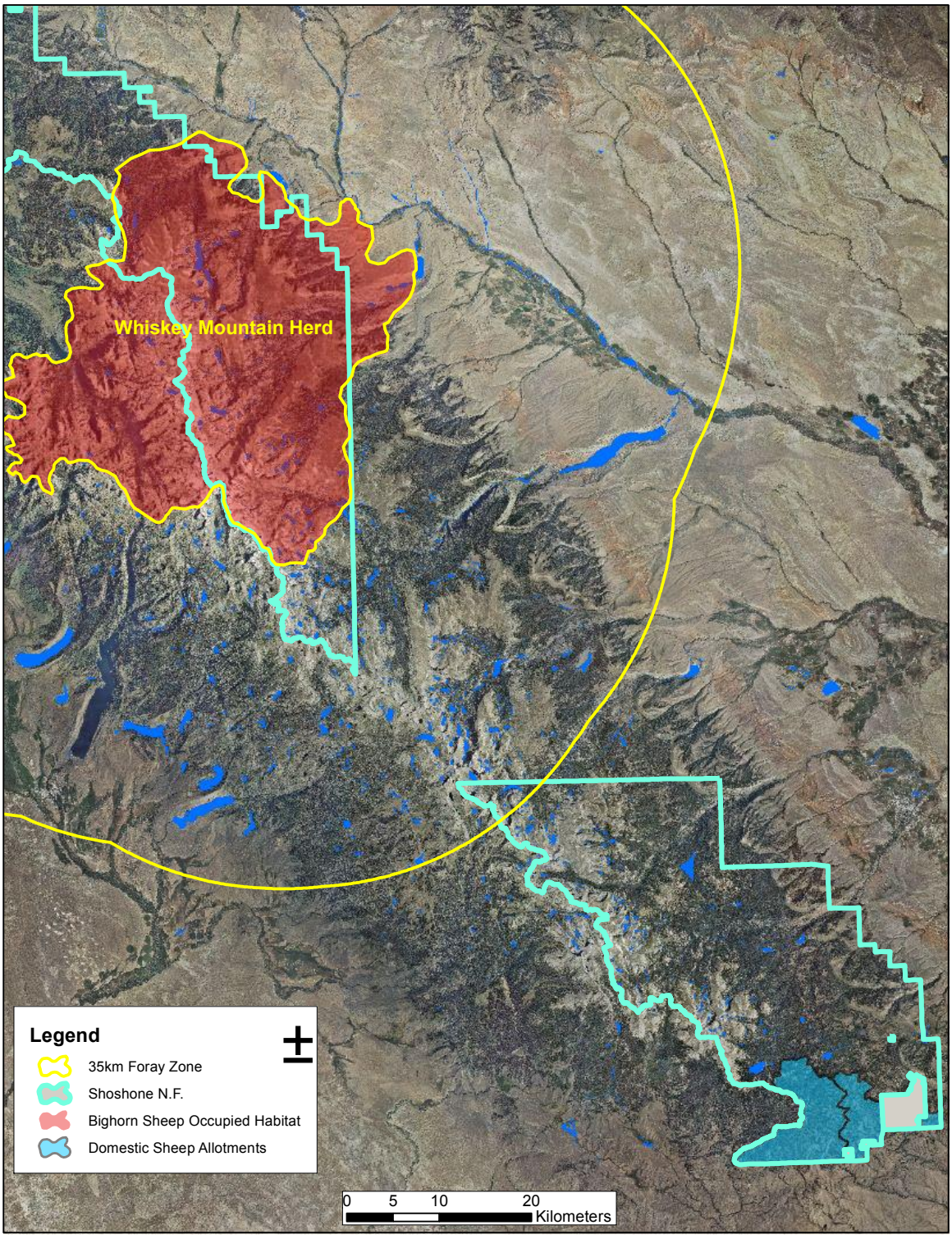

Figure 3. Whiskey Mountain bighorn sheep herd and domestic sheep grazing allotments on the Shoshone National Forest.

This herd's current occupied range is very confined, suggesting that they no longer are a migratory herd or have little, if any interchange with bighorns in the Whiskey Mountain population (Beecham et al. 2007). Furthermore, past telemetry data from both the Whiskey Mountain and Temple Peak herds show more of an east-west migration rather than a north-south migration. This makes the likelihood of movement between the Temple Peak and Whiskey Mountain herds unlikely. Connectivity between the two has not been demonstrated (McWhirter, WGFD, pers. comm. 2017). The WGFD is currently collecting data on the Temple Peak herd to examine distribution and movements (McWhirter, WGFD, pers. comm. 2017).

In the recent past, domestic sheep grazing occurred on the Wind River Reservation in proximity to this herd's winter range (BIA, pers. comm. 2017). The closest domestic sheep grazing on the SNF is approximately 29 km (18 miles) southeast of the Temple Peak herd (Table 3). Pack goat use occurs within the occupied habitat of this cooperative review herd.

Methods

As stated earlier, an August 2011 letter from the Deputy Chief of the Forest Service outlined an approach to risk assessment and viability analysis (USDA Forest Service 2011b). The analysis process outlined in the letter consists of four steps:

1. Gather applicable data and information from appropriate sources.
2. Assess spatial and temporal overlap of bighorn sheep core herd home ranges with domestic livestock allotments, use areas, and driveways.
3. Assess likelihood of contact (low, moderate, high) based on spatial and temporal overlap between domestic livestock use areas and bighorn sheep herds.
4. Identify management practices with the goal of separation between domestic livestock and bighorn sheep where necessary to provide for Forestwide bighorn sheep viability.

This RADT follows that four-step process. This issue is not as complex on the SNF as it is on other national forests in the Western United States because of the limited amount of domestic sheep and goat use in occupied bighorn habitat on the SNF.

Qualitative risk assessment is a commonly used method to determine where risk exists and how it can be mitigated. In this RADT report, qualitative information is used to determine the risk of physical contact between bighorn sheep and domestic sheep or goats. This level of analysis is commensurate with the complexity of the proposed action on the SNF (separation of domestic sheep and goats from bighorn sheep in core native bighorn sheep habitat), the available data, the current management situation, the probability of contact, and the potential risk of disease transmission. This Risk Assessment process involved participation by Forest Service wildlife biologists and rangeland management specialists, and WGFD biologists. Substantial public input was received during the Forest Plan revision process. Bighorn sheep herd core home ranges have been delineated by a combination of telemetry and observation data.

The scale of this risk assessment is the planning unit, in this case the SNF. The main focus is on active and vacant domestic sheep allotments within the SNF, and areas that have been identified as pack goat use areas (Figure 1, Figure 4). Recognizing the limits of SNF

regulatory authority, this assessment also considers the potential cumulative impacts from adjacent lands outside the boundary of the SNF.

Steps 1 and 2

Gather applicable data and assess spatial and temporal overlap between domestic livestock use areas and bighorn sheep herds

See the three previous sections of this RADT: *Domestic Sheep Grazing on the Shoshone National Forest*, *Domestic Goat Use on the Shoshone National Forest*, and *Bighorn Sheep Status on the Shoshone National Forest*.

Step 3

Assess likelihood of contact (low, moderate, high) based on spatial and temporal overlap between domestic livestock use areas and bighorn sheep herds

The sequence of events by which contact between bighorn sheep and domestic sheep or goats in a permitted grazing allotment or pack goat use area located outside a bighorn core home range might occur can be broken down into a number of steps. First, to reach a domestic sheep allotment or pack goat use area, a bighorn sheep must:

1. leave its core home range,
2. travel far enough to reach the domestic sheep grazing allotment or pack goat use area, and
3. intersect the allotment or pack goat use area.

For disease transmission to occur, the bighorn must:

4. come into physical proximity to a domestic sheep or goat in the allotment or pack goat use area, and
5. contract a disease from the domestic sheep or goat.

Finally, for a disease outbreak to affect the bighorn's home herd, the infected bighorn must:

6. return to their, or another herd's, core home range, and
7. transmit disease to other members of their, or another, herd.

For domestic sheep allotments or pack goat use areas that overlap portions of a bighorn core home range, steps 1–3 and 6 do not need to occur, thereby likely increasing the potential for a disease transmission event to occur, and also likely increasing the potential for a subsequent disease outbreak in the bighorn home herd.

In recognition of this fact, the Forest Service/Bureau of Land Management Risk of Contact Tool presumes a 100% probability of contact when there is direct overlap between a bighorn core home range and an allotment or pack goat use area (USDA Forest Service 2013). Therefore, by definition, an allotment or pack goat use area that overlaps with a bighorn core home range is assumed to experience at least one bighorn contact per year. We adopt that assumption in this analysis.

Although we assume a contact rate of 1.0 for allotments and pack goat use areas that overlap a bighorn core home range, annual contact rates could be higher with multiple contacts occurring per year. When there is direct overlap between an allotment or pack goat use area and a bighorn core home range, there is a high risk for contact and therefore no need to model the potential for contact by foray.

The only bighorn sheep herd on the SNF in proximity to domestic sheep allotments on the SNF is the Temple Peak herd. On the basis of discussions with WGFD and Region 4 Forest Service staff, data currently available were determined to be not sufficient to accurately delineate the core home range for the Temple Peak population (Figure 2). WGFD has committed to collecting additional data using radio-marked bighorn sheep. Once collected, these data will be used to better understand the status of the Temple Peak population (USDA Forest Service 2016b).

Because information on foray distances and probabilities are also lacking for bighorn sheep herds on the SNF, the analysis in this Risk Assessment uses the default value for maximum foray distances from the Risk of Contact Tool. The Risk of Contact Tool model estimates the proportion of rams and ewes reaching each 1-km band outside of a herd's home range. The model estimates this proportion out to 35 kilometers (21 miles) away from the home range, which incorporates the extent of most forays throughout the Western United States (USDA Forest Service 2013).

Because the data currently available for the Temple Peak herd are not sufficient to accurately delineate its core home range (USDA Forest Service 2016b), and because no other bighorn herd on the SNF is within 35 km of a domestic sheep allotment on the SNF, the Bighorn Sheep Risk of Contact Tool was not used for this analysis (USDA Forest Service 2013). Rather, a qualitative assessment was conducted for all herds on the SNF. Quantitatively modeling the risk of contact from lands outside the jurisdiction of the SNF was beyond the scope of this analysis.

Rationale for Risk Rankings

The risk of physical contact between bighorn sheep and a domestic sheep allotment or pack goat use area was given a qualitative rating of "High," "Moderate," or "Low" based on factors relating to spatial and temporal separation. Risk of disease transmission with a subsequent bighorn mortality event, however, is not modeled explicitly and is rather considered a correlate of contact, not an effect. Although disease transmission is discussed in this assessment, these ratings are not intended to be an estimate of disease transmission probability, only an estimate of relative level of risk for physical contact between domestic livestock and bighorn sheep. The likelihood of disease transmission following physical contact, and the potential for a subsequent bighorn mortality event, is not known with certainty and remains the subject of debate, and therefore will not be used as the basis for determining relative level of risk.

- A rating of "High" risk indicates that contact between domestic sheep and goats and bighorn sheep is thought to be likely in the immediate future, although disease transmission resulting in a subsequent bighorn mortality event is not assumed to be a certainty. Conversely, if allotments or pack goat use areas have been operated for many years without evidence of disease transmission, we do not use this observation to infer a

lower risk rating. The fact that contact has not been observed, or a bighorn disease event has not been detected, does not imply a lower risk for such events happening in the future. For this reason, the allotment or pack goat use area would still receive a rating of "High" risk. A rating of "High" risk would occur when there is direct overlap between an area of domestic livestock use and mapped bighorn range, or when these areas are within 10 miles (17 km) of an allotment or unmitigated pack goat use area and there is good bighorn source habitat connectivity for bighorn dispersal.

- A rating of "Moderate" risk indicates that physical contact between bighorn and domestic sheep and goats may occur at some point in the future, but effective separation may be achieved and/or maintained for many years. Factors that reduce the apparent risk of contact could include the presence of towns, the presence of terrain features and/or habitat features that act as barriers to bighorn sheep movement (Schommer and Woolever 2001), and bighorn sheep distribution patterns. A rating of "Moderate" risk could occur when there is no direct overlap between mapped bighorn range, these areas are 10 to 21 miles (18 to 35 km) from an allotment or pack goat use area, and/or there is fair bighorn source habitat connectivity for bighorn dispersal. It could also occur when there is direct overlap between mapped bighorn sheep range and pack goat use areas, but mitigation measures are in place.
- A rating of "Low" risk indicates that physical contact between domestic sheep and goats and bighorn sheep is believed to be unlikely or irregular and unpredictable, with the potential for a subsequent bighorn disease outbreak thought to be unlikely or irregular in the future under the configuration of domestic sheep and goat use and bighorn range. A rating of "Low" risk could occur when there is no direct overlap between mapped bighorn range, and these areas are greater than 21 miles (35 km) from an area of domestic livestock use and/or there is poor bighorn source habitat connectivity for bighorn dispersal.

Results

As discussed previously, this risk assessment analysis is focused on the "risk of contact" between bighorn sheep and domestic sheep allotments and goat use areas. No presumption is made that physical contact would lead to disease transmission or a subsequent bighorn sheep mortality event. However, the assumption is made that physical contact between bighorn sheep and domestic sheep or goats results in an increased risk of disease transmission to bighorn sheep, with increased potential for a subsequent bighorn mortality event.

Assessment of Risk from Domestic Sheep and Goats by Herd Unit

The Absaroka Metapopulation – Clarks Fork, Trout Peak, Wapiti Ridge, Younts Peak, and Francs Peak Herds

None of these core native bighorn sheep herds have occurred close (within 112 km) to domestic sheep allotments on the SNF in recent history (Table 3). All domestic sheep allotments within these herd units on the SNF have been closed or converted to cattle due to

the willingness of grazing permittees to move to other allotments. Although the foray distances or probabilities for bighorn sheep on the SNF are not known, no occupied habitat for core native herds occurs within 35 km of domestic sheep allotments on the SNF. Because of the low risk of contact as a result of domestic sheep grazing activities on the SNF (Table 4), there is a reduced disease transmission risk from domestic sheep to these herds.

Table 4. Risk of contact ratings and herd status of bighorn sheep herds on the Shoshone National Forest

[Risk ratings were made by WGFD and SNF wildlife biologists with local knowledge of areas. Rationale is provided in text.]

Bighorn Sheep Herd	Risk rating from domestic sheep on SNF	Risk rating considering domestic sheep on adjacent lands	Pack goat use in core native bighorn sheep habitat allowed	Pack goat use in core native bighorn sheep habitat prohibited	Herd status
Clarks Fork	Low	High	High	Low	Core native
Trout Peak	Low	Low	High	Low	Core native
Wapiti Ridge	Low	Low	High	Low	Core native
Younts Peak	Low	Low	High	Low	Core native
Francs Peak	Low	Moderate	High	Low	
Whiskey Mountain	Low	Low	High	Low	Core native
Temple Peak	Low	unknown	High	High	Cooperative review

However, risk increases if adjacent lands are considered. As a result of domestic sheep grazing on adjacent Bureau of Land Management and private lands (Table 3), and specifically, recent domestic sheep grazing in Owl Creek within 3 km of the Francs Peak herd, risk of disease is considered elevated for the Francs Peak herd. However, because the Wyoming Wild Sheep Foundation and the individual landowner in question have recently cooperated to develop water sources at lower elevations (33 km from occupied sheep habitat) to reduce the need to graze domestic sheep in closer proximity to occupied bighorn sheep habitat (McWhirter, WGFD, pers. comm. 2017), the threat is reduced to **Moderate**. Similarly, risk is considered **High** for the Clarks Fork herd when adjacent private lands are considered (Table 4). Risk is considered **Low** when non-SNF lands adjacent to the Trout Peak, Wapiti Ridge, and Younts Peak herds are considered, because the adjacent lands in question are separated from these herds' home ranges by miles of habitat unsuitable for bighorn dispersal as well as by Highway 120 (Minnick, BLM, pers. comm. 2017; McWhirter, WGFD, pers. comm. 2017). Information on the temporal overlap between the Clarks Fork and Francs Peak herds and domestic livestock on adjacent lands is not available.

Pack goat use is not currently known to have occurred within any of the Absaroka core native bighorn sheep ranges. However, the Forest Service has had inquiries in recent years from people potentially interested in using pack goats in these areas. If there were no prohibition on pack goat use in these areas, it is reasonable to assume that some level of use would occur, and this could include situations where there was spatial and temporal overlap between pack goats and bighorn sheep. As a result, there would be a "high" risk of contact and increased disease transmission risk (Table 4).

If a prohibition on pack goat use were in place for these herds, there would be no spatial and temporal overlap between domestic pack goats and bighorn sheep. As a result, there would be a "low" risk of contact between pack goats and bighorn sheep and reduced disease transmission risk (Table 4).

Whiskey Mountain Herd

This core native bighorn sheep herd has not occurred close (within 81 km) to domestic sheep allotments on the SNF in recent history. In the past, domestic sheep from active domestic sheep allotments on the BTNF have wandered into occupied habitat of the Whiskey Mountain herd. However, those domestic sheep allotments on the BTNF have now been closed (USDA Forest Service 2016b). As a result, no known domestic sheep grazing occurs within 35 km of this herd, either on the SNF or BTNFs (Table 3), and none is known to occur on adjacent lands. Therefore, the risk of contact and disease transmission to this herd from domestic sheep is currently considered **Low**.

Goat packing has regularly occurred within the occupied habitat of this core native herd (Figure 1), but has been prohibited by special order since 2011. A portion of the trails historically used for goat packing in the Fitzpatrick Wilderness are within and adjacent to areas consistently used by bighorn sheep, including rocky escape cover and open alpine meadows (Figure 4). These trails are in year-round bighorn sheep habitat. Therefore, without a prohibition on pack goat use there would be spatial and temporal overlap between pack goats and bighorn sheep. Contact between bighorn sheep and pack goats would be expected, thus increasing the risk of disease transmission. Due to the spatial and temporal overlap, the risk of contact would be high under this scenario (Table 4).

If pack goat use in core native bighorn sheep range were prohibited, pack goats would not occur within occupied habitat for this herd on the Shoshone National Forest and there would be no spatial and temporal overlap with bighorn sheep. This would reduce the risk of contact between pack goats to bighorn sheep, and the risk rating would be "low" (Table 4). Pack goat use would still occur within occupied habitat for Whiskey Mountain bighorn sheep on adjacent BTNF lands.

Temple Peak Herd

The closest portion of the Temple Peak herd is about 29 km from domestic sheep allotments on the SNF. The connected South Fork Little Wind River herd on the Wind River Indian Reservation is about 33 km from the allotments.

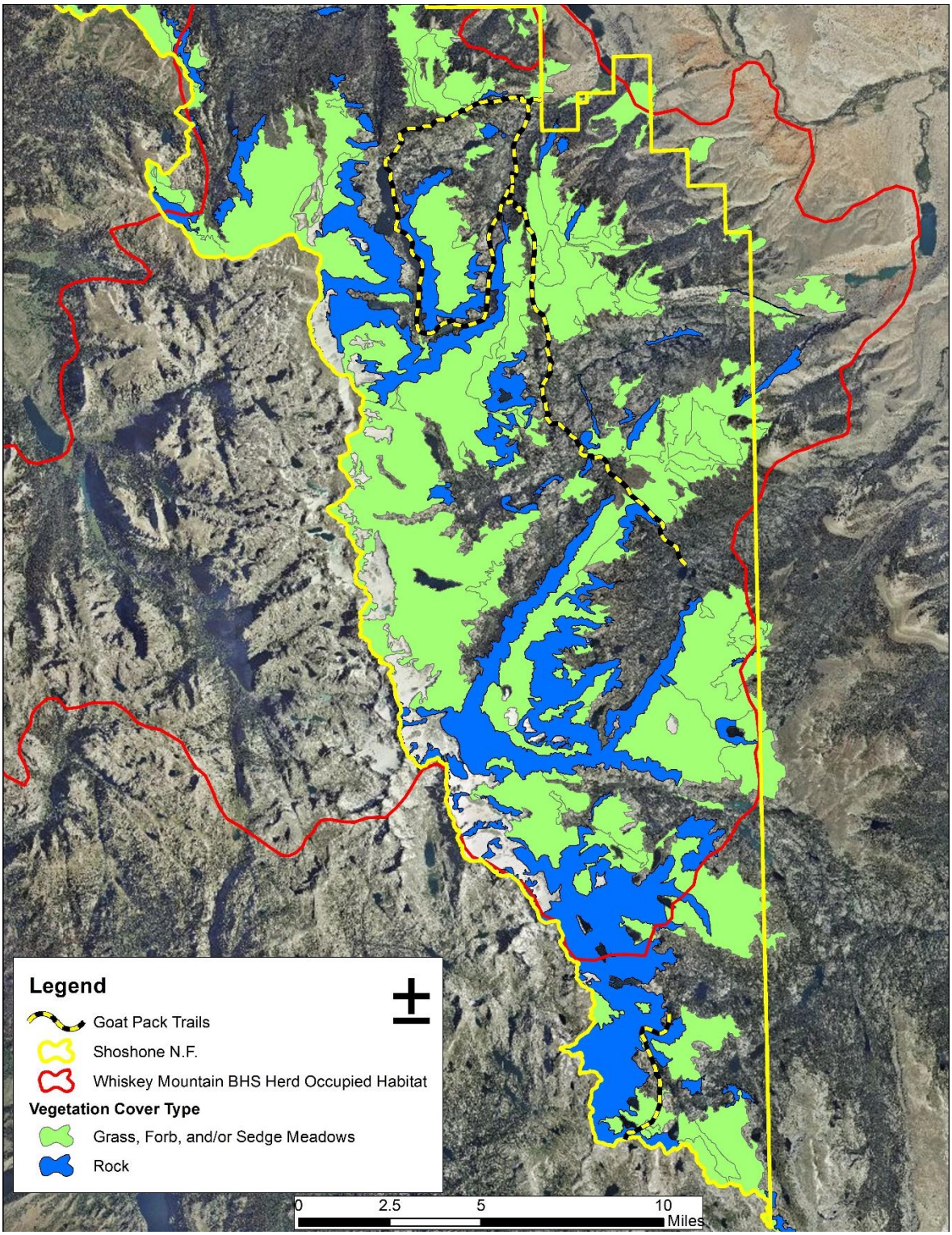

Figure 4. Potentially suitable bighorn sheep habitat and historically used goat packing trails within the Whiskey Mountain bighorn sheep herd's occupied habitat.

As stated earlier, the nearby domestic sheep allotments on the SNF likely provide very limited suitable habitat because they are mostly forested. In addition, there is a high amount of unsuitable forested landscape between currently occupied habitat for these two herds and the allotments. Furthermore, the migrations of this herd are primarily east-west (rather than north-south). All of these factors reduce the likelihood of bighorn sheep making contact with sheep allotments on the SNF. Additionally, domestic sheep grazing in the Pine-Willow and Slate Creek sheep allotments is only authorized on the pasture south of Rennecker Peak. This means that not all of the acreage in the two allotments is available for domestic sheep grazing. This reduces the risk of contact even further. Therefore the risk of contact from domestic sheep grazing on the SNF is **Low** for this cooperative review bighorn sheep herd.

The risk of contact to this herd as a result of domestic sheep grazing on adjacent lands is **Unknown** (BIA pers. comm. 2017; McWhirter WGFD, pers. comm. 2017).

Goat packing occurs within occupied habitat of this cooperative review herd. Portions of trails used for goat packing are within and adjacent to habitat used by bighorn sheep. These trails are in year-long bighorn sheep habitat; therefore, there is spatial and temporal overlap between goat packing and bighorn sheep. This increases the opportunities for contact between bighorn sheep and pack goats. As a result of the overlap of pack goat use on the occupied range of the Temple Peak herd, the risk of contact is **High** (Table 4).

Step 4

Identify management practices with the goal of separation between domestic livestock and bighorn sheep where necessary to provide for Forestwide bighorn sheep viability

Spatial and/or Temporal Separation

Separating domestic sheep allotments, domestic goats, and wild sheep habitat is widely recognized as the most viable current management option to prevent the spread of disease from domestic sheep and goats to wild sheep (Foreyt 1989, Cahn et al. 2011, WAFWA 2012, O'Brien et al. 2014, The Wildlife Society 2015). Most wildlife biologists and veterinarians have now concluded that bighorn and domestic sheep and goats should not occupy the same ranges or be managed in close proximity to each other (Foreyt and Jessup 1982, Goodson 1982, Coggins 1988, Onderka and Wishart 1988, Foreyt 1989, Foreyt 1990, Callan et al. 1991, Coggins and Matthews 1992, Foreyt 1992b, Foreyt et al. 1994, Foreyt 1995, Martin et al. 1996, WAFWA 2012, The Wildlife Society 2015). Consequently, current recommendations for minimizing pneumonia outbreaks in bighorn sheep are to maintain spatial or temporal separation between bighorn sheep and domestic sheep and goats on native ranges at all times (Schommer and Woolever 2001, WAFWA 2012, The Wildlife Society 2015). Where assessments indicate a high risk to bighorn sheep population viability, spatial and/or temporal separation between domestic sheep and goats and bighorn sheep is the most prudent management action that can be used to manage risk of disease transmission (WAFWA 2012).

Until recently, the primary management recommendation used for interspecies separation was the use of a standard buffer distance (e.g., 14.5 km) to reduce the potential for contact, but this is not applicable across all national forest situations and bighorn sheep habitats.

Singer et al. (2001) recommend focusing management for persistent bighorn sheep populations on large habitat patches more than 23 km from domestic sheep. However, Monello et al. (2001) analyzed population records of 99 bighorn sheep herds ranging from the southwestern United States to Alaska, in an investigation designed to discover the ecological correlates of pneumonia epizootics. They found that bighorn sheep populations that had suffered a pneumonia-induced die-off were located on average significantly closer to domestic sheep allotments (24.1 ± 11.5 km) than either those that had not suffered a die-off or those that had suffered a die-off not induced by pneumonia (39.6 ± 8.5 km). The minimum buffer used in Hells Canyon was 25 miles (41 km) and yet was not effective in separating the species (Schommer and Woolever 2001).

Vaccines for bighorn sheep that could reduce the potential for disease transmission are being investigated (Subramaniam et al. 2011), but are unlikely to be ready for use in the field anytime soon. For this reason, the most effective means of reducing the risk of disease transmission is to minimize the potential for contact through effective separation. The results of recent research on strain-specific immunity also support existing management direction to prevent contacts that could lead to pathogen transmission from domestic small ruminants to wild sheep, even if the wild sheep have previously been exposed (Cassirer et al. 2016). Effective separation will help avoid introducing new strains of *M. ovipneumoniae* and other pathogens into wild sheep populations. However, effective separation is complicated by the tendency of bighorn sheep, both rams and ewes, to leave their core herd home range and carry out occasional exploratory forays.

Proposed Mitigation Measures for Pack Goats

During the Forest Plan revision process, a variety of mitigation measures were proposed by the North American Pack Goat Association to provide for separation between pack goats and bighorn sheep and reduce the risk of disease transmission (Jennings 2011). Some were considered to be infeasible and were not considered further. The mitigation measures determined to be feasible include:

1. Implementing a system that would require a permit for all pack goat use. Pack goat users would be informed on required and recommended actions for reducing the risk of contact between pack goats and bighorn sheep when obtaining their permit.
2. Requiring any observed contact between pack goats and bighorn sheep, as well as any lost pack goats, to be reported to the Forest Service as soon as possible as a condition of obtaining a pack goat use permit.
3. Limiting the number of pack goats per party.
4. Requiring pack goats be leashed or in direct control by their owners.
5. Requiring pack goats be high-lined or restrained in campsites.
6. Requiring pack goats to have bells attached to their collars at all times.
7. Requiring veterinary health inspection and disease testing of all pack goats before entering Shoshone National Forest lands, and requiring handlers to be in possession of a health and disease testing certificate for each pack goat.

These mitigation measures would help maintain spatial separation between pack goats and bighorn sheep. Mitigation measure 1 would ensure that pack goat users understood the required and recommended actions for preventing contact between their pack goats and bighorn sheep. It would also help to track pack goat use on the Forest, and provide a mechanism to require reporting of any contact between pack goats and bighorn sheep. Reporting of any observed contact between pack goats and bighorn sheep would facilitate determination of disease transmission, especially if biological samples could be taken from the pack goats that contacted bighorn sheep. Reporting of lost pack goats could facilitate recovery efforts before contact with bighorn sheep occurred, and would help track how often this occurred. However, pack goat users may be disinclined to report contact between their goats and bighorn sheep, or even lost goats, for fear of incurring additional restrictions on their use.

The use of domestic goats as pack animals causes different effects than grazing allotments due to the amount of control that could be exerted over pack goats, especially through implementation of mitigation measures 3, 4, and 5. Limiting the number of pack goats would allow greater control because fewer animals are easier to control. Requiring goats to be leashed together while traveling down the trail and high-lined in campsites would improve control of pack goats and reduce the risk of contact with bighorn sheep. Pack goats readily bond to their human handlers and have a strong desire to stay with them (Jennings 2011). The use of bells would allow users to track the movements of their goats and therefore keep them under close control.

However, users may not always be able to control their pack goats despite implementation of these techniques. Pack goat use occurs in remote, rugged settings where circumstances cannot always be controlled, and pack goats occasionally are lost on the Forest for a variety of reasons such as being scattered by predators or having too many tied on a high-line. Even conscientious pack goat users may not always be successful controlling their goats (J. Dirks, email conversation with J. Harper, Forest Service Wildlife Biologist, 2011). Additionally, it is perceived as dangerous to have goats tied together by leads when travelling through difficult terrain, and users typically disconnect them from each other in such settings (Jennings 2011). Uncontrolled or lost goats within bighorn sheep habitat could have direct contact with bighorn sheep.

In addition, the movements of bighorn sheep cannot be controlled. Wild sheep are unpredictable in their movements and have been shown to travel great distances, which can bring them into contact with pack goats as well as other wild sheep (USDA Forest Service 2017). Bighorn sheep and domestic sheep and goats are attracted to each other, particularly during rut, which increases the probability that they will make the close contact necessary for disease transmission (Onderka et al. 1988, Foreyt 1989, Ward et al. 1997, Dubay et al. 2002, Borg et al. 2016). This could occur even under a scenario where pack goats were under close control as required by mitigations 4 and 5.

Requiring veterinary health inspection and disease testing of pack goats and handler possession of a health certificate for each pack goat entering the Forest would help limit the risk of disease transmission if contact with bighorn sheep were to occur. A veterinary inspection would detect disease in animals showing symptoms of respiratory disease or other infectious conditions such as pink eye and sore mouth. Disease testing using approved protocols could be conducted for pathogens commonly implicated in bighorn die-offs to identify potentially infectious but non-symptomatic animals. However, implementation of

this requirement would be difficult. Veterinarians commonly conduct health inspections and disease testing for a variety of domestic animals using standardized protocols to conform to various state or federal regulations. However, disease testing of pack goats would involve specific sampling protocols for a suite of potential pathogens (H. Edwards, WGFD, personal communication 04/20/2017). In contrast to the health inspections and testing normally done by veterinarians, these are not standardized protocols and would be unfamiliar to most veterinarians used by pack goat enthusiasts. There is also the possibility that "certified" animals could come into contact with other livestock after being tested and inspected, and potentially contract pathogens that could be transmitted to bighorn sheep.

To be effective, these measures would depend on the diligence of the pack goat user. Pack goat users have stated that "the restrictive nature of these best management practices will act as a deterrent for those users not willing to submit to the extensive preparation and implementation of these practices" (Jennings 2011). If mitigation measures are perceived by pack goat users as restrictive and difficult to implement as implied by this statement, noncompliance with them could be substantial. Compliance checks by the Forest Service would be infrequent due to the very remote and rugged environments that goat packing takes place in.

Summary

A long history of large-scale, all-age die-offs in bighorn sheep exists across North America, many associated with domestic sheep and goat contact. Although limited knowledge of transmission dynamics exists, extensive scientific literature supports the relationship between disease in bighorn sheep populations and contact with domestic sheep and goats. The literature documents both circumstantial evidence linking bighorn die-offs in the wild to contact with domestic animals, and controlled experiments where healthy bighorn sheep exposed to domestic sheep resulted in bighorn sheep mortality. Recent serological research has documented the transmission of specific pathogens between domestic and bighorn sheep that are non-lethal in domestic sheep, but lethal in bighorn sheep.

Although the scientific literature on the risk of disease transmission between domestic sheep and goats (including pack goats) and bighorn sheep is not complete, some conclusions are available. Domestic sheep and goats carry disease organisms with serious consequences for bighorn sheep (Herndon et al. 2011, Miller et al. 2011, Wehausen et al. 2011, Besser et al. 2014, Drew et al. 2014, O'Brien et al. 2014, Shannon et al. 2014, Fox et al. 2015, Sells et al. 2015). The central role of domestic sheep and goats in bighorn sheep exposure to pathogens is well documented; pathogen transmission from domestics to bighorn sheep is the only hypothesis supported in experimental trials. Even minimal direct contact is believed to contribute to the death of individual wild sheep, herds of wild sheep, and entire populations.

Likelihood of Contact between Domestic Livestock Use Areas and SNF Bighorn Sheep Herds

All core native bighorn sheep herds on the SNF are currently at **Low** risk of disease transmission from domestic sheep on the Forest due to the distance their occupied habitat is from domestic sheep allotments on the Forest. No further conservation measures are needed related to domestic sheep grazing on the SNF and bighorn sheep. However, concerns remain regarding the risk of contact between the Clarks Fork and Francs Peak herds and domestic sheep on adjacent lands.

Additionally, without a pack goat closure order, the likelihood of direct contact and risk of disease transmission as a result of pack goat activities is **High** for all bighorn sheep herds on the SNF, although mitigation measures could be applied to reduce this risk to **Moderate** levels.

Cumulative Effects

Management of bighorn sheep and domestic sheep and goats (including pack goats) to avoid physical interactions is often complex. It is important that separation of the three species is maintained at all times; however, as noted above, the distance needed to attain this can be different in each situation, and collaboration among all parties is needed to achieve this. The SNF is working with other State, Federal, and local partners (State-wide Bighorn Sheep/Domestic Sheep Interaction Working Group) to better identify where bighorn sheep occur, where they wander, and how they might interact with other herds and domestics. This effort is expected to help reduce potential cumulative effects to bighorn sheep on the SNF.

Currently, there are no documented cases of disease transmittal from domestic sheep or goats to bighorns on the SNF. With the exception of the Temple Peak herd, domestic sheep herds on the SNF are all outside the 35 km foray distance of any bighorn sheep herd on the forest.

However, four of the six core native herds on the SNF are potentially within 35 km of domestic sheep that are on lands adjacent to the Forest (Table 3). The potential presence of domestic sheep on lands outside the jurisdiction of the SNF, yet still within the 35 km foray distance of bighorn sheep, adds to the risk of contact between bighorn sheep on the Forest and domestic sheep. For example, in the past, domestic sheep from active domestic sheep allotments on the BTNF have wandered into occupied habitat of the Whiskey Mountain herd (however, those sheep allotments are now reportedly closed or vacant (USDA Forest Service 2016b)). Such incidents originating from lands adjacent to, but outside the jurisdiction of, the SNF increase the likelihood of contact with domestic sheep and increase the risk of disease transmission to these herds. Because there is no known “safe distance” between the three species, the risk of a future transmittal cannot be discounted.

Opposing Views, Incomplete Information, Scientific Uncertainty

Despite the large body of evidence, some contend that disease transmission between bighorn sheep and domestic sheep and goats is not a relevant factor in bighorn sheep distribution and population declines in the wild. Still, some collaborative working groups (USAHA 2009) have recommended domestic goats not be allowed to graze in occupied bighorn sheep habitat because of their gregarious nature and tendency to wander. We are aware of the continuing debate and discussion between wildlife advocates, some domestic sheep and goat industry proponents, and resource managers regarding the credibility or scientific merit of past findings (CAST 2008, USAHA 2009). That debate is founded largely on criticisms of experimental design or rigor, and the limitations of drawing inferences about natural disease events when compared to controlled experiments in confined settings (WAFWA 2012).

While there clearly are gaps in the knowledge base on the causal factors and mechanisms of bighorn sheep die-offs and disease transmission between the species, the majority of the literature supports the potential for disease transmission between the species, documents bighorn die-offs near domestic sheep and goats, and supports the management option of keeping these species separate to prevent disease transmission. Further, and perhaps most importantly, there is no peer reviewed literature that suggests bighorn sheep can be in proximity to domestic sheep and goats without concern for disease transmission between the species. Scientists from both sides of the issue recommend that the species be kept separate until the mechanics of disease transmission is better understood.

Although the preponderance of scientific literature supports the potential for respiratory diseases to be transmitted from domestic sheep and goats to bighorn sheep, frequently followed by bighorn mortality events (e.g., Martin et al. 1996, Schommer and Woolever 2001, USDA Forest Service 2010a, USDA Forest Service 2011b, Besser et al. 2012 a, b, WAFWA 2012, Cassirer et al. 2013), we recognize that opposing arguments still question this science and dispute the connection. Some of these contentions are valid. For example, we do not understand all of the mechanisms involved in disease transmission between the species. Arguably, much of the evidence is circumstantial; however, the compilation of data over many decades contributes to an increasing body of scientific evidence that overwhelmingly demonstrates bighorn sheep near domestic sheep and goats are at risk for disease transmission, even though "contact" may not have actually been observed. We note, however, that there is emerging science, yet to be published, that suggests that pack goats may not carry certain disease-causing pathogens to the degree suggested by other published peer-reviewed research (Dr. Margaret A. Highland, pers. comm. 2016).

This analysis considered the degree of scientific uncertainty concerning the risk of foray contact and potential disease transmission. For example, there is uncertainty regarding how the behavioral attraction between domestic sheep and goats and bighorn sheep could increase the risk of contact within the landscape. However, because there is mutual attraction, while on forays bighorns are more likely to come into contact with domestic sheep or goats. Since *Mannheimia* spp. and *Pasteurella* spp. transmission both require very close (less than 60 feet) contact to transfer contagions through coughing or sneezing, it is more likely to occur between bighorn sheep and domestic sheep or goats due to their attraction to one another (Dixon et al. 2002). Determining the probability that a bighorn sheep will reach an occupied domestic sheep or goat area on the SNF, and that contact between the species will result in

disease transmission, is problematic, because essentially there is no research that would allow such a determination (USDA Forest Service 2010a).

The natural behavioral attraction between the species also makes it more likely that straying domestic sheep or goats may seek out and comingle with bighorn sheep. For this reason, straying domestic sheep or goats increase the likelihood of physical contact occurring between the species. The rate of domestic sheep or goat strays is not known and thus it is not possible to determine with certainty to what degree strays might increase the risk of physical contact between domestic sheep and goats and bighorn sheep. Overall, however, the effect of mutual attraction likely results in increased potential for physical contact between the species, but the degree of increased potential for contact is unknown.

There are also risk factors outside the scope of the Forest's authority or control that may influence bighorn sheep populations on the SNF. For example, there is uncertainty regarding incidents of bighorn sheep foraying from herds on the SNF and coming into contact with domestic sheep off of NFS lands. Domestic sheep on private lands or adjacent jurisdictions may be contacted by foraying bighorns, which then return to their home herd, potentially introducing disease to it and thereby affecting bighorn populations across the landscape. In some cases, adjacent private landowners or jurisdictions do not manage their lands to prevent circumstances that could lead to disease transmission to bighorn herds on the SNF. However, mitigating the risk of contact between bighorn and domestic sheep and goats off of NFS lands is beyond the control of the SNF.

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Appendix A. Shoshone Forest Order 16-003

Order Number 16-003

UNITED STATES DEPARTMENT OF AGRICULTURE
U.S. FOREST SERVICE
SHOSHONE NATIONAL FOREST
FOREST ORDER

Pursuant to 36 C.F.R. § 261.50(a), the following acts are prohibited on the Shoshone National Forest:

Possession or use of domestic goats on any National Forest System lands on the Wapiti, Clarks Fork, Greybull and Wind River Ranger Districts as shown on the attached map.

PROHIBITIONS:

1. Possession or use of domestic goats in special closure area. 36 C.F.R. § 261.53(a) and 36 C.F.R. § 261.58(s).

EXEMPTIONS: Pursuant to **36 CFR 261.50(e)** the following persons are exempt:

(1) Persons with a Forest Service permit specifically authorizing the otherwise prohibited act or omission.

(2) Any Federal, State or local officer, or member of an organized rescue or firefighting force engaged in the performance of an official duty.

(3) Forest Service contractors or permittees engaged solely in the performances of official permit or contract obligations.

AREA DESCRIBED: National Forest System lands as depicted on Exhibit A.

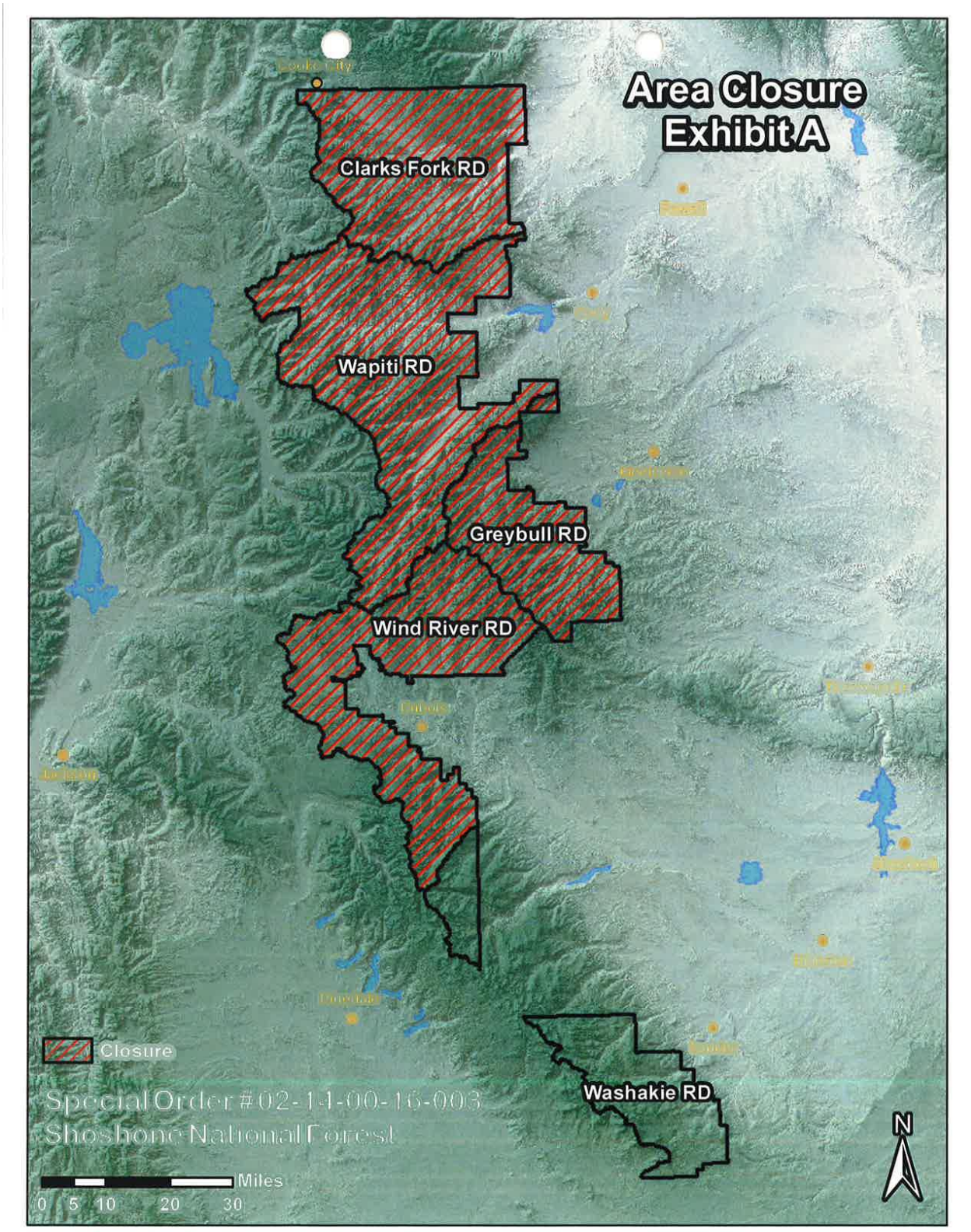
PURPOSE: The purpose of this Order is to protect the health and viability of bighorn sheep, a Region 2 sensitive species, on their core habitat, until a thorough risk assessment can be completed.

IMPLEMENTATION: This Order will be in effect on June 24, 2016 and shall remain in effect until rescinded, until December 31, 2019, whichever event occurs first.

Done at Cody, Wyoming, this 24th day of June 2016.

Joseph G. Alexander
Forest Supervisor
Shoshone National Forest

Any violation of this Order is punishable as a Class B misdemeanor by a fine of not more than $5,000 for an individual or $10,000 for an organization or imprisonment for not more than six (6) months, or both. [Title 16 USC 551, Title 18 USC 3571 (b)(6), Title 18 USC 3581 (b)(7)].


Area Closure
Exhibit A
Clarks Fork RD
Wapiti RD
Greybull RD
Wind River RD
Washakie RD
Closure
Special Order #02-14-00-16-003
Shoshone National Forest
Miles
0 5 10 20 30
N