SALMON RIVER BIGHORN SHEEP PROJECT

Final Report

2007 – 2015

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2007 – 2015

A Cooperative Research Effort Among

Idaho Department of Fish and Game

Nez Perce Tribe

USDA Forest Service

USDI Bureau of Land Management

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EXECUTIVE SUMMARY

A cooperative interagency project was undertaken from 2007-2015 to assess population status of bighorn sheep along the Salmon River in central Idaho, USA. Cooperators included Idaho Department of Fish and Game; Nez Perce Tribe; USDA Forest Service, Nez Perce-Clearwater and Payette National Forests; and USDI Bureau of Land Management, Cottonwood Field Office.

The goal of this project was to gain a better ecological understanding of bighorn sheep within the project area and provide pertinent findings to cooperating federal land management agencies to facilitate concurrent land-use planning efforts addressing domestic and bighorn sheep management issues including potential risk of contact between the species and subsequent disease transmission to bighorn sheep. Specific objectives included assessing habitat, space use, population structure and connectivity, demographics, and potential risk of contact with domestic sheep.

The project area was located within the Salmon River drainage in west-central Idaho of the western United States, including that portion of the Salmon River and tributaries within the Payette and Nez Perce-Clearwater National Forests. The project area encompassed the Lower Salmon River bighorn sheep population, 1 of 5 within the Salmon River drainage. Salmon River bighorn sheep populations have undergone previous assumed pneumonia-caused die-offs and are thought to be disease limited. Terrain was remote, rugged, and sparsely populated; land ownership was predominantly federally-managed public lands; and land uses included livestock grazing, timber harvest, and recreation. The largest tributary within the project area, the South Fork of the Salmon River (South Fork), was almost solely within a designated Wilderness Area, and was more remote and rugged than the main stem Salmon River (main stem).

Habitat modeling identified continuous bighorn sheep habitat within the project area and the larger Salmon River drainage. Habitat distribution was dendritic, closely associated with the rugged canyon breaks of the Salmon River and its main tributaries. Lesser amounts of more fragmented habitat were identified at higher elevations associated with mountain and ridge tops.

Data collection relied on radio-collared (collared) study animals. From 2007–2013, 82 (43 females, 39 males) bighorn sheep were collared and tracked from the ground and air. Bighorn sheep within the Lower Salmon River population were distributed within an estimated 990 km^2 population range encompassing an 84-km reach of the main stem and the lower 21 km reach of the South Fork.

Five female (Manning Bridge Ewes, Wind River, Indian Creek, Jersey Creek, South Fork Ewes) and 4 male (Manning Bridge Rams, Bull Creek, Blowout Creek, South Fork Rams) social groups (groups) were identified. Female groups used discrete use areas, were distributed sequentially and continuously along the main stem and South Fork, and either shared or slightly overlapped adjacent group boundaries. Female groups did not display seasonal (summer vs. winter, lambing vs. non-lambing) space use, using the same general area year-round. Male groups were also distributed sequentially and continuously within the project area. Annual use areas for males ($\overline{x}$ = 172 km^2) was nearly twice as large as those of females ($\overline{x}$ = 96 km^2). Mean seasonal use area size for male groups differed between rut (271 km^2) and non-rut seasons (61 km^2) with rut season use areas almost 4 times larger than those during the non-rut season. Male group use areas were discrete and disjunct during the non-rut season, but overlapped extensively during the rut season.

Female and male groups displayed strong site and group fidelity. Adult female forays into neighboring female use areas averaged 0.4 incidents per year accounting for <2% of female locations. Most forays were short-distance movements ($\overline{x}$ = 4 km), but infrequent (3 of 14 recorded incidents) long-distance ($\overline{x}$ = 30 km) movements demonstrated the potential movement capabilities of females. Three of 40 collared females potentially changed group membership; an estimated rate of 2% per year. Adult male forays outside of non-rut use areas were low. Two of 26 collared males made 1 foray incident each and no males were documented to have changed group membership. Estimates of foray movements and change in group membership may be low as our sample was restricted to adult study animals.

Spatial analysis and probability modeling established a high level of connectivity among main stem groups; primarily through male movements during the rut season. Female groups along the main stem contributing to population connectivity through low-level, year-round female-female group interactions. During the rut season, males along the main stem abandoned site and group fidelity and traveled long distances in search of female groups; resulting in a high level of connectivity as they interacted with multiple female and males groups. Connectivity between the 2 South Fork groups (South Fork Ewes and South Fork Rams) and main stem groups appeared low. We did not document collared members of either South Fork group within neighboring main stem group use areas and a single collared male from the adjacent main stem Blowout Creek group interacted with South Fork groups during the rut season.

Federally-managed public land domestic sheep allotments occurred in the western portion of the project area and overlapped estimated use areas of 3 bighorn sheep social groups; Manning Bridge Ewes, Manning Bridge Rams, and Wind River. Proximity of domestic sheep in the western portion of the project area coupled with a high degree of connectivity among bighorn sheep groups raised concerns over potential disease transmission throughout the population. Independent risk of contact analyses conducted by cooperating federal agencies, predicted a high (>100%) probability of contact between Lower Salmon River bighorn sheep and administered domestic sheep allotments. Consequently, domestic sheep grazing was discontinued on allotments posing the greatest risk of contact reducing modeled risk of contact to $\leq$ 4%.

Concentrations of trace minerals and prevalence of bacterial and viral diseases and endo- and ectoparasites we measured were generally within ranges reported for other bighorn sheep populations. Although morbidity of most diseases we tested is thought to be low as primary agents, their role as opportunistic or pre-disposing agents in polymicrobial disease complexes such as respirator pneumonia remains a concern. High exposure rates of *Mycoplasma ovipneumoniae* (97%) and PI3 (72%), and prevalence of Mycoplasma ovipneumoniae (20%) and *Mannheimia Haemolytica* (44%) in upper respiratory tract samples are indicative of a pneumonic population.

Summer lamb survival and recruitment were low, but increasing trends in these parameters and population counts provided evidence for a growing population during the term of the project. Adult survival ($\overline{x}$ = 0.90 females, $\overline{x}$ = 0.79 males) and annual female reproductive rates ($\overline{x}$ = 0.83) remained consistent through the project period, and were within ranges reported for stable to declining populations. Annual summer lamb survival was low ($\overline{x}$ = 0.28 2009–2010), increasing in trend after 2010 ($\overline{x}$ = 0.51 2011–2015), and was indicative of a pneumonic population. Recruitment rates were low averaging 0.21 from biological years 2000-2012 and were in line with those estimated for declining populations. As with summer lamb survival, lowest estimates were obtained in 2010 ($\overline{x}$ = 0.14 2009–2010) with an increasing trend observed thereafter ($\overline{x}$ = 0.27 2011–2012), although data precision was low. Recruitment within South Fork Ewes was consistent across years and higher ($\overline{x}$ = 0.36) than main stem groups ($\overline{x}$ = 0.16). Population counts accounted for substantially more (250%) bighorn sheep than previously estimated and the maximum count of 347 bighorn sheep should provide for a greater degree of resiliency against demographic and environmental stochasticity than previously thought. An average 12% annual increase in population counts was observed.

Although we were unable to quantify the extent of pneumonia and its impacts, taken together, health sampling, demographic patterns, and field observations suggested respiratory pneumonia, manifested primarily through lamb mortality, is likely a chronic condition in this population. Although lamb summer survival and recruitment remained low, apparent increasing trends in vital rates and population counts provide evidence for population growth and recovery. Given evidence of chronic pneumonia and low lamb survival and recruitment, continued monitoring of this population is warranted to determine if apparent increasing population performance results in continued recovery.

ACKNOWLEDGEMENTS

The Salmon River Bighorn Sheep Project (project) was a collaborative interagency effort and would not have been possible without dedicated commitment, funding, and in-kind support from cooperating federal and state agencies and private organizations. Principle funding for this project was provided by the USDA Nez Perce-Clearwater (NCNF), and Payette National Forests (PNF), USDI Bureau of Indian Affairs (BIA), USDI Bureau of Land Management (BLM), and USDI Fish and Wildlife Service (FWS). Additional funding was provided by the National Wildlife Federation, Oregon Foundation for North American Wild Sheep, and Wild Sheep Foundation.

Idaho Department of Fish and Game (IDFG) provided expertise and staff for capturing, collaring, and health sampling study animals; and assistance with field surveys. We would like to thank Matt Cambier, Paul Christensen, Jay Crenshaw, Clay Hickey, Scott Kinnen, Julie Mulholland, Jeff and Erin Rohlman, Mike Scott, and the many other capture crew members from the Clearwater and McCall regional offices. Special thanks to jet boat pilot Roy Kinner for keeping us safe on the river. Additional thanks to veterinarians Mark Drew and Phil Mamer for collecting and coordinating analysis of health samples. Special recognition to Nathan Borg for his never-ending enthusiasm for this project while assisting with capture operations and other field work, and providing a better understanding of the genetics of this population through his M.S. degree.

The project received unending support from many passionate agency professionals. Dave Renwald, David Wooten, and Anna Schmidt with the BIA; Barbara Behan with the FWS; and Tom Rinkes and Allen Rowley with the BLM took a special interest in the project. Their extra efforts securing continued funding, prioritizing project needs, and offering many other means of support are greatly appreciated. Joanne Bonn with the NCNF was always available and responsive to project needs and inquiries on the Forest. Special recognition to Ana Egnew, Chans O'Brien, and Patricia Soucek with the PNF for their long-term commitment to this project; providing funding, guidance, field assistance, and a lasting camaraderie. Craig Johnson's passion for the project was infectious. His efforts securing continued BLM funding, monitoring study animals, sharing bighorn sheep observations, and coordinating pertinent BLM activities among cooperator's contributed greatly to the success of the project. Advice and guidance received, during the planning stages and throughout the project, from bighorn sheep experts Tim Schommer and Melanie Woolever with the USDA Forest Service; Victor Coggins with Oregon Department of Fish and Wildlife; and Frances Cassirer and Pete

Zager with IDFG was invaluable in placing the project on sound footing. Special thanks to George Houston and Larry Jacobs with the Oregon Foundation for North American Wild Sheep for their continued support through the duration of the project.

Air support was foundational for this project. Leading Edge Aviation provided helicopter-capture services. Their efficiency and care in capturing and handling study animals is appreciated. Sawtooth Flying Service conducted aerial monitoring flights and provided support for field operations. We appreciate the dedication, flexibility, and skilled flying talent of owner/operator Mike Dorris.

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BACKGROUND

BIGHORN SHEEP POPULATIONS ACROSS THE WESTERN UNITED STATES

Based on archaeological evidence and early accounts of settlers and explorers, bighorn sheep (*Ovis canadensis*) were widely distributed and abundant prior to European settlement. Their range was contiguous throughout mountain and desert habitats and extended from southwestern Canada, south through western United States to northern Mexico, and east to western portions of North and South Dakota, Nebraska, and Texas (Buechner 1960, Thorne et al 1985, Toweill and Geist 1999, Valdez and Krausman 1999). Although historic population levels are difficult to estimate, Seton (1929) and Beuchner (1960) suggested 1.5–2.0 million bighorn sheep may have been present prior to 1800 (But see Demarchi 1977, Demarchi et al. 2000). Irrespective of the accuracy of Seton's estimate, there is widespread agreement that bighorn sheep prior to European settlement were one of, if not the most, abundant ungulate species within the mountainous western United States.

Concurrent with European settlement, bighorn sheep suffered range-wide population declines across the western United States; in some states once abundant bighorn sheep populations were extirpated or reduced to remnant populations in as little as 50 years (Toweill and Geist 1999). Dramatic and swift declines in abundance occurred during the mid 1800s to mid 1900s and were attributed to overharvest, habitat loss, and competition for forage with and disease transmission from domestic livestock (Hornaday 1914, Honess and Frost 1942, Jones 1950, Smith 1954, Buechner 1960, McQuivey 1978, Jessup 1981, Wehausen et al. 1987, Goodson 1982, Valdez and Krausman 1999). The pattern of decline was similar across western states (Toweill and Geist 1999). Initial declines were attributed to overharvest primarily from unregulated market hunting associated with early timber and mining settlements. More dramatic declines were attributed to subsequent introduction of widespread livestock grazing. Early unregulated livestock grazing contributed to loss of habitat quality, competition for forage and water, and importantly disease transmission from domestic sheep. Areas of widespread population declines and extirpations coincided spatially and temporally with domestic sheep grazing across the west (Hornaday 1908, Buechner 1960, Goodson 1982, Smith 1982, Toweill and Geist 1999, Wehausen et al. 2011). Numbers of domestic sheep grazed on rangelands across the 11 western states peaked at around 28 million by 1920 and remained at those levels until around 1945 (Goodson 1982).

The pattern and timing of population declines were so consistent and dramatic across the west that over a 28 year period between 1889–1917 seven western states closed take of bighorn sheep through legislative action (Arizona, California, Colorado, Montana, Nevada, New Mexico, and Texas; Toweill and Geist 1999). Within roughly a 40-year period between 1900–1940, bighorn sheep were extirpated (Nebraska, North Dakota, Oregon, South Dakota, Texas, and Washington) or reduced to remnant population levels (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming) across their range in the western United States, resulting in significant range reduction, habitat fragmentation, and population isolation (Toweill and Geist 1999). Currently, bighorn sheep occur at a fraction of historic numbers and range in a fragmented distribution (Singer et al. 2000*a*, *b*).

BIGHORN SHEEP POPULATIONS IN IDAHO

Idaho supports populations of California (*O. c. californiana*) and Rocky Mountain (*O. c. canadensis*) subspecies of bighorn sheep (But see Ramey 1993, Wehausen and Ramey 2000, Buchalski et al. 2016). California bighorn sheep are restricted to the Owyhee desert and canyon lands of south-central and southeastern Idaho while Rocky Mountain bighorn sheep occupy a much larger range within the remainder of the state, including the Salmon River drainage. The term bighorn sheep, as used in this document, refers to Rocky Mountain bighorn sheep unless otherwise noted.

Historically, bighorn sheep were abundant and widespread throughout the mountainous regions of Idaho including the Salmon River canyon (Merriam 1891, Seton 1929, Smith 1954, Buechner 1960, Toweill and Geist 1999, IDFG 2010). The history of bighorn sheep in Idaho mirrors that of other populations across the west. Prior to settlement around 1850, bighorn sheep were thought to be one of if not the most abundant and widespread ungulates within Idaho's mountains and deep river canyons. During the 1860s and 1870 market hunting in support of mining towns reduced the bighorn sheep population primarily on accessible winter ranges. However, bighorn sheep remained healthy up until around 1870. Domestic sheep grazing was introduced in 1860 and by 1870 the first series of die-offs connected to domestic sheep grazing were reported. By 1910 a single native population survived at remnant levels in the rugged canyon breaks of the Salmon River. It was estimated that between 1920 and 1940, only 1,000 bighorn sheep remained in the Salmon River drainage (IDFG 1990). This last remaining native population continues to survive despite periodic die-offs thought to be caused by respiratory disease epizootics.

Statewide, Rocky Mountain bighorn sheep estimates attained a peak of around 3,850 in 1990, but declined to around 1,710 (a decline of more than 55%) by 1998, primarily associated with disease and despite restoration efforts (Toweill and Geist 1999, IDFG 2010). Population levels have not changed appreciable since, with current statewide estimates being relatively stable around 1,900 animals (IDFG 2010, 2011, 2013, 2015). Both subspecies (Rocky Mountain and California bighorn sheep) have declined by 80–90% from historic levels and populations are currently considered stable, however, average densities across potential habitat within the state are estimated at 0.3 bighorn sheep/km^2, which is considered low (IDFG 2010, 2015).

CONSERVATION STATUS OF BIGHORN SHEEP IN THE SALMON RIVER

Bighorn sheep were historically abundant and the most common ungulate throughout the Salmon River drainage. Although bighorn sheep were not extirpated from this area, they represent the last remaining native population in the State of Idaho and current population levels remain low. Respiratory disease is thought to be the primary hurdle to recovery. Disease related die-offs were reported as early as the 1870s (Smith 1954), and have continued to be documented or implicated since then (Akenson and Akenson 1992; Toweill and Geist 1999, IDFG 2010). Bighorn sheep within the Salmon River represent the core of Idaho's bighorn sheep populations and this unique native genetic stock represents a heightened conservation need across federal, state, and tribal jurisdictions.

<u>Idaho Department of Fish and Game</u>

Bighorn sheep are managed as a trophy big game species by the Idaho Department of Fish and Game (IDFG). At initiation of the Salmon River Bighorn Sheep Project (project), from 1991–2009, bighorn sheep were managed under the *Bighorn Sheep Species Management Plan* 1991–1995 (1990 plan; IDFG 1990). Under the 1990 and prior plans, bighorn sheep were managed on a statewide population basis, and emphasis was on regulating sport harvest and bighorn sheep translocations. The 1990 statewide estimate for Rocky Mountain bighorn sheep was 3,850 with a 1995 management goal to increase the statewide population by 10% (4,235 sheep). This goal was not reached and populations remain below 1990 levels today.

During the course of the project IDFG finalized the *Idaho Bighorn Sheep Management Plan 2010*, which updated and replaced the 1990 plan (IDFG 2010). The IDFG has also completed a final draft revised State Wildlife Action Plan (IDFG 2015). In this revision IDFG has assigned bighorn sheep an S2 NatureServe conservation status and a Tier 2 species of greatest conservation need (SGCN). An S2 ranking applies to species "imperiled in the state/province because of rarity due to very restricted range, very few populations…, steep declines, or other factors making it very vulnerable to extirpation from the State/province". A tier 2 SGCN ranking applies to "species with high conservation needs-that is, species with longer-term vulnerabilities or patterns suggesting management intervention is needed but not necessarily facing imminent extinction…" For bighorn sheep the stated rationale for a Tier 2 SGCN ranking was widespread declines historically and over the past 25 years. The IDFG also recognized the primary limiting factor as disease transmitted from domestic sheep.

Nez Perce Tribe

Bighorn sheep along the breaks of the Salmon River canyon, as elsewhere across the Nez Perce Tribe's (Tribe) Treaty Territory, are a culturally significant treaty resource (Pinkham 2007). Based on archeological evidence and verbal histories of tribal elders, prior to European settlement bighorn sheep were the primary game animal that sustained the Nez Perce way of life (Randolph and Dahlstrom 1977, Pinkam 2007). Bighorn sheep were used for a large variety of purposes including food, clothing, tools, utensils, and weapons (Pinkham 2007). Native bighorn sheep within the Salmon River drainage are of particular importance to the Tribe as they represent the last genetic stock that has sustained the Tribe's subsistence lifestyle from time immemorial. The Tribe is in the process of designating bighorn sheep as a Tribal critically imperiled species (Nez Perce Tribe 2016) and continues to work towards bighorn sheep restoration along with state, federal, and other partners.

USDA Forest Service

Bighorn sheep are a USDA Forest Service (USFS) designated Sensitive Species in Regions 1 and 4 which include the Salmon River drainage in Idaho (USFS 2011, USFS 2016). Sensitive Species (USFS 2005*a*) are those for which population viability is a concern and are trending towards listing under the ESA as evidenced by significant current or predicted downward trends in population numbers or density or habitat capability that would reduce a species existing distribution. Sensitive Species receive special management emphasis to ensure their viability and to preclude trends toward endangerment that would result in the need for Federal listing. Management objectives for Sensitive Species include implementing practices to ensure species do not become threatened or endangered because of USFS actions, and to maintain viable populations distributed throughout their geographic range on National Forest System lands.

USDI Bureau of Land Management

Bighorn sheep are a USDI Bureau of Land Management (BLM) designated Idaho Sensitive Species (Special Status Species Type 2; BLM 2015). Sensitive Species status recognizes those species that are trending towards endangerment under the Endangered Species Act (ESA) and in need of heightened conservation measures to conserve the species and their habitats and reduce the likelihood and need for listing pursuant to the ESA (BLM 2008*a*, 2008*b*).

DISEASE TRANSMISSION

Following is a brief summary of this broad and important topic. More detailed reviews are provided elsewhere (Martin et al. 1996, Schommer and Woolever 2008, USFS 2010*a*, Wehausen et al. 2011, BLM 2016*a*).

Disease was a significant factor in the historic range-wide declines of bighorn sheep across western United States and remains the most important mortality factor limiting recovery today (Jessup 1981, Singer et al. 2000*c*, Monello et al. 2001, IDFG 2010, Cahn et al. 2011, Wehausen et al. 2011, Besser et al. 2012a, WAFWA 2012, TWS 2014). Current bighorn sheep abundance and distribution appears to be largely limited by recurrent disease epizootics (Hobbs and Miller 1992, Jorgenson et al. 1997, McCarty and Miller 1998). Although free-ranging bighorn sheep are susceptible to a variety of diseases that can affect herd viability, respiratory disease resulting in pneumonia has the greatest impacts on populations and extensive all age die-offs from pneumonia have occurred in every western state (Martin et al. 1996, Monello et al. 2001, Cahn et al. 2011, TWS 2014).

Bighorn sheep have a high probability of contracting fatal disease, primarily respiratory pneumonia, through contact with domestic sheep. Bighorn sheep are vulnerable to pathogens carried by, and transmitted from healthy domestic sheep. Once transmitted, these pathogens are fatal to bighorn sheep and there is no effective treatment. Historic accounts documenting the relationship between bighorn sheep disease and contact with domestic sheep extend back to the late 1800s when domestic sheep were first introduced to the west. Early accounts of bighorn sheep die-offs following introduction of domestic sheep grazing were common (Honess and Frost 1942, Jones 1950, Smith 1954, Buechner 1960). A large body of scientific literature further documents this relationship through observational evidence linking bighorn sheep die-offs in the wild to contact with domestic sheep (McQuivey 1978, Foreyt and Jessup 1982, Goodson 1982, Coggins 1988, Martin et al. 1996, Singer et al. 2001, Coggins 2002, George et al. 2008) and controlled penned experiments (Onderka and Wishart 1988, Foreyt 1989, Foreyt 1990, Coggins and Matthews 1992, Foreyt 1994, Callan et al. 1991). Comingling of domestic and bighorn sheep under controlled penned experiments resulted in high (100%) mortality rate among bighorn sheep while all domestic sheep remained healthy. No known published peer reviewed literature documents penned or free-ranging bighorn sheep remaining healthy in the presence of domestic sheep.

Although the relationship between domestic sheep and disease in bighorn sheep has been recognized for over 100 years, the specific etiology of respiratory disease in bighorn sheep remains elusive because the etiology is complex, potentially involving multiple pathogens, and technological limitations of past research tools precluded accurate assessment of involved pathogens (Wehausen et al. 2011, Besser et al. 2012*b*, Besser et al. 2013). More recent advances in culture independent genetic analysis methods such as polymerase chain reaction (PCR) and DNA sequencing hold promise to further understand this complex relationship. Bacteria in the genera *Bibersteinia*, *Mycoplasma*, *Mannheimia*, and *Pasteurella*, are thought to be the most important respiratory pathogens in pneumonia outbreaks in bighorn sheep (Onderka et al. 1988 Foreyt 1989, Foreyt 1990, Foreyt 1998, Foreyt et al. 1994, Miller 2001, Lawrence et al. 2010, Besser et al. 2012*b*, Besser et al. 2013, Besser et al. 2014).

Although the clinical pathways of respiratory pneumonia in bighorn sheep are not yet fully understood, devastating population impacts of this fatal disease are well documented. Pneumonia outbreaks can have significant long-term impacts on bighorn sheep populations. Pneumonia in bighorn sheep normally results in an initial short-term all-age die-off including high mortality across all age classes within a herd, often resulting in the mortality of a large proportion of the population. This is commonly followed by long-term chronic high lamb mortality for up to 20 years after the initial outbreak, depressing recruitment, population growth, and recovery (Rush 1927, Festa-Bianchet 1988, Foreyt 1990, Coggins and Matthews 1992, Ward et al. 1992, Foreyt 1995, Jorgenson et al. 1997, Aune et al. 1998, Singer et al. 2000*c*, Enk et al. 2001, Monello et al. 2001, Hnilicka et al. 2002, Cassirer and Sinclair 2007, Cassirer et al. 2013). This pattern of pneumonia and affects on bighorn sheep populations has been widespread, common, and documented in more than 70 peer-reviewed scientific publications (TWS/AAWV 2015).

Management alternatives for reducing the impacts of respiratory disease on bighorn sheep are limited, as there currently is no treatment for pneumonia in free-ranging populations. Wildlife professionals, veterinarians, and federal land management and western state fish and game agencies have concluded that domestic and bighorn sheep are not compatible when occupying the same range. Currently, the most effective management tool available for minimizing risk of disease transmission is to separate the two species in space and/or time (Hunt 1980, Jessup 1980, Foreyt and Jessup 1982, Goodson 1982, Jessup 1982, Kistner 1982, Wishart 1983, Coggins 1988, Onderka and Wishart 1988, Foreyt 1989, Desert Bighorn Council 1990, Foreyt 1990, Callan et al 1991, Coggins and Matthews 1992, Foreyt 1992, Foreyt 1994, Foreyt et al. 1994, Pybus et al. 1994, Foreyt 1995, USFS 1995a, USFS 1995b, Martin et al. 1996, BLM 1998, Schommer and Woolever 2001, FWS 2001, WAFWA 2012, TWS 2014, BLM 2016*b*).

INTRODUCTION

The Salmon River Bighorn Sheep project was initiated in response to the Chief of the USFS's 2005 appeal decision that remanded the Payette National Forest's (PNF) 2003 Land and Resource Management Plan (Forest Plan) for amendment to ensure viable bighorn sheep populations across the forest (USFS 2005*b*). In part, the appeal decision recognized continued domestic sheep grazing on the forest would jeopardize bighorn sheep viability due to the risk of contact with and subsequent disease transmission to bighorn sheep. In response to this appeal decision, the PNF completed a qualitative risk analysis of disease transmission between domestic and bighorn sheep on forest lands (USFS 2006a). This analysis and a subsequent Science Panel Review (USFS 2006b) identified a lack of data on bighorn sheep distribution and movements relative to domestic sheep allotment boundaries within the Salmon River canyon as a key factor hindering risk assessment. Subsequently the PNF initiated a National Environmental Policy Act (NEPA) review developing a supplemental Environmental Impact Statement (SEIS) to amend the Forest Plan to address bighorn sheep viability across the forest.

PROJECT NEED AND PURPOSE

At the time of project initiation, no intensive research had been conducted on bighorn sheep in the Salmon River canyon within the PNF and Nez Perce - Clearwater National Forest (NPCNF). Both national forests and the BLM managed active domestic sheep allotments (allotments) within the project area and shared common domestic–bighorn sheep management concerns. Further, the PNF had identified a need for more information on bighorn sheep within the project area to assist with their SEIS effort. The purpose of the project was to gain a better ecological understanding of bighorn sheep distribution, movements, temporal and spatial use patterns, and population status within the project area and to facilitate a more accurate assessment of the risk of contact between domestic and bighorn sheep. Project findings hoped to foster informed land-use decision making, and effective long-term management solutions by land management agencies, including the PNF, NPCNF, and BLM addressing and resolving common domestic–bighorn sheep management issues.

PROJECT HISTORY

Since bighorn sheep ranged across multiple jurisdictions with common domestic–bighorn sheep management issues, a collaborative interagency effort was thought to be the most efficient and effective approach. The project was initiated in 2007 as a cooperative research effort among the BLM, IDFG, NPCNF, PNF, and Tribe. Cooperators signed a Memorandum of Understanding (USFS 2007*a*; Appendix A) for the purpose of cooperatively identifying and implementing research needs on bighorn sheep within the Salmon River canyon. The Memorandum of Understanding established the Salmon River Bighorn Sheep Project Committee (Appendix B), comprised of cooperator representatives whose purpose was to implement research needs identified in the project's study plan (Mack 2007, Appendix C); facilitate resource sharing, communication, and soliciting funding; establish project direction; and coordinate project activities among involved agencies. Committee members advocated support, funding, and often provided field assistance from their respective agencies.

Project activities spanned a ten-year period from 2007 through 2016. Study year 2007 focused on planning and fundraising. Field efforts were initiated in late 2007 with the first bighorn sheep capture operation conducted in November of that year. Study year 2008 focused on locating bighorn sheep within the project area and working out logistics for accessing, capturing and collaring, and monitoring representative samples of the population. Data collection occurred 2009–2015; 2016 was dedicated to data analysis and final report preparation.

Data collection emphasis area, effort, and extent varied across study years. Data collection emphasis areas reflected changing priorities. Initially (2009–2013) emphasis was placed on documenting population distribution, social structure, and ram movements. Later (2013–2015) emphasis was placed on female production and lamb survival. Data collection effort in terms of number and type (VHF, GPS satellite) of radiocollars (collars) and monitoring frequency varied across years depending on funding availability. Lastly, data collection extent varied across the project area due to funding constraints. For the last 3 years of the project (2013–2015) location data was collected for the South Fork of the Salmon River (South Fork) portion of the project area only (location data collected for 1 of 9 known bighorn sheep social groups [groups] within the project area). The consequent variation in sampling effort across years, individuals, sex, and groups limited some data analyses.

PROJECT FUNDING

Project funding was secured through a combination of contributors and funding mechanisms (Fig. 1). Cooperating agencies, including the BLM and USFS (PNF and NPCNF), contributed funding through the federal Challenge Cost Share Program and Sole Source Contracting mechanisms. The US Fish and Wildlife Service provided funding through their Tribal Wildlife Grants Program while the Bureau of Indian Affairs provided funding through the Tribe's PL-638 contract. Non-governmental organizations including the Oregon Foundation for North American Wild Sheep, National Wildlife Foundation, and the Wild Sheep Foundation also contributed funds through their granting opportunities. Over the course of the project, a total of $1,821,688 was contributed to this project, averaging $182,169 per year; actual annual budgets varied from year to year, ranging from $0–345,000.

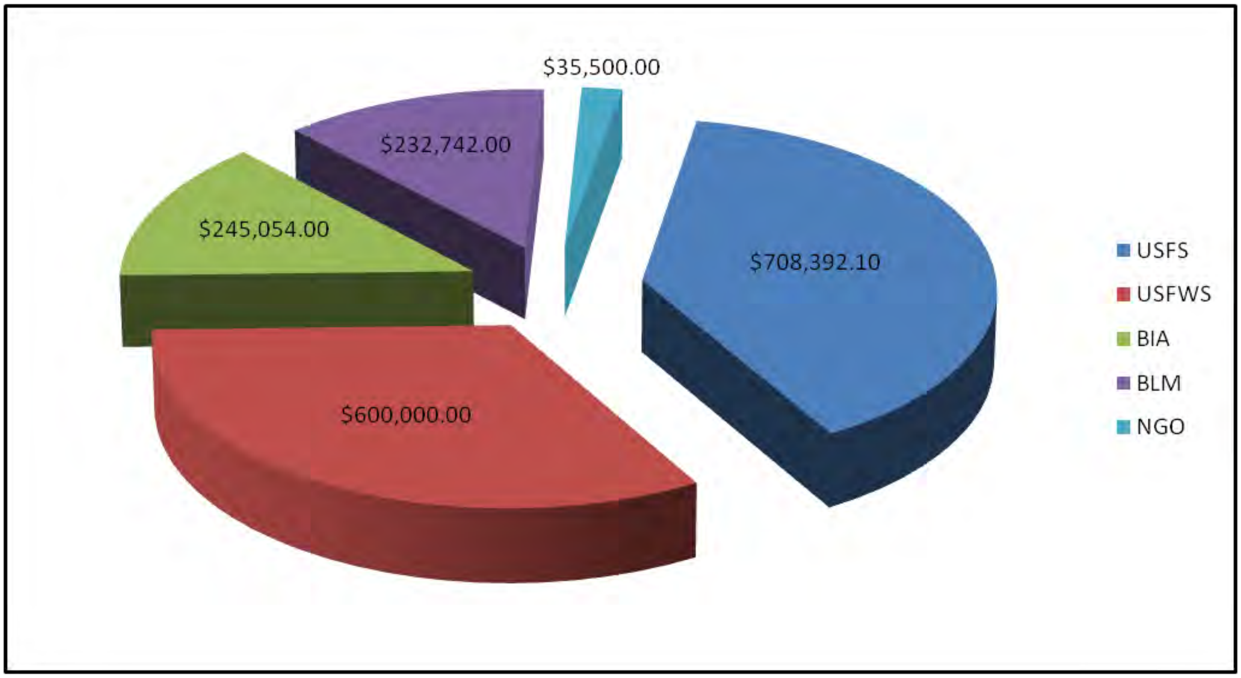

Figure 1. Project funding by source including project cooperators USDA Forest Service (USFS) and USDI Bureau of Land Management (BLM); other federal agencies Bureau of Indian Affairs (BIA) and USDI Fish and Wildlife Service (USFWS); and non-governmental organizations (NGO) including the National Wildlife Federation, Wild Sheep Foundation, and the Oregon Chapter of the Foundation for North American Wild Sheep. In-kind contributions are not shown. Salmon River Bighorn Sheep Project, ID, USA, 2007–2015.

FEDERAL LAND USE PLANNING

Project findings were used throughout the course of the study to assist cooperators with concurrent ongoing federal public-land-use planning efforts addressing domestic and bighorn sheep management issues. During the course of the project, the PNF, NPCNF, and BLM initiated NEPA reviews to amend, if necessary, existing management plans to address domestic and bighorn sheep management concerns.

Bureau of Land Management

The BLM Cottonwood Field Office administered 4 allotments in (Partridge Creek, Marshall Mountain, Hard Creek) and surrounding (Big Creek) the project area. In 2008, the BLM published the *Proposed Cottonwood Resource Management Plan and Final Environmental Impact Statement* (Management Plan; BLM 2008*c*). The 2008 Management Plan was protested to the Director of the BLM out of concerns for continued domestic sheep grazing on these 4 BLM allotments within bighorn sheep habitat. The Director found the 2008 Management Plan and final EIS did not provide an adequate range of alternatives to address potential disease transmission, from domestic sheep and goats, to bighorn sheep and remanded this portion of the 2008 Management Plan and final EIS to the BLM Idaho State Director. The Director also required a supplemental EIS be prepared for the purpose of analyzing the impacts of domestic sheep and goat grazing within the 4 allotments. In response to the Director's remand the BLM published the *Proposed Cottonwood Resource Management Plan Amendment for Domestic Sheep Grazing and Final Supplemental Environmental Impact Statement (BLM 2016a)* and a final Record of Decision (BLM 2017) amended the Management Plan in January 2017. The amended management plan discontinued domestic sheep grazing on all but the Big Creek allotment.

Nez Perce Clearwater National Forest

At the start of the project, the NPCNF administered one active domestic sheep allotment, Allison Berg, on the north side of the Salmon River (See project area). Out of concern for bighorn sheep, active grazing of this allotment was administratively discontinued in 2007. Future management of this allotment is being addressed through ongoing NEPA review of their *Nez Perce-Clearwater Land and Resource Management Plan*, initiated in 2012. As of January 2017, the NPCNF continues to prepare the required EIS with a draft anticipated sometime in 2018. The allotment will remain un-grazed while the EIS is being completed and a new Forest Plan adopted.

Payette National Forest

When the project started, the PNF administered 24 active domestic sheep grazing allotments in and adjacent to the project area (see project area). The PNF completed a *Southwest Idaho Ecogroup Land and Resource Management Plans Final Environmental Impact Statement* (2003 FEIS; USFS 2003*a*) and Record of Decision (2003 ROD) to supplement the 2003 *Payette National Forest Land and Resource Management Plan* (2003 Forest Plan; USFS 2003*b*). This 2003 FEIS and ROD were appealed based on the PNF's decision to continue grazing domestic sheep within or near occupied bighorn sheep range. Appellants contended continued domestic sheep grazing would threaten the viability of bighorn sheep through disease transmission.

In 2005, The Chief of the Forest Service (Chief) concurred with the appellants, citing the analysis pertaining to bighorn sheep, presented in the 2003 FEIS, did not adequately address viability (USFS 2005*b*). The Chief reversed the 2003 ROD, and instructed the Region 4 Forester to analyze bighorn sheep viability in the PNF, and amend the Forest Plan accordingly to ensure bighorn sheep viability.

In response to the Chief's reversal, the PNF initiated a 5-year supplemental EIS planning effort. *A Risk Analysis of Disease Transmission between Domestic Sheep and Bighorn Sheep on the Payette National Forest* was published in 2006 (USFS 2006*a*). This document acknowledged a need for a better understanding bighorn sheep distribution and movements, in the Salmon River canyon to adequately address risk of contact; and was a primary impetus for initiation of this project. In 2008, the PNF published the *Southwest Idaho Ecogroup Land and Resource Management Plans Draft Supplemental Environmental Impact Statement (USFS 2008)*, and in January 2010 an *Update to the Draft Supplemental Environmental Impact Statement* (USFS 2010*b*). The *Southwest Idaho Ecogroup Land and Resource Management Plans Final Supplemental Environmental Impact Statement* (2010 FSEIS; USFS 2010*a*) and Record of Decision (2010 ROD; USFS 2010*c*) were published in July 2010. The 2010 FSEIS and 2010 ROD amended the 2003 Forest Plan providing for bighorn sheep viability through separation between domestic sheep grazing operations and bighorn sheep range. The 2010 ROD protected (determined unsuitable for domestic sheep grazing) 346,696 acres of bighorn sheep habitat (94% of modeled summer source habitats on the Forest), including eliminated domestic sheep grazing across 68,718 acres (69% of suitable rangelands on the Forest).

REPORT SCOPE AND PURPOSE

This report summarizes project activities conducted from 2007–2015, and serves as the 2015 annual and final project reports for cooperators, and project final report requirements for US Fish and Wildlife Service's Tribal Wildlife Grant F14AP00625, the USDI Bureau of Land Management Challenge Cost Share Agreement L14AC00379, and the USDA Payette National Forest Sole Source Contract AG-0261-P-14-0306.

PROJECT GOALS AND OBJECTIVES

The goal of this project was to collect baseline ecological information, on bighorn sheep within the project area, which may prove useful to federal land management agencies (USFS, BLM) engaged in land-use planning efforts, while addressing domestic and bighorn sheep management issues. It was hoped baseline data collected during this project would contribute to future management and conservation of bighorn sheep within the Salmon River, and complement similar ongoing research in the westward adjacent bighorn sheep metapopulation in the Hells Canyon area of the Snake River in Oregon, Washington, and Idaho (Hells Canyon).

Objectives of the project included:

1. Model and validate bighorn sheep habitat within the project area.

2. Assess population distribution, structure, space use, and connectivity within the project area.

3. Investigate genetic structure, diversity, and connectivity among the Lower Salmon River and adjacent bighorn sheep populations.

4. Investigate extent of spatial and temporal overlap between occupied bighorn sheep range, modeled bighorn sheep habitat, and domestic sheep allotment boundaries within the project area.

5. Assess potential risk of contact between bighorn and domestic sheep within the project area.

6. Assess population demographics including population health; lamb production, summer lamb survival, and recruitment; adult mortality and survival; and population size and composition.

PROJECT AREA

The project area was located within the Salmon River drainage in west-central Idaho of the western United States. The Salmon River, also known as the "River of No Return", is the second longest river in Idaho, second only to the Snake River, of which it is the largest tributary, flowing 685 km from its headwaters in eastern Idaho's Sawtooth Range, west across the state to its confluence with the Snake River, then along Idaho's western border with Oregon (Denny and Tardy 2009). The Salmon River basin is wholly contained within the state and is the second largest (36,260 km^2) in Idaho (Miller et al. 2002). The River of No Return is the longest free-flowing river in the lower contiguous United States for rivers wholly contained within one state (National Wild and Scenic Rivers System 2017). This free-flowing system drains sparsely populated, remote, and rugged country including three Wilderness Areas. One hundred and twenty five miles of the Salmon River is designated a Wild and Scenic River (National Wild and Scenic Rivers System 2017). The Salmon River is most noted for cutting through the central Idaho Batholith, a large emplacement of 65–100 million year old Intrusive igneous rock covering 39,886 km^2 of central Idaho (Idaho State University 2017), forming the second deepest gorge on the continent (only Hells Canyon on the Snake River, just to the west is deeper; Recreation.gov 2017). This 35–45 million year-old rugged granite-walled canyon is over 300 m deeper than the Grand Canyon and runs over 1,600 m deep for a 290-km reach (Recreation.gov 2017, National Wild and Scenic Rivers System 2017).

The project area includes a 108-km portion of the Salmon River and tributaries from the town of Riggins, ID east and upstream to the confluence of Big Mallard Creek (Fig. 2). Major tributaries include the lower 32 km of the Little Salmon River from Hazard Creek downstream to its confluence with the main stem Salmon River (main stem), and the lower 21 km of the South Fork from Smith Creek at Hettinger Ranch downstream to its confluence with the main stem. Terrain was markedly more rugged and access more restricted within the South Fork reach compared to the main stem reach resulting in some differences in data collection methodologies and sample sizes between the 2 reaches.

HABITAT AND CLIMATE

The geology and topography of the project area is dominated by the Salmon River Mountains, an expansive area of the Idaho Batholith. These remote and rugged mountains are not organized into distinct typical mountain ranges with topographic orientation (e.g. north to south) but rather are characterized by a jumble of contiguous mountains lacking any particular topographic orientation that define a large block-shaped massif extending across 23,000 km^2 of central Idaho.

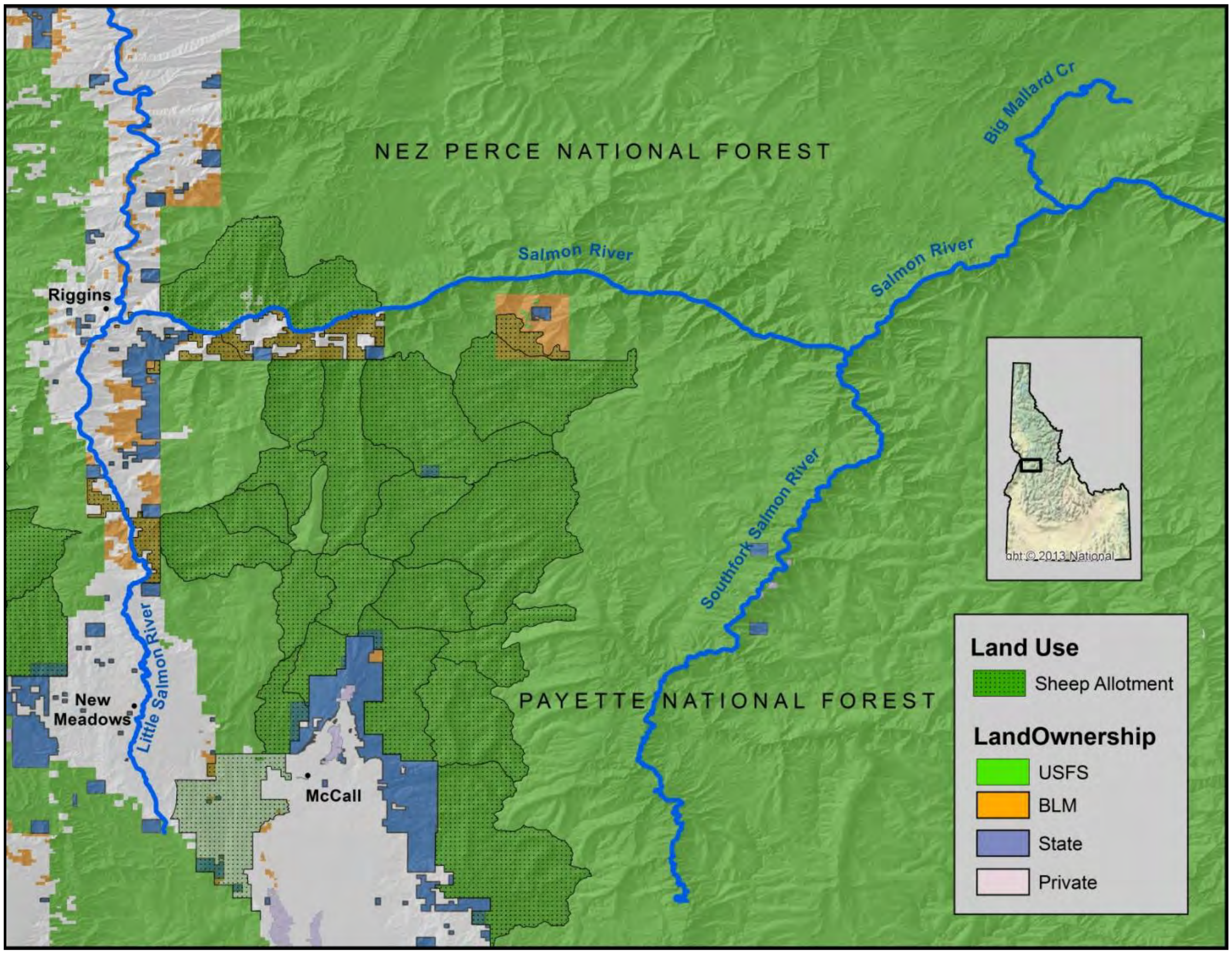

Figure 2. Project area showing land ownership and domestic sheep allotments (BLM = Bureau of Land Management, USFS = US Forest Service). Salmon River Bighorn Sheep Project, ID, USA.

The project area supports a mosaic of habitats due, in large part, to a combination of prevailing weather patterns, lack of topological orientation, and extreme elevation gradients. The project area is geographically located between two climate zones influenced by maritime weather patterns to the north and continental weather patterns to the south. The lack of topographic orientation and extreme elevation gradient provide a cline of aspect/elevation combinations influencing temperature, precipitation, wind exposure, and other climatic elements.

The project area is located within the Idaho Batholith ecoregion characterized as mountainous, deeply dissected, partially glaciated, and underlain by granitic rocks (USEPA 2017). Soils are typically shallow, non-productive, and erosive. Climate is generally characterized by extreme ranges in annual temperature and precipitation including hot dry summers and cold wet winters. This ecoregion is further subdivided into 10 sub-regions, four of which occur within the project area: South Clearwater Forested Mountains, Southern Forested Mountains, High

Idaho Batholiths, and Hot Dry Canyons (Fig. 3, USEPA 2017). These sub-regions are also largely defined by maritime vs. continental climate influences and elevation gradients.

South Clearwater Forested Mountains

This mid-elevation forested ecoregion is located north of the Salmon River. Habitats here are more influenced by a maritime climate than those on the south side of the river. Grand fir (*Abies grandis*)–Douglas-fir (*Pseudotsuga menziesi*) forest types predominate, and at higher elevations western spruce (*Picea engelmannii*)–subalpine fir (*Abies lasiocarpa*) habitat types are common. Western larch (*Larix occidentalis*) and ponderosa pines (*Pinus ponderosa*) are also found but less common.

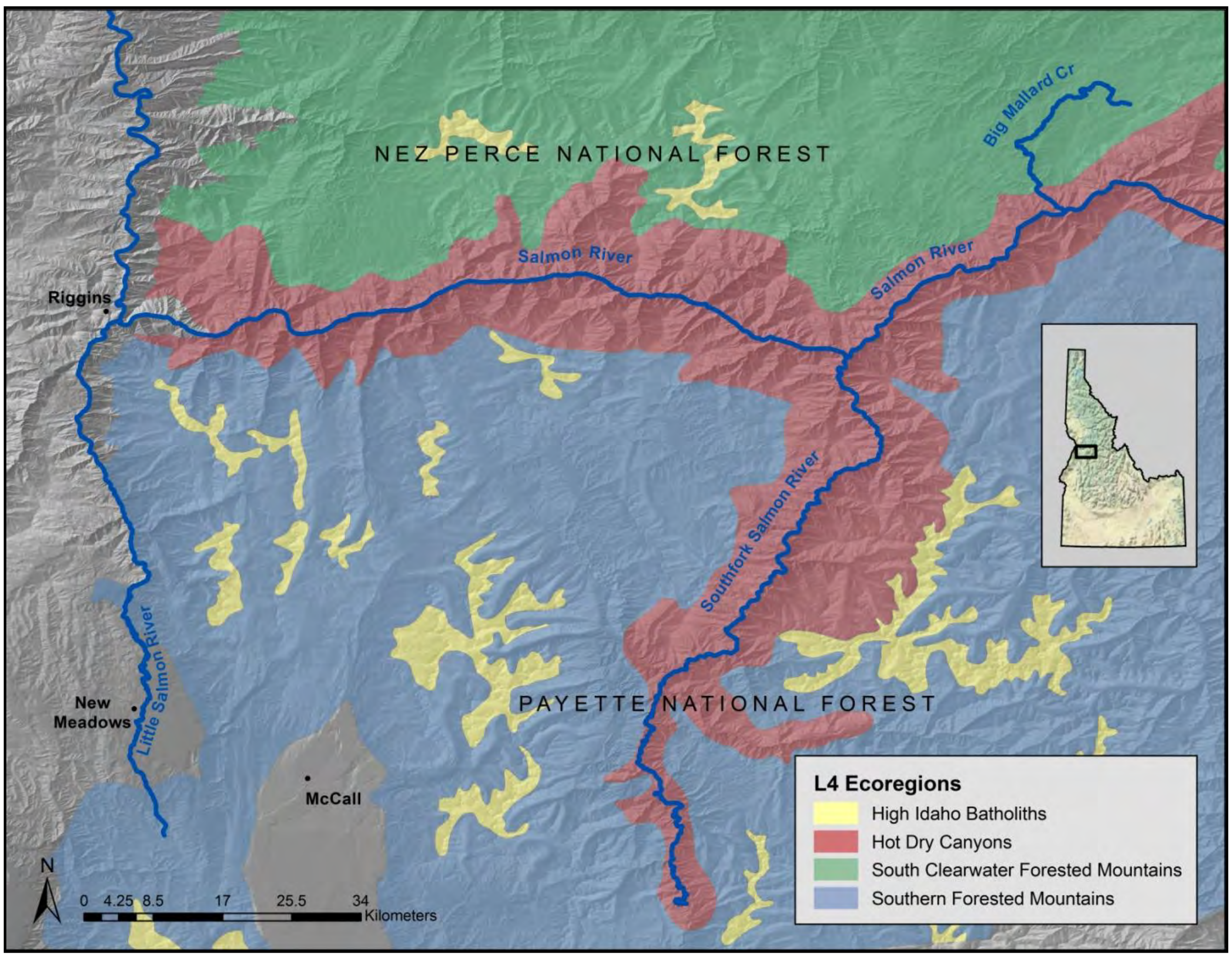

Figure 3. Level 4 ecoregions within the project area, Salmon River Bighorn Sheep Project, ID, USA, 2007–2015. Bighorn sheep habitats occur primarily within the Hot Dry Canyons and secondarily within the High Idaho Batholith ecoregions.

Southern Forested Mountains

The dominant mid-elevation forested habitats south of the Salmon River are within the southern forested mountains ecoregion. These habitats are influenced by a continental climate and are overall drier than on the north side of the river. Grand fir–Douglas-fir and western ponderosa pine forests dominate. Subalpine fir forest occurs at higher elevations and open stands of ponderosa pine with mountain mahogany (*Cercocarpus ledifolius*), Idaho fescue (*Festuca idahoensis*), and bluebunch wheatgrass (*Pseudoroegneria spicata*) understories grow at lower elevations.

High Idaho Batholith

This ecoregion defines the highest elevations on either side of the river and is fragmented into island habitats characterized by jagged peaks, glacial cirques, and extreme exposure. Habitats within this ecoregion receive more precipitation than the surrounding lower elevation ecoregions and are snow-covered for much of the year. Soils are very stony and unproductive and the growing season is restricted to a short summer season.

Western spruce-fir forests predominate and alpine meadows are common. Engelmann spruce, subalpine fir, lodgepole pine (*Pinus contorta*), and whitebark pine (*Pinus albicaulis*) grow in rocky cirques or on exposed sites as scattered trees, or very open-canopied stands with little to no understory. Alpine grasslands, meadows, and wetlands are common above treeline.

Hot Dry Canyons

This ecoregion describes the deep canyon breaks of the Salmon River, and its larger tributaries, which can reach elevation gradients of 1,524 m. This ecoregion provides the majority of bighorn sheep habitat within the project area. Low-elevation habitats within this ecoregion are warmer and dryer than other ecoregions in the project area. There is little winter snowfall, although the river freezes over most years. Terrain is steep, open, and rocky with many consolidated cliff faces. Vegetation is dominated by grasses and forbs with scattered ponderosa pine. South-facing slopes are dryer, warmer, and less forested than north-facing slopes, and are dominated by mountain big sagebrush (*Artemisia tridentata*), bluebunch wheatgrass, Idaho fescue and scattered ponderosa pines. North-facing slopes are cooler and wetter and support denser stands (stringers or pockets) of, primarily, ponderosa pine and Douglas-fir.

Within the project area, annual temperature and precipitation range widely primarily due to extreme elevation gradients. Elevations range from 500 m above sea level in the town of Riggins to just under 3,000 m in the Gospel Hump Wilderness. In the canyon bottoms, summers are hot and dry while winters are mild with little snow. Average monthly temperature in Riggins ranges from -2–34° C with summer temperatures above 38° C common. Average annual precipitation is 43 cm, (Western Regional Climate Center 2017). Higher-elevation habitats receive cool dry summers and cold wet winters with substantial persistent snowpack. Average annual temperatures range from -18–26° C while average annual precipitation can exceed 1,200 cm.

LAND OWNERSHIP

Land ownership within the project area is dominated by federally-managed public lands but also includes lesser amounts of state and private land holdings (Fig. 2). Federally-managed public lands are administered primarily by the USFS including two national forests: the NPCNF on the north side of the main stem and the PNF on the south side. The upper 71 km (66%) of the main stem reach within the project area runs through USFS designated Wilderness Areas (Gospel-Hump and Frank Church River of No Return) and is within a Wild and Scenic River corridor. A few small private inholdings are scattered along the river through this upper reach. The lower 37 km (34%) of the main stem reach within the project area flows through a matrix of non-Wilderness public lands administered by the USFS and BLM, as well as State and private lands.

The South Fork reach runs entirely through public lands administered by the PNF, and all but the upper one mile within the project area is within the Frank Church River of No Return Wilderness. A few small private inholdings are scattered along the river within this reach.

The Little Salmon River is dominated by private lands along the valley floor and a mix of private, BLM, and state lands along the foothills. Higher elevations are USFS public lands administered by the PNF and NPCNF.

LAND USE

Primary land uses within the project area include livestock grazing (primarily cattle and domestic sheep; secondarily, horses and mules) and timber harvest within the lower main stem including the Little Salmon River. Recreational activities predominate along the upper main stem and South Fork reaches including hunting, fishing, and floating (both rafting and jet boating).

DOMESTIC SHEEP GRAZING

When the project started, 3 domestic sheep producers were permitted to graze around 14,000 ewe/lamb pairs (24,000 total domestic sheep) and 18,000 dry ewes on 19 PNF, 1 NPCNF, and 3 BLM public lands allotments within the project area (USDA 2006a; D. Huibregtse, BLM, personal communication; D.Sorensen, USFS, personal communication; Fig. 2; Appendix D). A fourth producer was permitted to graze around 6,895 ewe/lamb pairs and 5,025 dry ewes on an additional 5 allotments on the west side of the PNF adjacent to the project area. Domestic sheep also were grazed on State and private lands within the project area. Grazing of domestic sheep occurred primarily within the western portion of the project area.

Payette National Forest

The 19 allotments administered by the PNF within the project area were located south of the main stem reach, were allocated to 3 permittees, and provided higher-elevation summer (ewe/lamb pairs) and fall (dry ewes) pasture from 1 July–15 October. Numbers of permitted domestic sheep averaged around 12,115 ewe/lamb pairs and 15,931 dry ewes and band size ranged from 800–1,333 for ewe/lamb bands and 1,333–2,666 for dry ewe bands. During the course of the project, the PNF modified their Forest Plan through extensive NEPA review addressing bighorn sheep viability concerns across the Forest. The final 2010 FSEIS and 2010 ROD resulting in discontinued grazing on all (n = 12) or portions (n = 2) of 14 of the 19 allotments (See Land Use Planning section).

Nez Perce Clearwater National Forest

The single Allison Berg allotment administered by the NPCNF within the project area was located on the north side of the Salmon River, was permitted to a single permittee, and provided spring and winter pasture with a split grazing season between 1 April–7 July, and 28 October–1 March each year. The allotment was located in core bighorn sheep habitat encompassing the breaks of the Salmon River for several miles upstream from the confluence with the Little Salmon River, extending from the river's edge upslope to the highest ridges. The permittee's base property was situated along the Salmon River surrounded by the allotment. Approximately 900 acres of private-base property were interspersed with the 37,250 acre public allotment. Historically, up to 1,600 ewe/lamb pairs and 2,400 dry ewes were permitted to graze this allotment. The NPCNF administratively closed this allotment to domestic sheep grazing, in 2007, over concerns for bighorn sheep health. This allotment was to remain closed to grazing until completion of an ongoing NEPA Forest Plan review (see Land Use Planning section).

Bureau of Land Management

The BLM Cottonwood Field office administered 4 active allotments; three of which were within the project area: Partridge Creek, Marshall Mountain, and Hard Creek (BLM 2016*a*). The Partridge Creek allotment was located on the south side of the Salmon River within core bighorn sheep habitat, encompassing canyon breaks from the river's edge upslope to higher forested ridges. The allotment provided spring and fall pasture with a split authorized grazing season between 11 April to 15 July, and 15 October to 30 November each year. The 16,000-acre allotment was operated as a single unit but had an intermingled land ownership pattern that included 5,845 acres of private lands owned by the permittee, 640 acres of state lands, and 9,564 acres of public BLM lands. The BLM permitted around 800 domestic sheep to graze public lands within the allotment; however, total numbers of sheep grazed across the entire allotment could reach 1,200–2,000 during portions of active grazing seasons.

The 32,833 acre Marshall Mountain Allotment was administered jointly between the BLM and PNF and was composed of a 4,212-acre contiguous block of BLM lands surrounding 28,621 acres of PNF lands. This allotment was a high elevation summer pasture grazed by 815 sheep.

The Hard Creek allotment was a lower-elevation spring (15 June–15 July) pasture used as a transition allotment to higher-elevation summer allotments grazed by 1,050 ewe/lamb pairs.

During the course of the project, the BLM temporarily closed the Partridge Creek (2009) and Marshall Mountain (2011) allotments while the Hard Creek allotment remained under non-use. Domestic sheep grazing on all 3 of these allotments was discontinued after completing a NEPA review and amending their *Cottonwood Resource Management Plan* in 2017 (See Land Use Planning section).

BIGHORN SHEEP POPULATION

Bighorn sheep within the Salmon River drainage are considered to occur in a metapopulation structure, a network of multiple distinct populations interacting across large regional landscapes. Although population boundaries and interactions between populations are not well understood, the IDFG identifies 5 Population Management Units (PMU) within the Salmon River drainage: Lower Salmon River, Middle Fork Salmon River, Lower Panther–Main Salmon River, Middle Main Salmon River, and East Fork Salmon River (IDFG 2010). Bighorn sheep within the project area are managed under the Lower Salmon River PMU encompassing Game Management Units 14, 19, 19A, western portions of 20 and 20A, 23, 24, and 25.

Prior to initiation of the project, little was known about bighorn sheep within the project area. Limited information on population numbers and general distribution were determined from incidental bighorn sheep counts recorded during winter (January and February) elk surveys conducted primarily in units 19, 20, and 20A. Units were not surveyed every year, and not all units were surveyed in any one given year. Although data were limited, survey results indicated a downward trend across sexes and age classes. During the period 1986–2007 (most recent high count prior to project initiation), the number of total sheep counted declined from 411 to 127 animals, a 70% decline consistent across ewes, rams, and lambs (IDFG 2007). This time period roughly corresponds to a 61% decline within the larger Salmon River drainage (D. Toweill, IDFG, unpublished data) and a 55% statewide population decline (IDFG 2010). These population declines became an added impetus for initiating this project.

Current densities within the Lower Salmon River PMU are recognized to be below potential habitat capability, disease is identified as the primary limiting factor, and harvest is limited to 6 controlled permits. The management objective for this PMU is to maintain or increase bighorn sheep populations.

HABITAT MODELING

Core bighorn sheep habitat within the project area (and throughout the Salmon River drainage) is associated with steep canyon breaks of the Salmon River and its main tributaries, corresponding closely with the Hot Dry Canyon ecoregion. Because of its close association with river canyons, bighorn sheep habitat is linear and dendritic in configuration, and is contiguous throughout the drainage. Substantial, but more fragmented, bighorn sheep habitat also occurs along higher-elevation mountain ranges within the High Idaho Batholith ecoregion. Bighorn sheep reside primarily within the steep river canyons while only occasional sightings have been reported within high-elevation habitats.

A bighorn sheep source habitat model was developed by the PNF during development of the 2010 FSEIS (USFS 2010*a*). Habitat modeling was described in Appendix L: Modeling and Analysis Technical Report and is summarized here.

Payette National Forest habitat modelers adapted an earlier model developed for the Hells Canyon metapopulation (HCI 1997) to better represent habitat conditions on the PNF, including within Salmon River canyon. The Hells Canyon model included 4 habitat components to model summer, winter, and lambing ranges: escape terrain, horizontal visibility, distance to water, and patch size. The PNF model excluded the distance to water variable, as water was assumed not limiting on the PNF, and excluded and estimate of lambing range. The PNF model was refined after field testing. Satellite image layers used to determine horizontal visibility were updated using LANDFIRE vegetation imagery (LANDFIRE 2006) providing more detailed and finer-scaled results. A ruggedness index was developed to provide more specificity in identifying escape terrain, and winter habitat range was restricted by removing areas that were snow covered $\geq$2 out of 7 years. The model also limited modeled habitat to a minimum patch size of 2 km^2.

The source habitat model was validated for the project area using radiotelemetry (telemetry) locations of collared bighorn sheep; 85% of summer and 90% of winter locations were within mapped source habitat. The source habitat model identified 867 km^2 of summer range and 536 km^2 of winter range within the project area (Fig. 4).

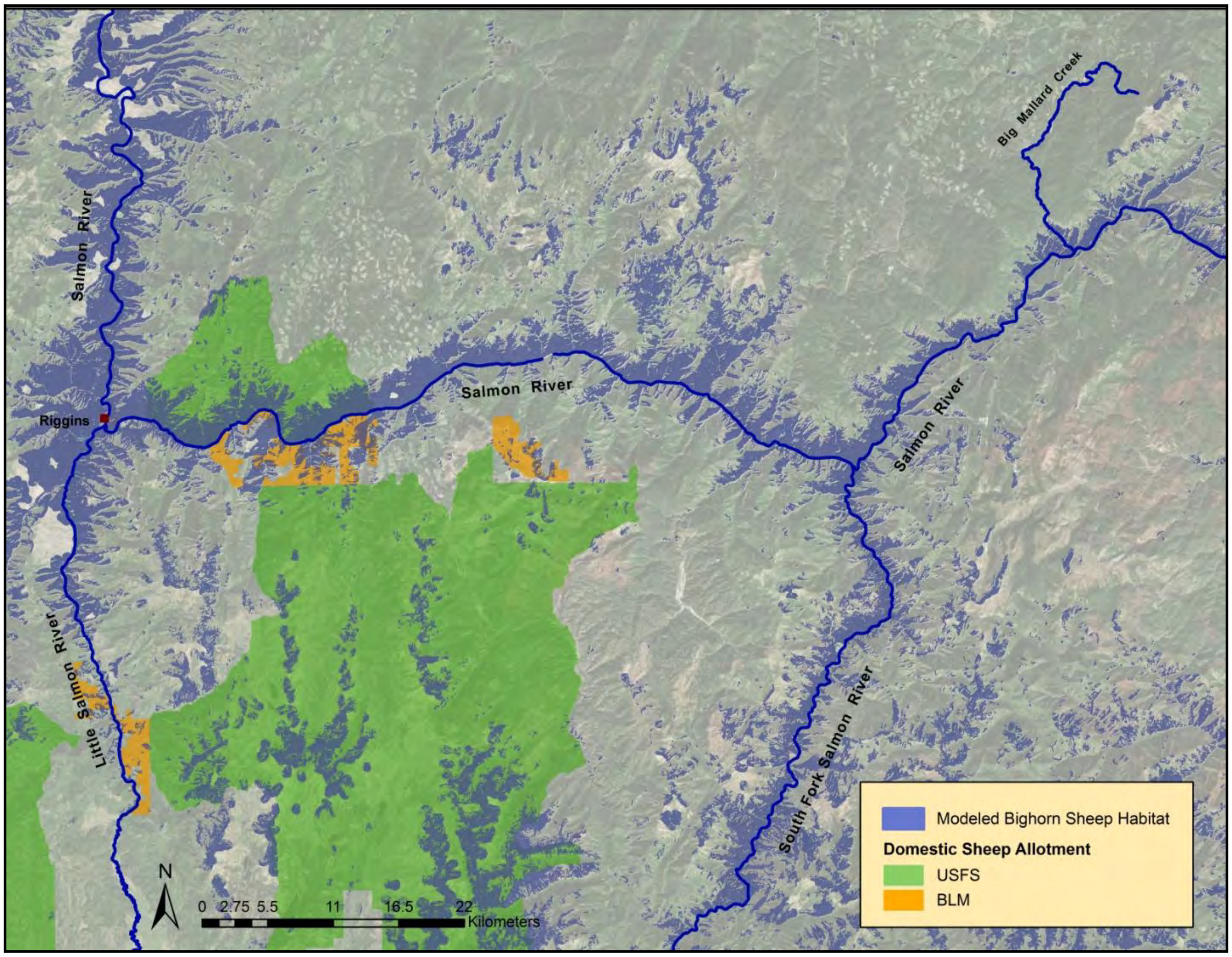

Figure 4. Modeled bighorn sheep source habitat within the Salmon River, ID, USA. Source habitat model developed by the Payette National Forest, McCall, ID.

GENERAL DATA COLLECTION

Data collection relied on radio-collared (collared) study animals. Methods for capturing, processing, collaring, and monitoring study animals were common across all project objectives.

METHODS

Capture and Processing

Initial (2007–2010) capture efforts focused on males to better understand potential for long-distance movements, particularly during the breeding season, and delineate exterior population boundaries. Subsequent (2011–2013) capture efforts focused on females to better understand social group structure and population demographics. Capture operations were organized and conducted by IDFG personnel at least annually 2007–2013. Capture operations were conducted during late fall/early winter (November through early December; 7 operations) or late winter (late January through mid March; 5 operations) to take advantage of when males and females occurred in larger mixed-sex groups for breeding and were more accessible at lower elevations along the river's edge. Timing of operations was influenced by weather and river conditions (flow levels and icing conditions).

Study animals were captured using ground darting, drive netting, and net gunning. Ground darting operations were conducted in November during the breeding season. Capture crews patrolled the river using a jet boat to locate accessible sheep or groups of sheep in areas safe for darting (defined as close to the river with areas of more modest terrain lacking rocky escape terrain). Target animals were anesthetized using a combination of Carfentanil (3 mg/ml, 0.045 mg/kg, Wildlife Pharmaceuticals, Inc., Windsor, CO, USA) and Xylazine (450 mg/ml, 0.2 mg/kg, Wildlife Pharmaceuticals, Inc., Windsor, CO, USA) delivered in a 1–2 ml P or C dart with a 2.5–3.2 cm (1–1¼) inch needle using a Pneudart Model 193 or 196 projector (Pneu-Dart, Inc. Williamsport, PA USA), or a 1.5–3 ml dart with a 2.5–3.2 cm (1–1¼) inch needle using a JM Special Dan-inject projector (DanWild LLC, Austin, TX). Anesthetized animals were released on site after administration of Naltrexone (50 mg/ml, 100 mg/1 mg Carfentanil, Wildlife Pharmaceuticals, Inc., Windsor, CO, USA) and Tolazaline (100 mg/ml, 3 mg/kg, Tolazine, Llopyd Laboratories, Shenandoah, IA).

A helicopter was used to capture bighorn sheep using a drive-net or a net-gun (Leading Edge Aviation, Clarkston, WA). A single drive-net operation was conducted in February 2008 and captured bighorn sheep were processed and released on site. Net-gun operations were conducted from early December through mid-March. Captured bighorn sheep were transported from the capture site, in a sling bag on a long line, to a nearby central processing station where they were processed and released.

All captured study animals were blindfolded, placed in sternal recumbency, and monitored for vital signs as frequently as possible during processing. Study animals not chemically immobilized were physically restrained using blindfolds and hobbles during processing. Vital signs, including rectal temperature, pulse and respiration rates, mucous membrane color, and capillary refill time, were monitored and managed throughout processing to ensure animal safety.

Animals were marked with an ear tag that had a unique animal identification number. Animals that received anesthetic or other therapeutic agents received an additional ear tag with a unique identification number and a warning to not consume prior to contacting IDFG. Sex, age, horn measurements, and capture location were recorded. Biological samples for health assessment were collected including body condition index (BCS and Riney Score); pharyngeal, nasal, and ear swabs; and blood and fecal samples. Blood was collected via jugular venipuncture using an 18 g 2.5–3.8 cm (1.0–1.5 inch) needle and a 20-ml syringe, and placed into sterile glass tubes with and without anticoagulant (Becton-Dickinson Co, Franklin Lakes, New Jersey). When possible, blood was centrifuged in the field and serum and plasma were separated and placed into sterile cryovials (Thermo Fisher Scientific, Waltham, MA). Nasal and oro-pharyngeal swab samples were collected using Dacron tipped plastic swabs with Aimes media (Fisherfinest, Fisher Scientific, Thermo Fisher Scientific, Waltham, MA). Ear swabs were collected using Dacron tipped plastic swabs (Thermo Fisher Scientific, Waltham, MA). Fecal pellets were collected by digitally extracting 10–20 fecal pellets from the rectum and placed in whirl-pac bags (Fisher Scientific, Waltham, MA). All samples were refrigerated until delivered to the laboratory for processing.

Radio-collaring

Captured bighorn sheep were fitted with standard very high frequency (VHF) and global positioning system (GPS) collars. A variety of manufacturers and collar models were employed. All collars incorporated mortality sensors for monitoring animal status (live or dead).

Males were fitted with a VHF collar only (ATS M2510B, Advanced Telemetry Systems, Isanti, MN; or Lotek LMRT-4, Lotek Wireless Inc., Newmarket, Ontario, Canada), a GPS collar only (ATS G2110B), or a VHF (ATS M220B or M2510, or Lotek MRT-4) and a GPS (ATS G2110 or G2110B; Telonics TGW-4580 or TGW-4581,Telonics, Inc., Mesa, AZ; or North Star NSG-LD1, North Star Science and Technology, King George, VA) collar. All GPS collars incorporated collar release mechanisms allowing collars to drop off study animals on a programmed date, and had a shorter operational field life (OFL). Time period from date collar was deployed to programmed date of collar release was 1–2 years compared to 4–5 years of VHF collars. Telonics and North Star GPS collars provided real time data transmission while data collected by ATS GPS collars were stored on board and not available until the unit dropped off the study animal, was recovered from the field, and shipped to the manufacturer for data recovery. Larger male body size allowed slightly heavier collar configurations and most males were fitted with both VHF and GPS collars to extend data collection time period once the GPS collar expired and dropped off the animal. Collar configurations accounted for 0.04% (VHF only, ATS M2510B) to 1.3% (VHF and GPS; ATS M2510B and Telonics 4580 series) of average male body weight, well below recommended guidelines (Sikes 2011).

Females generally were fitted with a VHF collar only (ATS model M2510B or Lotek model LMRT-4) or a GPS collar only (Telonics model series TGW4583 or North Star model NSG-LC1). Some females fitted with Telonics GPS collars were also fitted with a second lightweight VHF collar (ATS model M2220B) to extend data collection time period. Females fitted with North Star GPS collars were not fitted with an additional VHF collar because of their heavier and bulkier configuration. Collar weights ranged from 160 grams (ATS M2220B) to 994 grams (North Star NSG-LC1) and configurations ranged from 0.05% (VHF only, ATS M2510B) to 1.5% (GPS only, North Star NSG-LC1) of average female body weight, well below recommended guidelines (Sikes 2011).

Monitoring and Tracking

Study animals were monitored and tracked from air, satellites, and ground. Aerial flights using fixed-wing aircraft (Cessna 170 or 185) were used to collect data for study animals fitted with VHF collars. Regular monitoring flights (monitoring flights) were scheduled once every two weeks year-round and scheduled flights were adhered to as closely as weather and funding allowed. An attempt was made to locate all marked study animals during a monitoring flight and complete each monitoring flight during a single day; however, some monitoring flights took 2 days to accomplish depending on the number of marked study animals, weather, and variation in time to locate animals. When monitoring flights could not be completed within a single day, they were completed the next consecutive day or as close as weather and schedules allowed. Monitoring flights along the main stem reach were terminated after 2013 due to funding constraints and subsequent (2014, 2015) monitoring flights focused on the South Fork portion of the project area. Location data obtained from monitoring flights were augmented by weekly aerial spring (June) and fall (October) surveys (survey flights) conducted to assess lamb production and survival.

During monitoring and survey flights, study animals were located using standard telemetry techniques with strut-mounted directional antennas, an antenna switch box, and a VHF scanner receiver. Date, animal identification, location coordinates, and visual observations of bighorn sheep were recorded. Location coordinates were obtained using an on-board GPS unit, and group size and composition (number of lambs, ewes, rams) from visual observations were recorded with the aid of 12X36 image stabilized binoculars (12X36 IS III binoculars, Canon USA Inc, Melville, NY, USA). During survey flights, lamb production and survival was determined by visually determining the lamb status (with lamb, not with lamb) of each female study animal.

Although study animals fitted with GPS collars were not always actively monitored or tracked during monitoring flights, at a minimum collar status (functioning correctly, malfunctioning, drop-off deployed) and animal status (alive or dead) was determined from GPS collar VHF beacon's during each monitoring flight. Telonics and North Star GPS collars provided "real time" location data obtained from CLS America (CLS America, Inc, Lanham, MD) and Remote Access Satellite Sensor Link System (North Star Science and Technology, LLC, King George, VA; Applied Design, Inc, Germantown, MD) respectively. Data was downloaded weekly, processed, and managed in separate databases for each manufacturer.

Location data were augmented through spring lamb production and fall lamb survival ground surveys, and helicopter surveys conducted by IDFG during a companion project to develop a bighorn sheep detection probability model for the Lower Salmon River PMU. Data recorded for each observation obtained during ground and helicopter surveys was similar to that collected during monitoring and survey flights including date, animal identification, location coordinates, and group size and composition. For ground surveys, location coordinates were obtained using a hand held GPS unit (Garmin GPSmap 76CSx, Garmin, Olathe, KS, USA); group size and composition were aided by binoculars (Canon 12X36 IS III) and 20X60 power spotting scopes.

RESULTS

Capture and Processing

Thirteen capture operations were conducted 2007–2013 (1 in 2009, 2011, 2012, and 2013; 2 in 2007 and 2010; 5 in 2008; Table 1). This included a single drive-net operation in February 2008; 5 net-gun operations in early December through mid March in 2008 (*n* = 2), 2010, 2012, and 2013; and 7 ground darting operations in November during the breeding season at least annually 2007–2011 (1 in 2009, 2010, and 2011; and 2 in 2007 and 2008). Eighty two bighorn sheep (43 females, 39 males) were captured, representing 70 unique sheep (41 females, 29 males) and 12 recaptures (2 females, 10 males; Table 1; Appendix E). The majority of males (*n* = 30, 77%) were captured during 2007–2010 when project objectives focused on movements and distribution, while the majority of females (*n* = 25; 58%) were captured during 2011–2013 when project objectives focused on demographic parameters. Number of captures were equal between ground darting (*n* = 40; 24 females, 16 males) and net gunning (*n* = 40; 19 females, 21 males) but only 2 males were captured during a single drive net operation. Capture operations emphasized adults (*n* = 77, 94%) although 5 yearling males were also captured. Two (2%) capture-related mortalities (1 female, 1 male) occurred during ground darting operations. In both cases, animals fled to and fell from steep rocky cliffs during induction period of administered anesthetic.

Table 1. Capture method, number of operations, and number of bighorn sheep captured during the Salmon River Bighorn Sheep Project, ID, USA, 2007–2013.

Year	Capture Method	No. Capture Operations	Females	Males	Total
2007	Ground Dart	2	5	6	11
2008	Ground Dart	2	5	4	9
	Net Gun	2	4	8	12
	Drive Net	1		2	2
2009	Ground Dart	1	2	1	3
2010	Ground Dart	1	2	2	4
	Net Gun	1		7	7
2011	Ground Dart	1	10	3	13
2012	Net Gun	1	4	3	7
2013	Net Gun	1	11	3	14
Totals	Ground Dart	7	24	16	40
	Net Gun	5	19	21	40
	Drive Net	1		2	2
	Total	13	43	39	82

Radio-collaring

Over the course of the project, 45 (29 females, 16 males) study animals were fitted with only VHF collars, 27 (6 females, 21 males) with a combination of VHF and GPS collars, and 9 (8 females, 1 male) with only GPS collars (Appendix E). Number of study animals actively monitored (monitored any portion of a year) varied from 10 in 2007 to 47 in 2011 and averaged 30 animals/year (Table 2). Although number of female and male study animals monitored in any one year was similar (female range = 5–26, $\bar{x}$ = 17; male range = 5–22, $\bar{x}$ = 14) when averaged across the project period, proportions of female and male study animals varied through time. Roughly equal numbers of female and male study animals were monitored

2007–2011, while a higher proportion of females were monitored 2012–2015 reflecting changing project priorities.

Table 2. Number of radio-collared female and male bighorn sheep monitored by year, Salmon River Bighorn Sheep Project, ID, USA, 2007–2015.

Sex	2007	2008	2009	2010	2011	2012	2013	2014	2015	$\bar{x}$
Females:	5	14	15	17	25	21	26	14	13	17
Males:	5	19	17	21	22	13	14	7	5	14
Total:	10	33	32	38	47	34	40	21	18	30

Monitoring and Tracking

During the term of the project, 35,911 locations of study animals were collected by aerial flights (4,321), satellite GPS collars (30,964), and ground (512) and helicopter surveys (114). Between 2007 and 2015, 284 monitoring and survey flights ($\bar{x}$ = 1.5 weeks/flight) were conducted. Individual collared bighorn sheep were located during most all monitoring and survey flights and study animals, or their associated groups, were visually observed about half the time (55%). Mean observed group size ranged from 1–38 and averaged 6.1 animals per group. The rare occasions when individuals could not be located were primarily due to collar malfunction or weather patterns that developed during monitoring or survey flights.

The majority (85%) of locations were collected by GPS satellite collars although GPS collar failure rates were high (Table 3). GPS collar component evaluated included VHF beacon, GPS engine, and collar release mechanism. VHF beacons were considered to have failed if they ceased transmitting a signal or if they incorrectly and permanently switched to mortality mode prior to the end of their scheduled OFL.

Table 3. Global Positioning System collar failure by type, manufacturer (Mfr), and sex. Salmon River Bighorn Sheep Project, ID, USA, 2007–2015.

					Number of Failures by Type		
Collar Mfr.	Sex	No. Collars	No. Collars Evaluated	No. Collars Failed *n* (%)	VHF Beacon *n* (%)	GPS Engine *n* (%)	Release Mechanism *n* (%)
ATS	M	12	11	6 (55)	2/ 9 (22)	3/9 (33)	6/11 (55)
Telonics	F	12	10	7 (70)	5/8 (63)	6/9 (67)	0/3 (0)
	M	4	4	4 (100)	4/4 (100)	4/4 (100)	
	subtotal	16	14	11 (79)	9/12 (75)	10/13 (77)	0/3 (0)
North Star	F	2	2	2 (100)	2/2 (100)	0/2 (0)	1/2 (50)
	M	5	4	4 (100)	3/4 (75)	4/4 (100)	3/3 (100)
	subtotal	7	6	6 (100)	5/6 (83)	4/6 (67)	4/ 5 (80)
	Total	35	31	23 (78)	16/27 (60)	17/28 (59)	10/19 (45)

GPS engines failed when they ceased obtaining location data prior to the end of their scheduled OFL. Collar release mechanisms failed if they released the collar prematurely or failed to release the collar after the programmed release date. Single and/or multiple component failure(s) affected detection of mortalities, ability to retrieve collars, and resulted in truncated data.

Failure rates could be evaluated for 31 of 35 GPS collars deployed. Twenty three of 31 (74%) evaluated GPS collars failed either partially (some date recovered, *n* = 21, 68%) or completely (no data recovered, 2 ATS collars, 6%) prior to reaching the end of their scheduled OFL. ATS models had the lowest failure rate (55%) followed by Telonics models (79%) and North Star models (100%). All GPS collar components evaluated failed for all manufacturers, except for the Telonics collar release mechanisms – which performed without failure. However, only 3 of 13 collar release mechanisms could be evaluated for Telonics models so reported failure rates may be low. Across manufacturers, VHF beacons and GPS engines failed at about the same rate (60% and 59% respectively) and collar release mechanisms failed at a slightly lower rate (45%) primarily due to the 100% success rate for Telonics models. Different North Star and Telonics models were used for female and male study animals. Failure rates were equal between females (100%) and males (100%) fitted with North Star models and higher for males (100%) than females (70%) fitted with Telonics collars. The higher failure rate for male Telonics collars was primarily due to a manufacturing defect. Collars ordered for placement on males were shipped with a single-wall rather than the normal double-wall canister design. The single-walled canisters did not stand up during rutting behavior. Repeated shock from head-butting caused a pendulum affect between the VHF and GPS collars, crushing the GPS collar canister to the point of failure. Failure rates for Telonics collars may have been lower if double-wall canisters were deployed, and if males were not fitted with a second VHF collar.

GPS collars were programmed to collect 1–6 locations per day according to 1–4 annual fix schedules (number of locations/day/time period) over a 1–4 year OFL (programmed OFL). Of those that did not fail completely, functional OFL (period of time collars functioned and collected some level of location data) averaged 78% of programmed OFL (Telonics 83%, ATS 80%, North Star 73%; Table 4). GPS collars obtained $\geq$1 location per day (Location day) on average 69% of days within the functional OFL (ATS 94%, Telonics 74%, North Star 40%) and met the expected fix schedule (programmed number of locations/day) on average 67% of location days (ATS 84%, Telonics 61%, North Star 55%). Due to differences in observed vs. expected OFL, location days, and fix schedule, GPS collars collected on average 48% (ATS 72%, Telonics 42%, North Star 29%) of locations expected from the programmed OFL.

Telonics and North Star collars were fitted on females and males. Collars from these manufacturers performed better when placed on females relative to males (Table 4). On average, collars worn by females had a longer functional OFL relative to programmed OFL (female = 81%, male = 69%), collected data over a higher percentage of location days within the functional OFL (female = 73%, males = 49%), obtained a higher percentage of expected programmed number of locations/day during the functional OFL (females = 66%, males = 50%), and collected a higher proportion of number of locations expected from the programmed OFL (females = 48%, males = 24%) compared to males.

Table 4. Global Positioning System collar performance by manufacturer and bighorn sheep gender. Summary statistics exclude 2 ATS collars that failed completely (failed to collect any location data). OFL = operational field life. Programmed OFL = time period (days) collar was expected (programmed) to collect daily location data. Functional OFL = actual time period (days) collar functioned at some level and collected some frequency of location data. Location Day = 24 hour period (midnight to midnight) when collar collected ≥1 location. Salmon River Bighorn Sheep Project, ID, USA, 2007–2015.

Collar Mfr.[a]	Sex	No. Collars	No. Collars Evaluated	% Programmed OFL[b]	No. Location Days/ Functional OFL (%)[c]	No. Location Days/ Programmed OFL (%)[d]	No. Expected Locations/ Functional OFL (%)[e]	No. Expected Locations/ Programmed OFL (%)[f]	% total expected Locations[g]
ATS	M	12	11	79.5	94.0	76.6	84.2	61.7	72.0
Telonics	F	12	10	99.8	76.4	60.1	65.8	38.0	48.6
	M	4	4	74.4	66.1	41.4	48.2	19.8	28.2
	subtotals	16	14	82.9	73.8	54.3	61.4	32.4	42.3
North Star	F	2	2	77.3	51.5	58.9	63.2	38.3	47.3
	M	5	4	62.7	35.9	26.1	51.0	13.4	19.9
	subtotals	7	6	72.8	40.4	37.0	54.5	21.7	29.1
	Totals	35	31	78.4	69.4	56.0	66.7	38.6	47.8

[a] Manufacturer
[b] Functional OFL/Programmed OFL
[c] Location Days/Functional OFL; percentage of days within Functional OFL collar collected ≥1 location; expected percentage = 100% (collar programmed to collect ≥1 location/day)
[d] Location Days/Programmed OFL; percentage of days within Programmed OFL collar collected ≥1 location; expected percentage = 100% (collar programmed to collect ≥1 location/day)
[e] Percentage of days collar collected the expected (programmed) number of locations (fix schedule) within the Functional OFL of the collar
[f] Percentage of days collar collected the expected (programmed) number of locations (fix schedule) within the Programmed OFL of the collar
[g] Total actual number of locations collected during Functional OFL/total expected number of locations during Programmed OFL

POPULATION DISTRIBUTION AND STRUCTURE

Bighorn sheep population distribution was assessed on a course scale by delineating a population range describing the external boundary of the geographic extent encompassing observed distribution of bighorn sheep within the project area. Population structure was assessed at a finer scale by delineating female and male social groups and their relative juxtaposition within the project area.

METHODS

Spatial Analysis

Location data of collared study animals obtained from fixed-wing monitoring and survey flights, GPS satellite locations, and ground and helicopter surveys, were combined and used to assess spatial dynamics of bighorn sheep within the project area. Data were organized by biological year (year, 1 May–30 April) and utilization distributions (UDs) were constructed using the fixed kernel estimator in program R (kernelUD, R package adehabitatHR, cran.r-project.org 2016, https://cran.rproject.org/web/packages/adehatitatHR/adehabitatHR.pdf). The smoothing factor was calculated using the ad hoc method. Depending on the analysis, UDs were constructed for different data groupings based on social categories (population, social group, individual) and seasons (summer, winter, lambing, non-lambing, rut, non-rut). Population level UDs were referred to as population ranges, social group UDs as use areas, and individual UDs as home ranges.

Estimates for the population range excluded long-distance foray movements of 2 study animals; female E50 and male R16. When constructing group use areas, we wanted to represent group movements of sheep that commonly and regularly associated with one another. This required censoring some non-group movements from the analysis. All locations for 3 study animals were censored because 1 female (E70) displayed unusual and extensive movements, 1 young male (R16) was considered a dispersing sheep in the Little Salmon River corridor and was not associated with a group, and 1 young male (R66) did not leave his natal ewe group during his data collection period and was not associated with a male group. Data was further filtered to exclude foray movements (2 females, E50 and E60) and yearling male locations (3 males; R3, R15, R23) not associated with adult male groups.

Conformity or similarity in space use from year to year or season to season was important to assess changes in population distribution, site fidelity of individuals and groups, and population connectivity. Similarity across UDs for a given data grouping was assessed by visually inspecting overlays of location data, and UDs in ArcMap (ArcMap 10.3.1, ESRI, Redlands, California, USA), and quantifying differences in area (km^2, area index) and degree of overlap (%, overlap index) of the 95% UD contours.

An area index was determined by first calculating the mean area of all UDs in a comparison set (e.g., annual UDs for a single study animal). Next, the percentage differences between each UD area in the set, and the set mean area was calculated. A final mean percentage difference across the set was then used as the area index value for the set. The area index provided a simple single metric to evaluate similarity between UD areas within and across various data groupings with lower index values indicating higher level of similarity.

An overlap index was determined by calculating the mean percentage overlap across a comparison set. Utilization distribution overlap within a comparison set was calculated using a 500 cell grid and the percentage overlap method in R package (adehabitatHR, method= HR) to compute the proportion of area of one UD covered by the area of another UD. When comparing overlap between a minimum pair of UDs, say population ranges calculated for years 2008 (Range2008) and 2009 (Range2009), the overlap function computes 2 overlap percentages; the percentage of Range2008 overlapped by Range2009 and the percentage of Range2009 overlapped by Range2008. The overlap function calculates these percentages for all pair-wise comparisons in a comparison set. The overlap index calculated the mean value for all pair-wise comparisons in the set. Based on the assumption, mean percentage overlap was proportional to the degree of similarity between individual UDs in the set; higher mean percentage overlap values represented greater similarity between UDs in the set.

Due to small sample sizes and data normality issues, differences among annual and seasonal home ranges between, and within, sexes were compared using the nonparametric Mann-Whitney U test.

Population Distribution

Locations for all study animals were pooled and annual population ranges were constructed for full study years. A full study year was defined as one where all study animals were actively monitored (data collected) across the entire study area and throughout the year. Similarity of population ranges across years was assessed by visually comparing displays using ArcMap, and calculating area and overlap indices.

Population Structure

The bighorn sheep population within the Salmon River canyon is comprised of multiple interacting female and male social groups distributed along the river corridor. Population structure was assessed by delineating the female and male groups within the project area. Initially, annual home ranges were constructed and compared for all individual study animals to assess the appropriateness (based on the degree of conformity between annual home ranges) of pooling data across years to increase sample size and improve home range estimates. Home ranges for individuals were then pooled as appropriate across years and used in a cluster analysis to assign each study animal to a unique social group.

Pooled annual home ranges (data combined across years) were constructed for each study animal and overlap of 95% contours between all pair-wise comparisons was calculated using R package adehabitatHR and Kerneloverlap. A model-based cluster analysis of home range overlap values was then conducted using the R package mclust (cran.r-project 2016b). We ran analyses separately for females and males. Final group assignments incorporated field observations and previous knowledge of collared study animal associations to facilitate interpretation of cluster analysis results.

RESULTS

Population Distribution

Location data supported 5 full study years, 2008–2012. Data was not collected throughout the full year for the first (2007) and last (2015) years of the project, and a shortfall in funding precluded monitoring study animals along the main stem portion of the project area during 2013 and 2014. The 2008–2011 population range estimates visually showed a high degree of similarity while the 2012 population range was noticeably smaller (truncated on the downstream end of the distribution; Fig. 5). This difference may have been, in part, an artifact of lower sampling effort due to fewer collared animals and a lack of GPS collars in this area compared to past years. Despite this potential bias, area and overlap indices indicated a high degree of similarity. Annual population range area varied from 984–1,424 km^2 with a mean of 1,289 km^2 (Table 5). Differences from the mean area ranged from 1–24% and the mean percent difference was 10%. Excluding the 2012 population range, differences from the mean area varied from 3–5% and the mean percent difference was 4%. Mean overlap of annual population ranges was high, varying from 66–97% (87–97% for 2008–2011) with a mean percent overlap value of 88% (92% for 2008–2011, Table 6). Area and overlap indices provided strong support for the notion that population distribution was static during the course of the project.

Based on a high level of conformity across years, we pooled the 2008–2012 data to construct a single representative population range. This boundary is based on the 95% contour, representing the area within which bighorn sheep in our project area spent the majority of time, and were most likely to be found (Fig. 6). The population range described a 990 km^2 area along the Salmon River canyon and encompassed 99% of study animal locations. Locations outside the population boundary (e.g. E50 and R16 locations, purple and black circles in figure 5 respectively) highlight infrequent but extensive movement capabilities of bighorn sheep.

Collared study animals were distributed along an approximate 84-km reach of the main stem Salmon River from the Lake Creek Bridge approximately 11 km up the Salmon River Road from Riggins, ID, upstream to Lemhi Bar, approximately 95 river km upstream from the town of Riggins, ID. Collared bighorn sheep along the main stem up to the confluence of the South Fork were located most commonly on the north side of the river. Upstream from the confluence of the South Fork, study animals were commonly distributed on both sides of the main stem. Collared bighorn sheep were distributed along both east and west sides of the South Fork from its confluence with the main stem upstream approximately 21 km to the confluence of Smith Creek at the Hettinger Ranch.

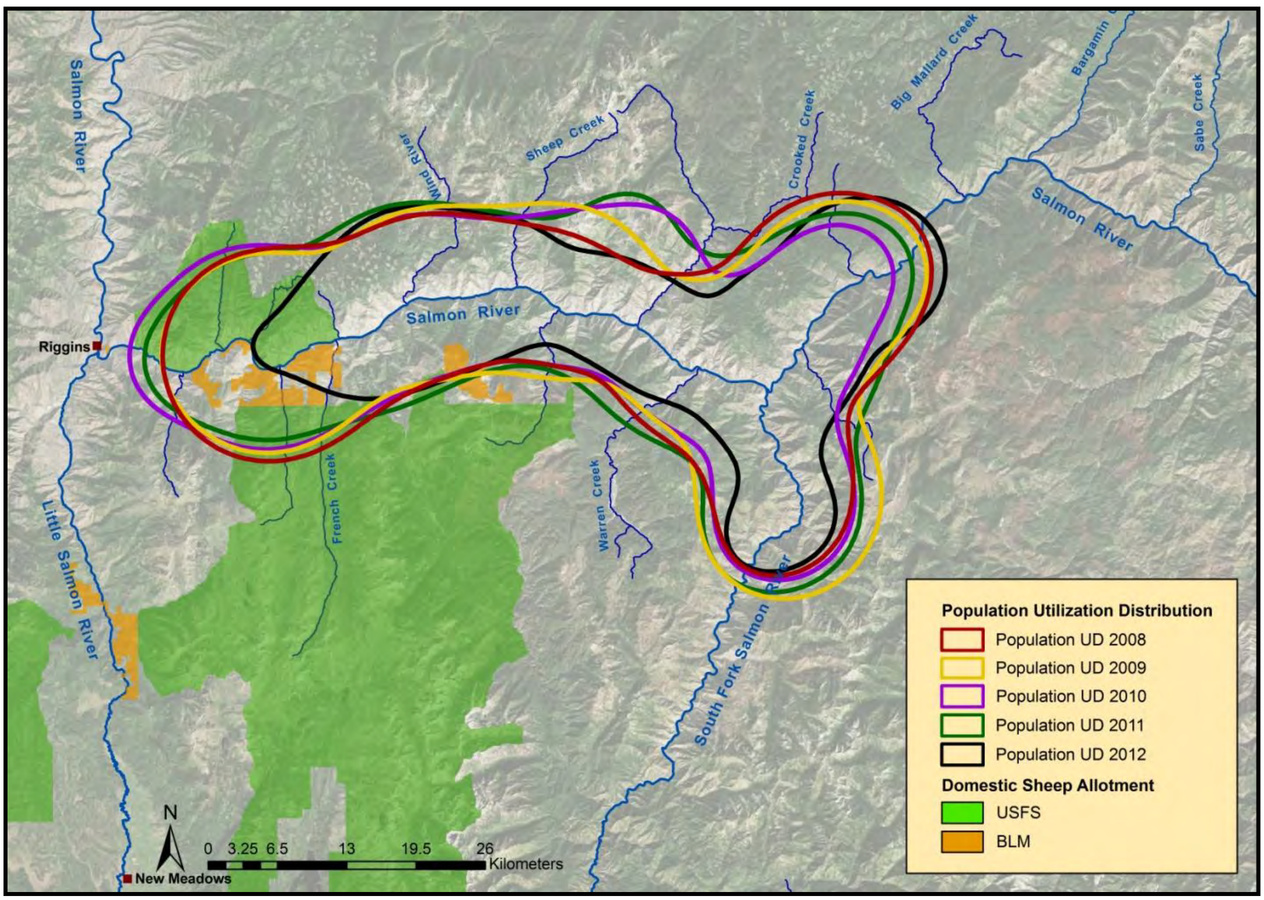

Figure 5. Annual population ranges representing location data pooled across all study animals. Salmon River Bighorn Sheep Project, ID, USA, 2008–2012.

Table 5. Similarity in annual bighorn sheep population ranges. Salmon River Bighorn Sheep Project, ID, USA, 2008–2012.

Year	Area (km^2)	% Difference from $\bar{x}$ Area 2008–2012	% Difference from $\bar{x}$ Area 2008–2011
2008	1,331	3.3	2.5
2009	1,403	8.9	2.8
2010	1,300	0.9	4.7
2011	1,424	10.5	4.4
2012	984	23.6	
$\bar{x}$ % Difference 2008–2012		9.5	
$\bar{x}$ % Difference 2008–2011			3.6

Table 6. Percent overlap of annual bighorn sheep population ranges. Table indicates percent of ranges in rows overlapped by ranges in columns. Salmon River Bighorn Sheep Project, ID, USA, 2008–2012.

Year	2008	2009	2010	2011	2012
2008	100.0	95.6	89.2	94.1	71.9
2009	90.7	100.0	86.7	93.8	68.1
2010	91.3	93.5	100.0	96.6	68.6
2011	87.9	92.4	88.2	100.0	66.0
2012	97.3	97.1	90.7	95.5	100.0
$\bar{x}$ % Overlap 2008–2012		87.8			
$\bar{x}$ % Overlap 2008–2011		91.7			

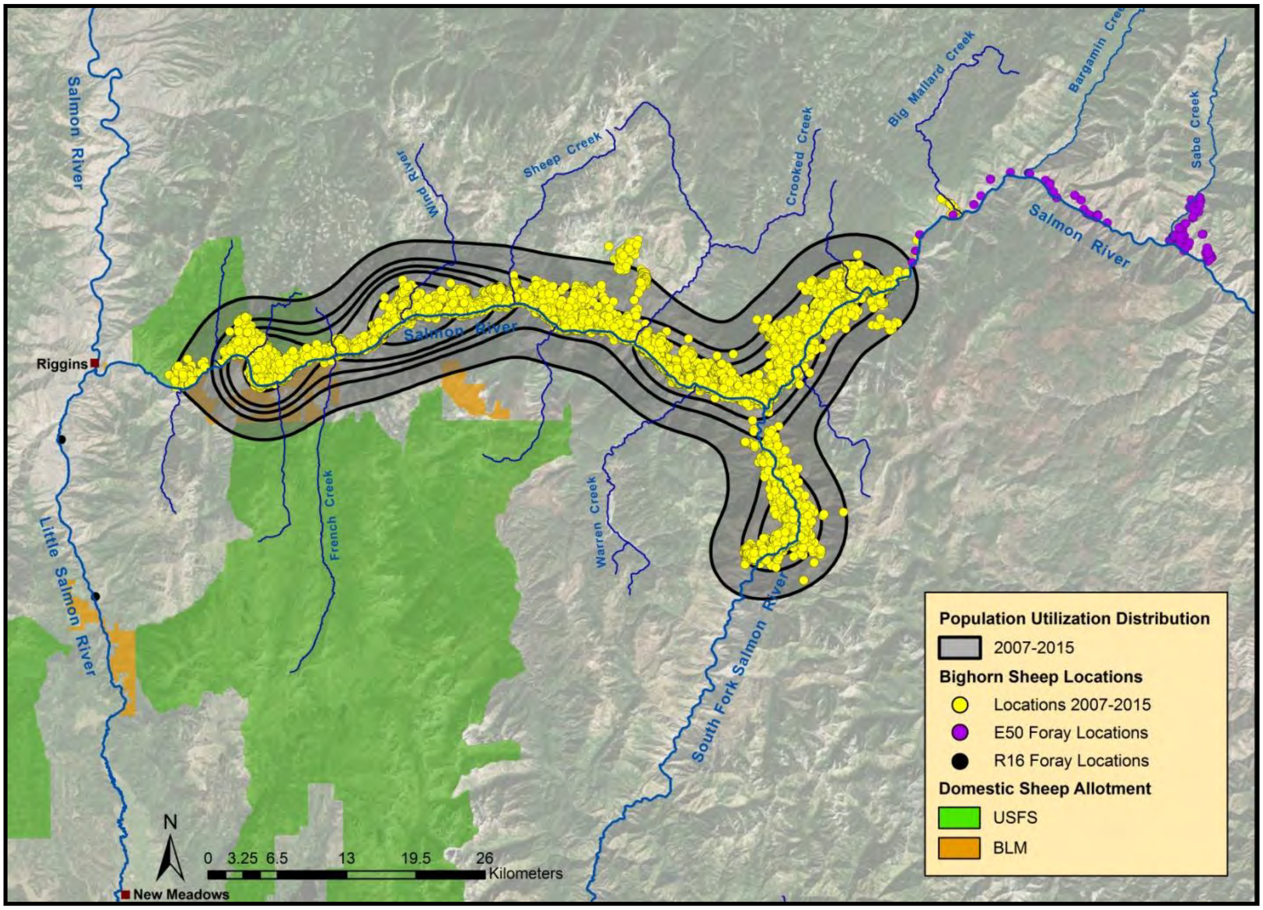

Figure 6. Salmon River bighorn sheep population range derived from radio-collared bighorn sheep locations pooled across study years. Population range encompassed 99% of locations and external locations indicate potential for long-distance movements. Salmon River Bighorn Sheep Project, ID, USA, 2007–2015.

Population Structure

Cluster analysis identified 9 female groups of spatially associated collared animals (clusters) and 3 male clusters with a high degree of conformity with previous social group assignments based on known associations of collared animals observed in the field.

Female Social Groups. The 9 female clusters were intuitively aggregated into 5 clusters corresponding spatially to the 5 previously identified female groups within the project area and their member assignments. This was done by combining modeled clusters 1 and 6, 2 and 4, 5 and 9, and 3 and 7; retaining group 8 (Fig. 7, Table 7). From down- to upstream, 4 female groups residing along the north side of the main stem were identified as Manning Bridge Ewes, Wind River, Indian Creek, and Jersey Creek.

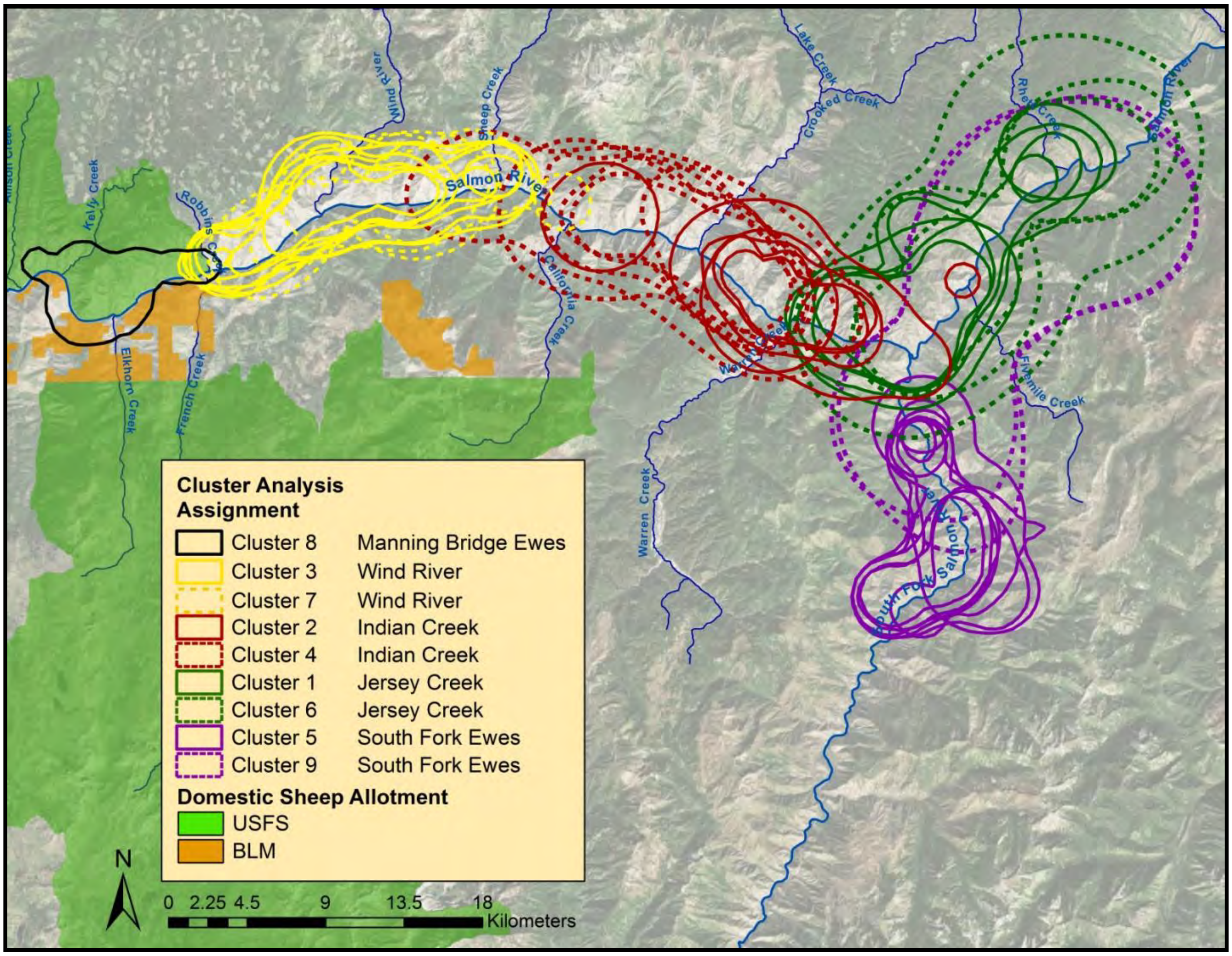

Figure 7. Cluster analysis results and social group (group) assignments of radio-collared female bighorn sheep along the Salmon River, ID, USA. Cluster analysis based on overlap of pooled annual home ranges (polygons) of individual radio-collared female animals. Cluster 8 (solid black line) represented the annual home range of female E60, the sole radio-collared member assigned to the Manning Bridge Ewe group. Radio-collared females belonging to cluster 3 (solid yellow lines) and 7 (dashed yellow lines) were assigned to a single group, Wind River. Radio-collared females belonging to cluster 2 (solid red lines) and 4 (dashed red lines) were assigned to a single group, Indian Creek. Individuals belonging to cluster 1 (solid green lines) and 6 (dashed green lines) were assigned to the Jersey Creek Ewe group and individuals belonging to cluster 5 (solid purple lines) and 9 (dashed purple lines) were assigned to the South Fork Ewe group. Depicted overlap between cluster 9 and 1 and 6 is misleading (see text for explanation).

Table 7. Radio-collared members of female and male bighorn sheep social groups along the Salmon River, ID, USA.

Sex	Social Group	No. Collared Animals	No. Years Monitored	Social Group Membership
Females	Manning Bridge	1	3	E60
	Wind River	10	9	E5, E17, E18, E20, E27, E44, E49, E57, E58, E59
	Indian Creek[a]	12	9	E8, E10, E11, E21, E25, E35, E43, E47, E48, E68, E69, E70
	Jersey Creek	8	9	E17, E37, E46, E50, E51, E52, E53, E54
	South Fork[b]	10	8	E29, E31, E33, E61, E62, E63, E64, E65, E67, R66
Males [c]	Manning Bridge	9	8	R12, R13, R14, R15, R28, R38, R39, R40, R41
	Bull Creek[d]	5	8	R4, R19, R22, R26, R36
	Blowout Creek	10	9	R2, R3, R6, R7, R23, R24, R30, R42, R45, R55
	South Fork	2	7	R32, R34

[a] Female E56 not included due to capture-related mortality
[b] Male R66 included in South Fork Ewes social group
[c] Male R16 not included; wondering animal not associated with a social group
[d] Male R9 not included due to capture-related mortality

The fifth female group, was identified as South Fork Ewes, and resided along the South Fork reach of the project area as well as the south side of the main stem upstream from the confluence of the South Fork to Lemhi Bar. The Manning Bridge Ewe group (Cluster 8) was represented by a single collared study animal, E60, which did not display site fidelity to this group. E60's locations were trimmed to exclude foray movements. Remaining locations were used to graphically display the general location of this female group, but were too few to include in further analysis. Depicted overlap between cluster 9 (South Fork Ewes), and 1 and 6 (Jersey Creek) in Table 7 is misleading. Cluster 9 represents pooled annual home ranges of 2 females (E63 and E65) belonging to the South Fork Ewe group. Although these animals spent the majority of their time on the east side of the South Fork, they traveled up the main stem to lamb on the south side of the main stem around Lemhi Bar, across from the Jersey Creek ewe group. The few locations (small sample size) around Lemhi Bar over-estimated the use area for these 2 females and inaccurately depicted overlap with the Jersey Creek group. The main stem appears to be a behavioral border between these two groups, as collared South Fork Ewe members were not located on the north side of the main stem and collared Jersey Creek members were not located on the south side of the main stem.

Male Social Groups. Two (clusters 1 and 3) of the 3 male clusters were in accordance with field observations, and the third cluster (cluster 2) combined what appeared to be two non-overlapping and disjunct male groups (Fig. 8). After visual inspection of cluster analysis results the third cluster was easily divided into 2 groups conforming to previous knowledge of known collared animal associations. From down- to upstream, the 3 main stem male groups were

Manning Bridge, Bull Creek, and Blowout Creek (Table 7). The fourth male group, South Fork Rams, resided along the South Fork portion of the project area.

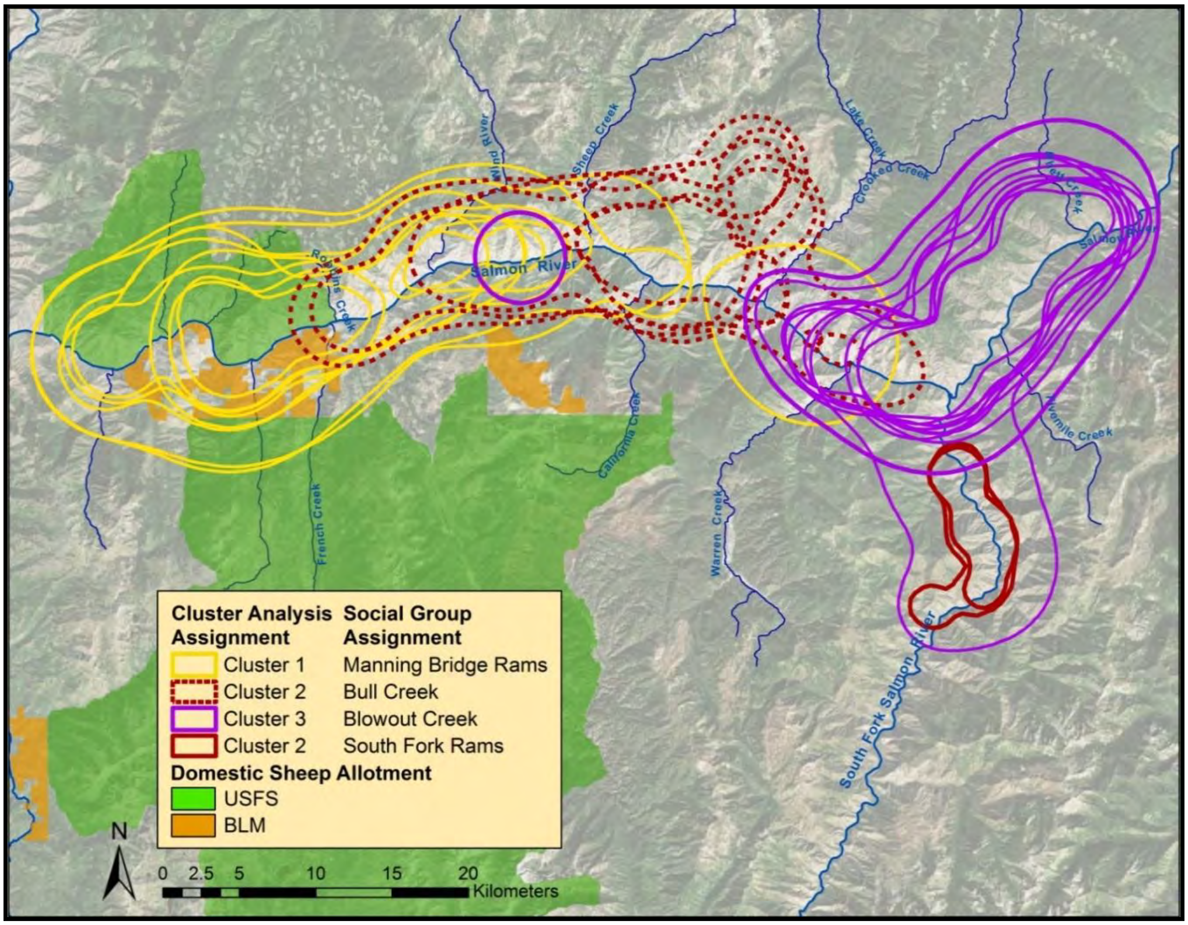

Figure 8. Cluster analysis results and social group (group) assignments of radio-collared male bighorn sheep along the Salmon River, ID, USA. Cluster analysis based on overlap of pooled annual home ranges (polygons) of individual radio-collared male animals. Radio-collared males belonging to cluster 1 (solid yellow lines) were assigned to the Manning Bridge Ram group. Radio-collared males belonging to cluster 2 (solid and dashed red lines) were assigned to 2 groups, Bull Creek (dashed red lines) and South Fork Rams (solid red lines). Reasons for South Fork and Bull Creek males to be clustered together dispite a clear lack of home range overlap, is an unexplained failure of the cluster analysis algorithm. Radio-collared males belonging to cluster 3 (solid purple lines) were assigned to the Blowout Creek group.

SPACE USE AND POPULATION CONNECTIVITY

Within the contiguous habitats of the Salmon River, the primary driver of population connectivity is the degree of interactions between female and male social groups. Although population connectivity has many demographic benefits, it can also contribute to the spread of disease which was of importance to this study. To investigate potential for disease spread throughout the population, we assessed group space use and quantified degree of overlap between male and female groups as an index to population connectivity.

METHODS

Initially, variation in annual space use and site fidelity was assessed on an individual and group level to gain an initial understanding of annual space use patterns and appropriateness of pooling data across years for more robust space use estimates. Potential for inter-group interaction was quantified based on estimates of shared space use using 2 different methods: (1) Space use overlap, or the percent of 1 group's home range overlapping another group's home range and (2) location overlap, or the percent of locations from 1 group falling within another group's home range. Influences of sex, seasons of year, and breeding season were assessed. Population connectivity was qualitatively evaluated using results from ArcMap displays, area and location overlap analyses, and assessment of foray movements and group membership fidelity of individual animals.

<u>Individual Space Use and Site Fidelity</u>
Annual home ranges were constructed for all individual study animals having multiple (>1) complete study year datasets ($\geq$15 locations collected during $\geq$ 9 months of the year). Similarity in space use across annual home ranges for each study animal was assessed by visually inspecting plots of ArcMap-generated home ranges and calculating area and overlap indices. The area index was used to quantify the variation in space use (home range size) and the overlap index was used as a measure of site fidelity (spatial orientation of space use). Mean index values were compared for females and males separately to assess gender-specific space use.

Home ranges were influenced by sample size related to collar type. There were fewer locations for study animals fitted with VHF collars compared with GPS collars. Home ranges constructed for study animals fitted with VHF collars tended to over-smooth home range estimates compared to those constructed for study animals fitted with GPS collars. This bias was of concern when comparing home ranges constructed for individuals outfitted with both types of collars in different years (e.g. a study animal fitted with a VHF collar for some complete study years, and a GPS collar for others). To account for this bias, we compared home ranges that were generated from similar collar types (VHF to VHF and GPS to GPS comparisons) and avoided home range comparisons of dissimilar collar types (VHF to GPS). The magnitude of this bias in our dataset was evaluated by comparing results of area and overlap indices obtained from similar-collar-type and dissimilar-collar-type comparisons.

Social Group Space Use and Site Fidelity

Annual use areas for social groups were constructed by pooling data across individuals assigned to each group and parsing that data by year. Annual use areas with <20 locations or a data collection period <9 months were assumed to not be representative of the entire group and were excluded from comparisons. Variation in use area size and spatial orientation (group fidelity) were assessed by comparing conformity of annual use areas for each group visually using ArcMap displays and calculating area and overlap indices.

Social Group Annual Space Use and Overlap

Pooled group use areas were constructed for 4 of 5 female and all 4 male groups. Insufficient data excluded the Manning Bridge Ewe group from the analysis. Pooled group use areas were constructed by pooling non-censored location data for all group members across all years. Potential for inter-group interactions was assessed by calculating and comparing area and location overlap across groups separately for female and male groups.

Social Group Seasonal Space Use and Overlap

Seasonal space use was investigated to assess temporal influences, if any, on inter-group interactions and evaluate the relative importance of environmental vs. behavioral drivers. Seasonal space use was assessed for 2 seasons of the year, summer (1 May–30 September) and winter (1 October–30 April) to assess if groups used distinct summer and winter ranges and if movements were influenced by environmental drivers (weather, forage phenology, etc.). Female space use during lambing (1 May–30 June) and non-lambing (1 October–30 April); and male space use during rut (1 October–31 December) and non-rut (1 May–30 September) were assessed to better understand influences of breeding behavior on movements and inter-group interactions. Space use was determined by constructing 95% contour group home ranges for each season and social group. Differences in space use between summer and winter, lambing and non-lambing, and rut and non-rut seasons were evaluated by visually inspecting ArcMap-generated displays and calculating area and overlap indices. Seasons of the year were analyzed separately for female and male groups.

Foray Movements and Social Group Fidelity

A foray movement was defined as any location of a collared study animal ≥1km outside of its assigned group home range boundary (95% contour). Location, date, season, incident, occurrence within non-assigned group home range, and distance from nearest assigned group home range boundary were recorded. Group membership fidelity was assessed by assigning each study animal to a social group at the time of capture, and recording the number of occasions study animals changed group membership. A change in group membership was recorded if a study animal traveled from its assigned group use area to a different known, or suspected same-sex group use area and remained there for the duration of the project.

RESULTS

Individual Space Use and Site Fidelity

Of the 68 monitored study animals, 25 of 40 (63%) females and 19 of 28 (68%) males had > 1 complete study years. Number of multiple complete study years ranged from 2–6 years and averaged 3.1 years/study animal ($\bar{x}$ female = 2.9 years, $\bar{x}$ male = 3.4 years).

Dissimilar collar type datasets did not occur for females but occurred for the majority of males (12 of 19, 63%), requiring censoring some data when conducting similar-collar-type comparisons. For example, if an individual had 3 complete years of data from a GPS collar and a fourth year of VHF data, then only the 3 years of GPS data were analyzed. Parsing data by collar type resulted in removing 2 males from the analysis, as both had only a single year each of VHF and GPS data.

Visual inspection of ArcMap displays indicated a high level of individual site fidelity for both females and males. ArcMap displays depicted conformity in space use across years but annual patterns indicated not all areas within an individual's home range were visited each year, and the proportion of time spent in areas varied. For all study animals, space use focused around a common core area, with year-to-year variation outside the core area evident for both sexes. In some cases, variation was due to changes in the proportion of time spent in an area (distribution of location data), and/or an artifact of comparing home range estimates based on differing sample sizes rather than actual changes in area used (Figs. 9 and 10). These influences tended to underestimate site fidelity as assessed here. Degree of annual variation in home range estimates varied among individuals of both sexes, and variation was primarily characterized by how far individuals moved up- or downstream from their core area in a given year (Fig. 11). For males, variation in space use appeared to be related to movements during the rut season as males interacted with different female groups from year to year.

For females, reasons for variation in space use were not as evident but may have been related in part to reproductive status (whether they produced and/or survived a lamb) and selection of lambing areas.

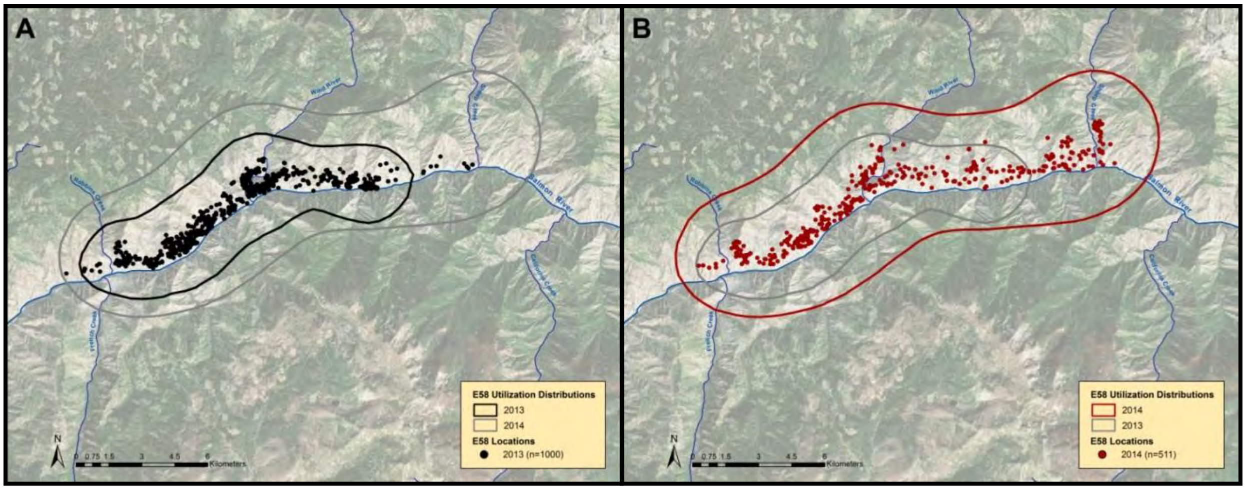

Figure 9. Telemetry locations and home ranges of radio-collared bighorn sheep female E58 in 2013 (A) and 2014 (B), Salmon River Bighorn Sheep Project, ID, USA, 2007–2015. Although E58 used the same general area in both years, a greater proportion of her time was spent in the Sheep Creek area of her home range in 2014 compared to 2013, resulting in differences in the utilization distribution polygons. Differences in the distribution of annual locations tended to underestimate the degree of site fidelity as assessed in this project.

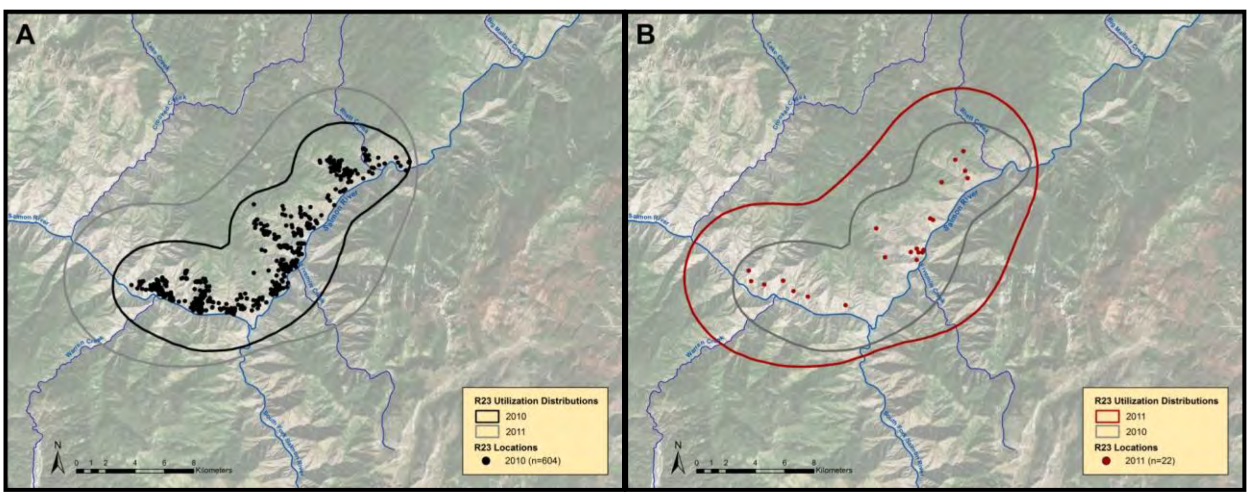

Figure 10. Telemetry locations and home ranges (polygons) for radio-collared bighorn sheep male R23 in 2010 (A) and 2011 (B), Salmon River Bighorn Sheep Project, ID, USA, 2007–2015. Although R23 used the same general area in both years, differences in sample size of locations between years resulted in markedly different home range estimates. This relationship tended to underestimate the degree of site fidelity as assessed in this project.

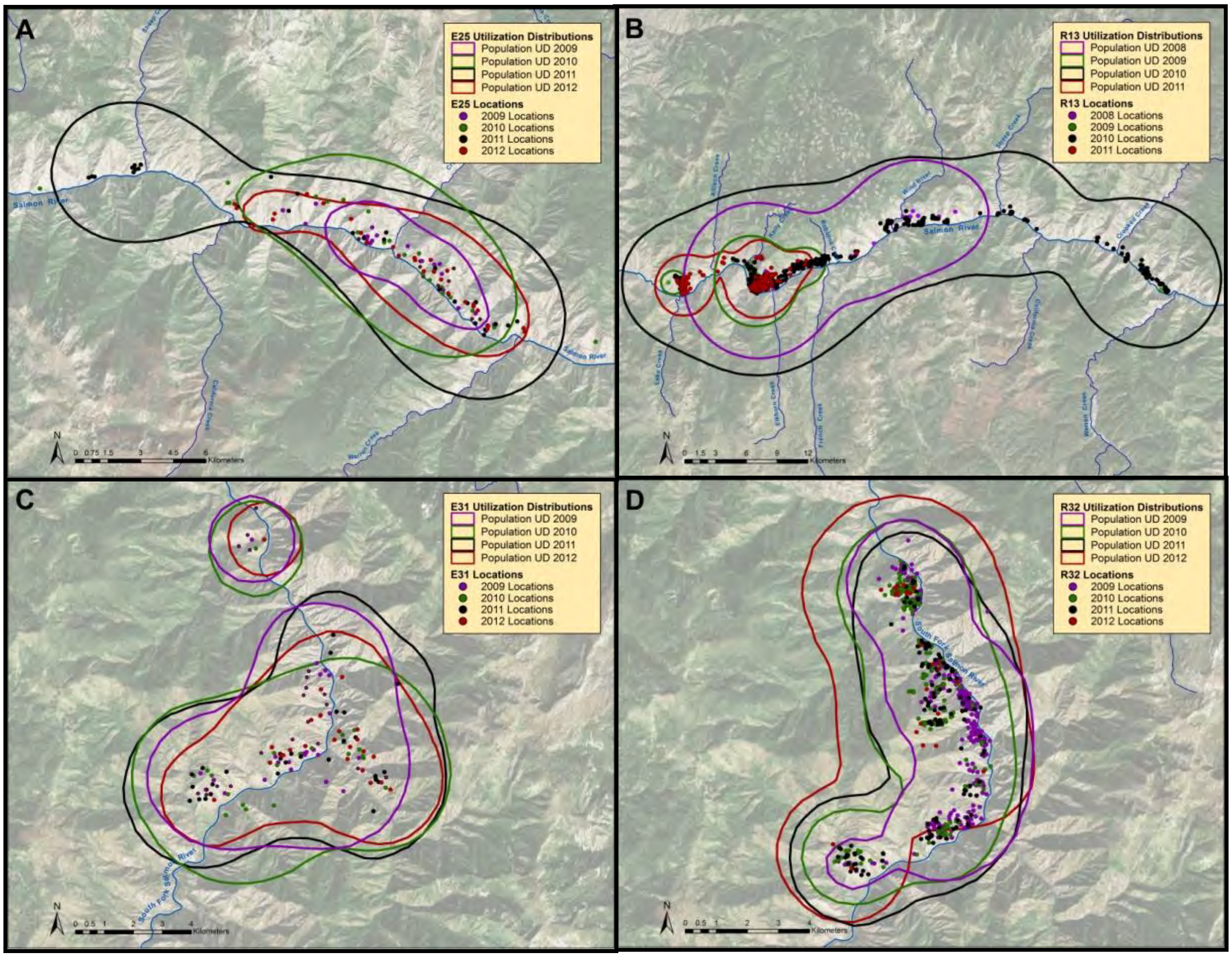

Figure 11. Examples of annual home range variation for female (A and C) and male (B and D) bighorn sheep in the Salmon River Bighorn Sheep Project, ID, USA, 2009–2012. Females exhibited less variation in annual space use than males, with most females similar to E31 (C). Observed extremes in variation among females was attributed to a few individuals exhibiting uncommon foray movements, such as female E25 in 2011 (A). Males exhibited greater variation in annual space use than females, primarily attributed to movements during the rut. Variation among males was attributed to their juxtaposition to female groups and the specific female groups visited each breeding season. Variation in male R13's space use (B) depended on which combination of 3 female groups (Manning Bridge, Wind River, Indian Creek) he visited during any one breeding season. Male R32 (D) exhibited little variation in space use as he visited a single female group (South Fork Ewes) whose group use area was sympatric with his home range.

Area and overlap index values supported observations of ArcMap displays, suggested little variation in home range size and a high degree of site fidelity across years for individuals of both sexes, and type of collar (VHF or GPS), had a minimal effect on results (Appendix F, Table 8). Not accounting for collar type, area index values indicated similarity in home range size across years for both sexes, although males had greater year-to-year variation. On average, percent difference in individual annual home range size was 26% (range = 2–68%) for females and 40% (range = 14–77%) for males. Similar-collar-type comparisons for males improved mean difference in home range area percentage slightly to 35%.

Overlap index values were high for both females and males. On average, percent overlap of individual annual home ranges was 79% (range = 59–92%) for females and 73% (range = 62–86%) for males. Similar-collar-type comparisons for males improved mean overlap percentage slightly to 75%.

Table 8. Average mean area and overlap index values[a] comparing individual female and male annual home ranges for bighorn sheep study animals along the Salmon River, ID, USA 2007–2015.

	Area Index		Overlap Index	
Sex	Range $\bar{x}$ Percent Difference	Average $\bar{x}$ Percent Difference	Range $\bar{x}$ Percent Overlap	Average $\bar{x}$ Percent Overlap
Female	1.9 – 67.7	26.2	59.4 – 92.1	78.5
Male	13.5 – 76.8	39.8	61.7 – 85.8	73.2
All Sheep	1.9 – 76.8	31.8	59.4 – 92.1	76.2

[a] Average across all females (or all males) of individual mean index values from each annual home ranges (e.g., mean of male R32 values from 2009–2012 home ranges).

Conformity in annual space use by individual female and male bighorn sheep provided justification for pooling data for each study animal across years. Pooled annual home ranges for male bighorn sheep ($\bar{x}$ = 225 km^2) were over twice as large of those for females ($\bar{x}$ = 95 km^2) and median home range size between sexes (male = 190 km^2, female = 74 km^2) differed at α = 0.05 (Mann-Whitney U, n_F = 34, n_M = 26, W = 734, 2-tailed P = 0.00).

Social Group Space Use and Site Fidelity

Not surprising, given the high degree of individual site fidelity, female and male groups also expressed high site fidelity, using the same general area from year-to-year (Fig. 12). Mean area and overlap indices for group use area comparisons conformed closely to those for individual study animals, were similar for females and males, and indicated similarity in use area size and a high degree of group site fidelity across years (Table 9).

Social Group Annual Space Use and Overlap

Observed high site fidelity provided justification for pooling location data across years and individuals assigned to each group to construct pooled female and male group use areas. For all but the Manning Bridge female group, female and male groups were extant prior to project initiation and remained intact and discrete during the term of the project. Prior extant female groups were monitored for $\geq$ 8 years, represented by 8–12 study animals within each group, and were monitored for a cumulative total of 154 animal-years. The Manning Bridge Ewe group, established in 2012 during the project, was represented by a single study animal whose group membership was still uncertain at the end of the project, precluding analysis of space use and overlap. Male groups were monitored for >7 years over a cumulative total of 125 animal-years represented by 2–10 study animals within each group.

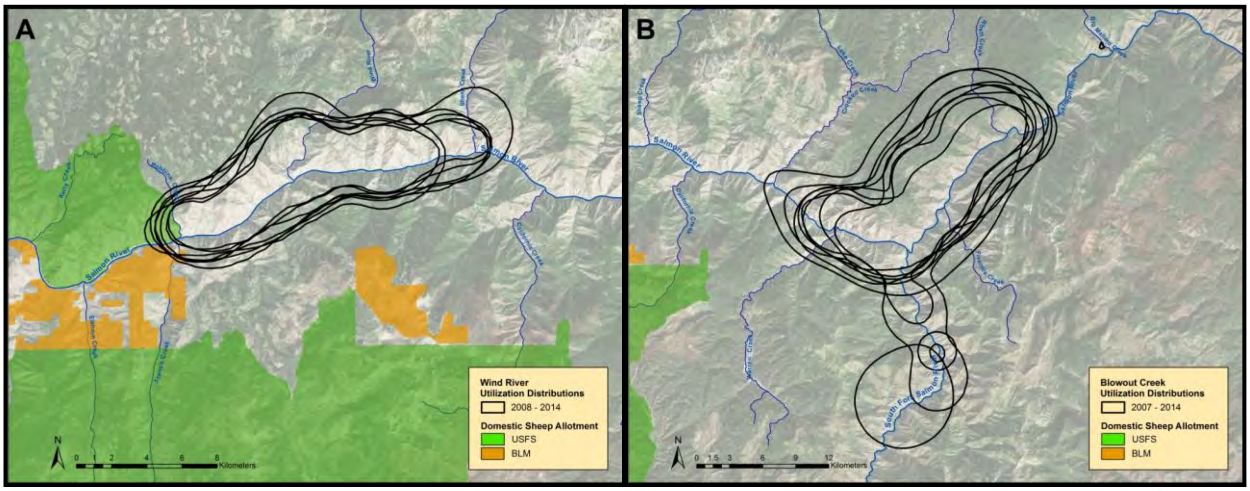

Figure 12. Typical examples of year-to-year conformity in annual space use (group site fidelity) for female (A) and male (B) social groups in the Salmon River Bighorn Sheep Project, ID, USA, 2007–2014.

Table 9. Mean area and overlap index values comparing annual group use areas (e.g., Wind River 2008–2014) averaged across all female and male social groups in the Salmon River Bighorn Sheep Project, ID, USA, 2007–2015.

	Area Index		Overlap Index	
Sex	$\bar{x}$ Percent Difference Range (%)	Average $\bar{x}$ Percent Difference	$\bar{x}$ Percent Overlap Range (%)	Average $\bar{x}$ Percent Overlap
Female	0.0 – 72.8	23.6	74.0 – 85.5	78.3
Male	1.9 – 71.7	25.3	66.0 – 79.5	73.5
All Sheep	0.0 – 72.8	24.4	74.0 – 85.5	75.4

Female Social Groups. Female groups in our project area used discrete use areas, were distributed sequentially and continuously along the main stem and lower South Fork river canyons, and either shared or slightly overlapped adjacent group boundaries (Fig. 13). Pooled annual group use area size ranged from 60–120 km^2 and averaged 96 km^2 across female groups (Table 10). Group use area size was consistent between Indian Creek, Jersey Creek, and South Fork Ewes. Wind River's use area was about half the size of other female groups, due in part to an increased sample size for this group. Female group use areas were linear in nature, following the main stem and South Fork river corridors. Group use areas were consistent in length across groups, ranging from 21–28 river km (Table 10). Insufficient data precluded calculating group use area size or length for the Manning Ewe group.

Use areas of 3 of 4 female groups overlapped, although overlap was slight ($\overline{x}$ = 10%) and occurred outside of core areas at the down- or upriver extremes of group use areas (Table 11). These 3 overlapping groups were the most upriver groups (Indian Creek, Jersey Creek, and South Fork Ewes). No overlap was identified between adjacent Wind River and Indian Creek, and no use area or overlap estimates could be made for Manning Bridge Ewes.

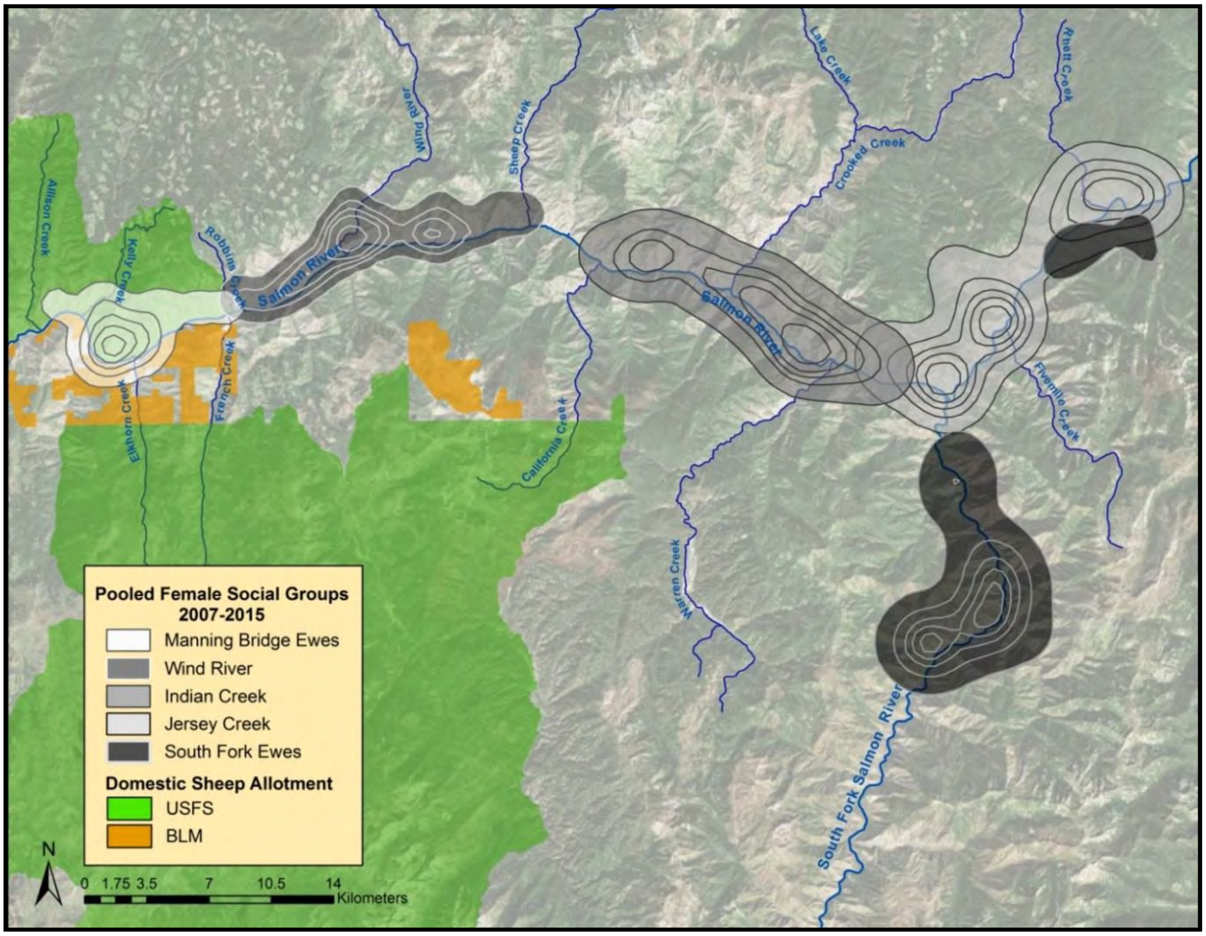

Figure 13. Pooled annual female social group use areas in the Salmon River Bighorn Sheep Project, Salmon, ID, USA, 2007–2015. Use areas represent 95% contours derived from a fixed kernel estimator. The Manning Bridge Ewe group use area is provided for display purposes only and is not included in analyses (see text for details).

Table 10. Female bighorn sheep social group monitoring statistics and annual use area measurements, Salmon River Bighorn Sheep Project, ID, USA, 2007–2015. Area and length estimates based on 95% contours derived from a fixed kernel estimator. Number of animal-years based on number of radio-collared animals monitored any time during the year.

Social Group	No. Study Animals	No. Years Monitored	No. Animal Years	Use Area (km^2)	Use Area (River km)
Manning Bridge	1	4	4	-	-
Wind River	10	9	43	60	21
Indian Creek	12	9	43	101[a]	23[a]
Jersey Creek	8	9	30	120[b]	28[b]
South Fork	9[c]	8	38	102	26
$\bar{x}$				96	24

[a] Excludes female E70
[b] Excludes female E50 forays
[c] Excludes male R66

Table 11. Percent overlap of pooled annual use areas estimated for 4 female social groups along the Salmon River, ID, USA, 2007–2015. Values indicate the percent of estimated use area belonging to groups in column "A" that are overlapped by those belonging to groups in column "B". Insufficient data excluded the Manning Bridge Ewe group from analysis.

A	B			
	Wind River	Indian Creek	Jersey Creek	South Fork
Wind River	-	0.0	0.0	0.0
Indian Creek	0.0	-	10.6	0.0
Jersey Creek	0.0	9.0	-	8.7
South Fork	0.0	0.0	10.1	-

Location overlap based on individual telemetry locations was similar to use area overlap for Indian Creek and Jersey Creek groups, but provided a finer scale and more accurate and contrary assessment of overlap between Wind River and Indian Creek, and between Jersey Creek and South Fork Ewes (Table 12, Appendix G). Although estimated use areas for Wind River and Indian Creek did not overlap, location data indicated some spatial overlap, suggesting potential for interaction between these 2 groups (Fig. 14A). Interaction between these groups was infrequent, with only 0.03% of Wind River locations collected over a nine-year period (representing 3 out of 43 animal-years monitored), occurred within Indian Creek's use area. Likewise, locations of Indian Creek members occurring within Wind River's use area were attributed to 2 members exhibiting infrequent and uncommon movements representing 2 of 43 animal-years monitored.

Table 12. Percent of telemetry locations occurring within neighboring annual use areas calculated for 4 female social groups along the Salmon River, ID, USA, 2007–2015. Values indicate the percent of locations for groups in column “B” occurring within use areas of groups in column “A”. Insufficient data excluded the Manning Bridge Ewe group from the analysis.

A	B			
	Wind River	Indian Creek	Jersey Creek	South Fork
Wind River	-	7.5	0.0	0.0
Indian Creek	0.03	-	7.1	0.0
Jersey Creek	0.0	2.1	-	0.0
South Fork	0.0	0.0	0.0	-

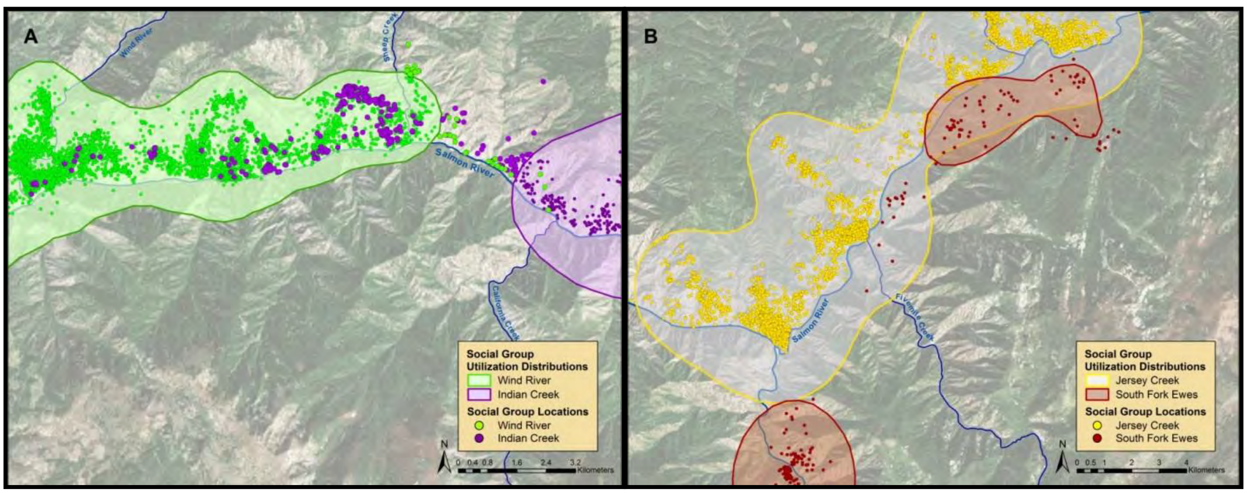

Figure 14. Estimated use areas and telemetry locations for 4 adjacent female social groups along the Salmon River, ID, USA 2007–2015. Although estimated use areas for Wind River and Indian Creek do not overlap, telemetry locations of infrequent foray movements show some level of shared space use between groups (A). Although estimated home ranges for Jersey Creek and South Fork Ewes overlapped, telemetry locations of collared members provide no evidence of interactions between these 2 groups (B).

Jersey Creek and South Fork Ewes shared adjacent use area boundaries along the Salmon River, with potential for interactions. Observed overlap of estimated use areas, however, is likely due in part to overestimating the home range of Jersey Creek. During spring and summer, some Jersey Creek members traveled upstream along the north side of the main stem to lamb in the Rhett Creek area. Likewise, some members of South Fork Ewes traveled to the confluence of the South Fork and continued upstream along the south side of the main stem to lamb in the Lemhi Creek area, across from Rhett Creek. Although members of each group were in proximity to each other, across the Salmon River during a portion of the year, no collared member of either group crossed the river into the neighboring use area (Fig. 14B). We believe the Salmon River acts as a behavioral barrier defining the boundary between these 2 groups.

Male Social Groups. Male social groups were also distributed sequentially and continuously along the Salmon River (Fig. 15). Annual use area size for male groups varied more and was nearly twice as large, on average, as female groups (Table 13). Median male and female group use area size differed at the α = 0.05 level (Mann-Whitney U, $F\ n$ = 4, n_M = 4, W = 6.0, 1-tailed P = 0.04). Annual use areas for 3 of 4 male groups (Blowout Creek, Bull Creek, and Manning Bridge) were similar in size (183 km^2 to 266 km^2), while the South Fork ram group was about a fifth the size (40 km^2). Male group use areas were also linear in nature but varied more across groups and were larger than those of females.

Annual group use areas overlap occurred among all male groups and appeared to be more extensive ($\overline{x}$ = 18%) than for overlapping female groups, although differences were not highly significant (Mann-Whitney U, n_F = 4, n_M = 4, U = 129.0, 1-tailed P = 0.10; Table 14). Other than South Fork Rams, male groups overlapped multiple other male groups. Blowout Creek overlapped portions of all other ram group use areas. South Fork Rams was the only male group not overlapping annual use areas of other male groups.

Overlap based on individual telemetry also indicated a greater degree of overlap between male groups compared to female groups, and greater overlap among main stem groups than main stem and South Fork groups (Table 15, Appendix G). Overlap based on locations also clarified the timing of overlap, and the nature of observed overlap between Blowout Creek and South Fork Rams. A majority (66%) of locations overlapping other male groups occurred during the rut, indicating space use overlap among males occurs primarily during the rut season. Similar to South Fork Ewes, South Fork Rams were more isolated from other male groups. Use area overlap between Blowout Creek and South Fork Rams was due to a single member of Blowout Creek, R30, traveling into South Fork Ram's use area during the breeding season. No locations of collared South Fork Ram members were observed within Blowout Creek's group, or any other main stem male or female group use area.

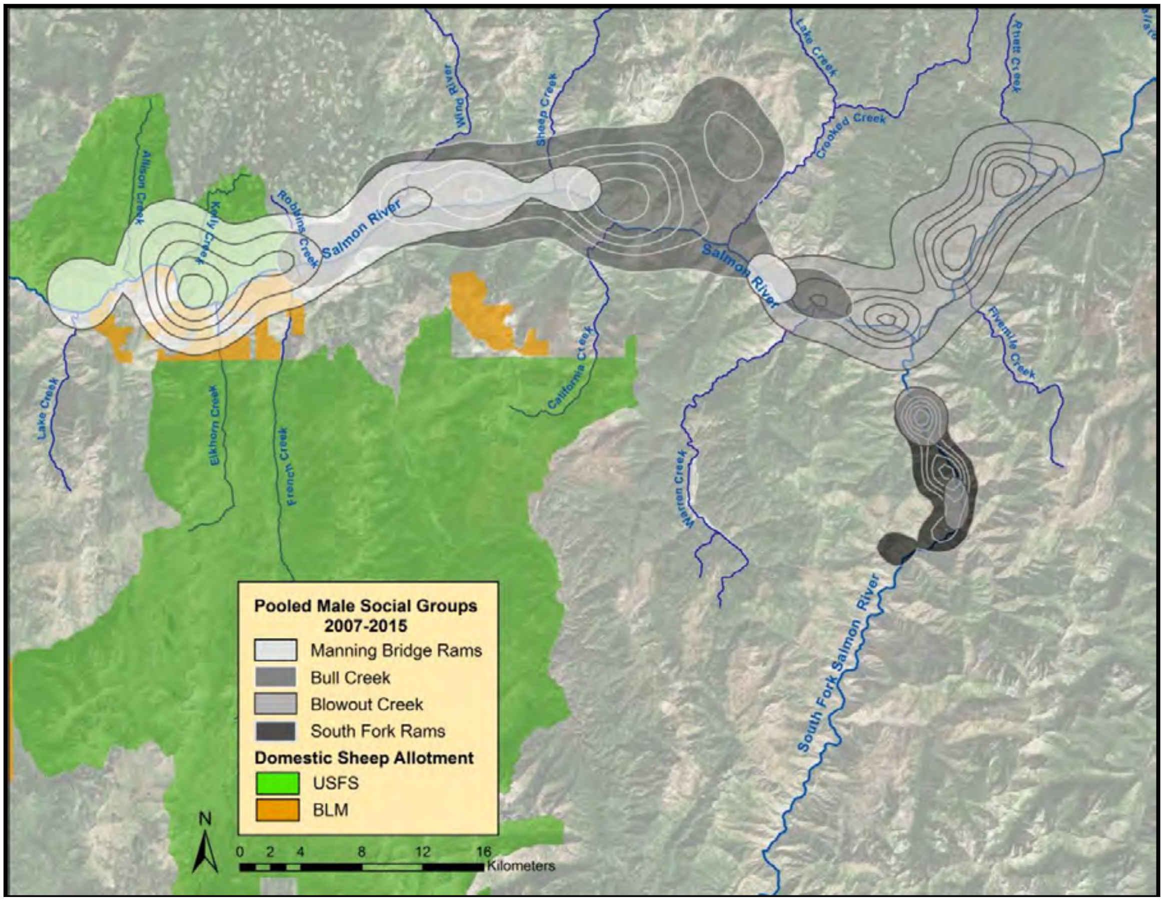

Figure 15. Pooled annual male social group use areas along the Salmon River, ID, USA, 2007–2015. Use areas represent 95% contours derived from a fixed kernel estimator.

Table 13. Male bighorn sheep social group monitoring statistics and annual use area measurements, Salmon River Bighorn Sheep Project, ID, USA, 2007–2015. Area and length estimates based on 95% contours derived from a fixed kernel estimator. Number of animal-years based on number of radio-collared animals monitored any time during the year.

Social Group	No. Study Animals	No. Years Monitored	No. Animal Years	Use Area (km^2)	Use Area (River km)
Manning Bridge	9	9	48	201	48
Bull Creek	5	8	24	266	43
Blowout Creek	10	9	44	183[a]	34[a]
South Fork	2	6	9	40	17
$\bar{x}$				172	36

[a] Includes only main stem portion of home range

Table 14. Percent overlap of pooled annual use areas estimated for 4 male social groups along the Salmon River, ID, USA, 2007–2015. Values indicate the percent of estimated use area belonging to groups in column "A" that are overlapped by those belonging to groups in column "B".

A	B			
	Manning Bridge	Bull Creek	Blowout Creek	South Fork
Manning Bridge	-	42.2	3.1	0.0
Bull Creek	35.0	-	6.1	0.0
Blowout Creek	3.8	8.8	-	7.9
South Fork	0.0	0.0	37.5	-

Table 15. Percent of telemetry locations occurring within neighboring annual use areas of 4 male social groups along the Salmon River, ID, USA, 2007–2015. Values represent the percent of locations for groups in column "B" occurring within use areas of groups in column "A".

A	B							
	Manning Bridge		Bull Creek		Blowout Creek		South Fork	
	All Locns[a]	Locns Rut[b]	All Locns	Locns Rut	All Locns	Locns Rut	All Locns	Locns Rut
Manning Bridge	-	-	39.3	74.3	0.04	0.0	0.0	n/a
Bull Creek	23.9	67.6	-	-	15.5	69.8	0.0	n/a
Blowout Creek	1.2	100	2.5	29.8	-	-	50.0[c]	39.3[c]
South Fork	0.0	n/a	0.0	n/a	3.2	82.9	-	-

[a] All Locns = all telemetry locations collected for a social group. Percentages represent proportion of all telemetry locations collected for a social group that overlapped another social group's use area.
[b] Locns Rut = telemetry locations collected during the rut season 1 October–31 December. Percentages represent proportion of all overlapping locations (All Locns) that occurred during the rut seasons.
[c] Overlapping locations due to single Blowout Creek male (R30) within South Fork Ram use area. No collared members of the South Fork Ram group were detected outside of their use area.

Social Group Seasonal Space Use and Overlap

Environmental factors did not appear to play a primary role in space use for either sex. Female groups appeared to use the same areas year-round, as use area size and spatial orientation was consistent between summer and winter seasons for all female groups. Male group use areas varied widely between seasons of the year, although the disparity appeared to be more related to breeding behavior (the winter season encompasses the rut-season) than seasons of the year.

Female Social Groups. Female bighorn sheep in our project area did not show pronounced seasonal differences in space use between summer and winter. Female groups did not use spatially disjunct summer and winter ranges, nor was there evidence for seasonal elevation shifts. Female groups used the same range year-round with consistently little change in size and spatial orientation between seasons (Table 16, Fig. 16A). For all groups, summer use areas were slightly larger ($\overline{x}$ = 29%) than winter use areas but differences were slight (Mann-Whitney

U, n_{summer} = 4, n_{winter} = 4, U = 23, 2-tailed P = 0.19), beyond the precision of our data to determine statistical or biological significance. Group use areas during the lambing season were consistently larger (53% on average, Table 16) than those for the non-lambing season for all but Wind River, but did not differ statistically (Mann-Whitney U, $n_{lambing}$ = 4, $n_{non\text{-}lambing}$ = 4, U = 22.0, 1-tailed P = 0.16). Female groups did not use spatially disjunct lambing ranges and overlap between lambing and non-lambing home ranges was high for all groups (range = 74–83%, $\bar{x}$ = 79%; Fig. 16B).

Table 16. Area (km2) and Overlap (%) statistics for female social group seasonal home ranges along the Salmon River, ID, USA, 2007–2015. Winter = 1 October–30 April, summer = 1 May–30 September, lambing = 1 May–30 June, non-lambing = 1 October–30 April. Diff = Difference.

Social Group	Winter Home Range Area (km^2)	Summer Home Range Area (km^2)	Diff[a] Winter from Summer (%)	$\bar{x}$ Percent Overlap	Lambing Home Range Area (km^2)	Non Lambing Home Range Area (km^2)	Diff Lambing from Non Lambing (%)	$\bar{x}$ Percent Overlap
Wind River	51.5	74.8	-31.1	84.9	38.8	51.5	24.7	82.9
Indian Creek	80.5	134.0	-39.9	79.6	169.9	80.5	111.1	73.5
Jersey Creek	103.6	134.4	-22.9	85.0	144.9	103.6	39.8	78.1
South Fork Ewes	94.6	122.9	-23.0	83.6	130.6	94.6	38.1	79.5
$\bar{x}$	82.6	116.5	-29.2	83.3	121.0	82.6	53.4	78.5

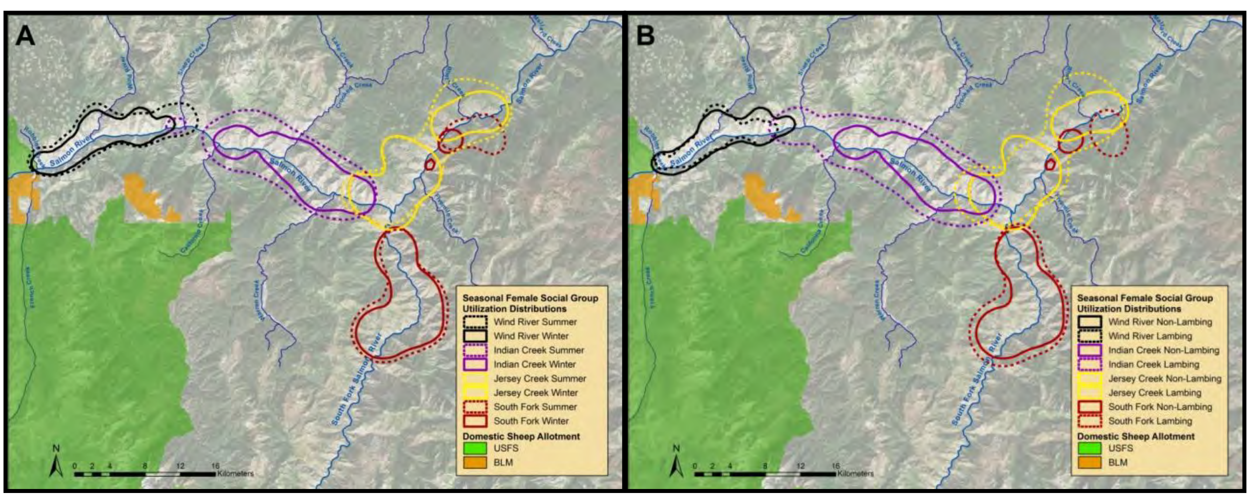

Figure 16. Female Social Group seasonal use areas along the Salmon River, ID, USA, 2007–2015. Seasons include summer (1 May–30 September) and winter (1 October–30 April, A) and lambing (1 May–30 June) and non-lambing (1 October–30 April, B).

Male Social Groups. Based on seasons of year, male seasonal use areas varied in size, but social groups did not use disjunct summer and winter ranges, nor was there strong evidence for seasonal elevation shifts (Fig. 17A). Unlike female groups, male winter use areas averaged 3.4 times larger than summer use areas ($\overline{x}_{\text{winter}}$ = 229 km^2, $\overline{x}_{\text{summer}}$ = 61 km^2; Table 17). Winter ranges incorporated the majority of summer ranges but expanded outside of core summer use areas; overlap remained high ($\overline{x}$ = 65%). Compared to the main stem groups, the South Fork group was comparably smaller and more consistent in size between seasons.

Based on breeding seasons, male group rut use areas were on average 3.6 times larger than non-rut use areas ($\overline{x}_{\text{rut}}$ = 271 km^2, $\overline{x}_{\text{non-rut}}$ = 61 km^2; Table 17; Fig. 17B). Male group use areas encompassed almost 3 times more river corridor during the rut season ($\overline{x}$ = 41 km) than during the non-rut season ($\overline{x}$ = 15 km), and individuals of all but the South Fork Ram group used extensive areas of the river corridor during this time of year. Pooling locations for individuals across monitored years, on average, males used areas encompassing 27 river kilometers (range = 6–50 km) facilitating a high degree of interaction among male and female groups Table 18; Table 19). Main stem male groups (Blowout Creek, Bull Creek, Manning Rams) had similar-sized rut use areas (range = 280–467 km^2; $\overline{x}$ = 345 km^2), that were considerably larger than South Fork Rams' (46 km^2), and significantly larger than main stem non-rut use areas (Mann-Whitney U, n_{rut} = 3, $n_{\text{non-rut}}$ = 3, U = 15.0, 1-tailed P = 0.04).

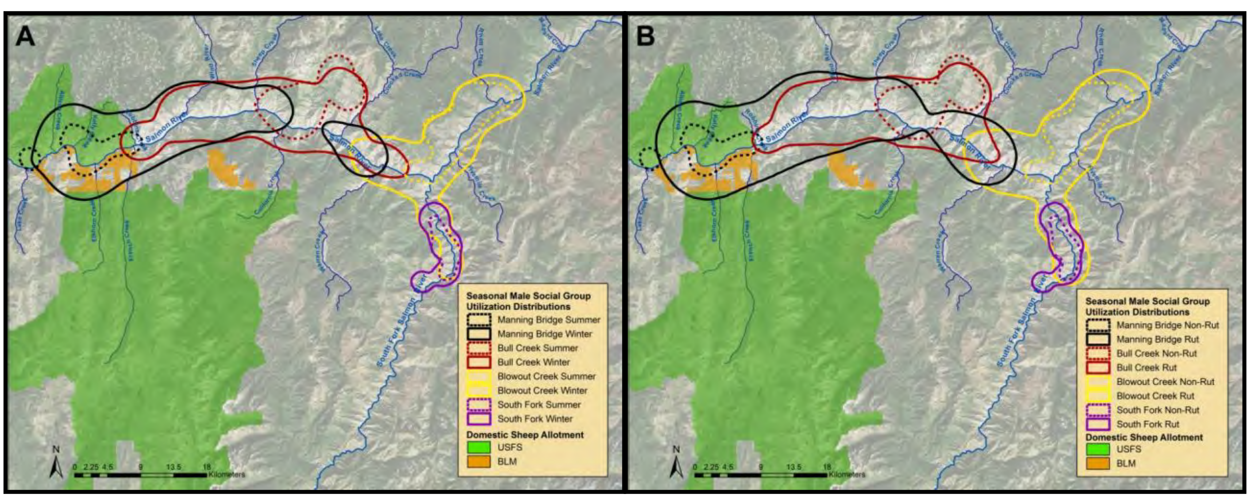

Figure 17. Male Social Group seasonal use areas along the Salmon River, ID, USA, 2007–2015. Seasons include summer (1 May–30 September) and winter (1 October–30 April, A), and rut (1 October–31 December) and non-rut (1 May–30 September, B).

Table 17. Area (km2) and Overlap (%) statistics for male social group seasonal use areas along the Salmon River, ID, USA 2007–2015. Winter = 1 October–30 April, summer = 1 May–30 September, rut = 1 October–31 December, non-rut = 1 May–30 September.

Social Group	Winter Use Area (km^2)	Summer Use Area (km^2)	Diff Winter from Summer (%)	$\bar{x}$ Percent Overlap	Rut Use Area (km^2)	Non Rut Use Area (km^2)	Diff rut from Non rut (%)	$\bar{x}$ Percent Overlap
Manning Bridge	352.6	49.1	617.6	50.6	467.1	49.1	850.7	49.1
Bull Creek	297.0	88.5	235.4	66.1	289.1	88.5	226.5	62.1
Blowout Creek	219.1	86.3	153.8	69.3	279.9	86.3	224.2	74.5
South Fork	47.0	21.2	121.5	73.8	46.4	21.2	118.7	75.0
$\bar{x}$ Main Stem	289.6	74.6	282.1	62.0	345.4	74.7	433.8	61.9
$\bar{x}$ All Groups	228.9	61.3	335.6	65.0	270.6	61.3	355.0	65.2

Table 18. Rut and non-rut seasonal use areas and movements of male bighorn sheep along the Salmon River, ID, USA, 2007–2015. Movements (Mvts.) represent maximum distance between down- and upstream most locations of individual males pooled across monitored years. Distances represent river kilometers.

	Rut Season			Non-Rut Season		
Social Group	Use Area Length (km)	$\bar{x}$ Mvts.	Range Mvts.	Use Area Length (km)	$\bar{x}$ Mvts.	Range Mvts.
Manning Bridge Rams	57.45	33.43	23.15 - 50.33	15.71	19.13	12.36 - 24.82
Bull Creek	36.75	27.44	14.15 - 37.29	9.29	16.33	10.42 - 28.2
Blowout Creek	53.54	24.33	13.06 - 33.01	22.83	15.85	6.87 - 35.45
South Fork Rams	16.52	11.63	5.48 - 16.20	10.77	10.95	10.87 - 10.98
$\bar{x}$	41.06	26.53	5.48 - 50.33	14.65	16.49	6.87 - 35.45

Table 19. Female and male social group interactions during the rut season (1 October–31 December) along the Salmon River, ID, USA, 2007–2015. Cells marked "X" indicate locations for members belonging to male social groups in column "B" overlapping use areas belonging to social groups in column "A".

A	B			
	Manning Bridge	Bull Creek	Blowout Creek	South Fork
Females				
Manning Bridge Ewes	X			
Wind River	X	X		
Indian Creek	X	X	X	
Jersey Creek	X		X	
South Fork Ewes			X	X
Males				
Manning Bridge Rams		X	X	
Bull Creek	X		X	
Blowout Creek	X	X		X
South Fork Rams			X	

Although rut and non-rut use areas, as we defined them, were not spatially disjunct, our definition of the rut season (1 October–31 December) may have included some pre- and post-rut movements. Additionally, we were not able to measured seasonal use areas at a fine enough scale to determine spatial separation between breeding seasons. Field observations indicated once males left their non-rut use area, they did not return until after the breeding season. Rut and non-rut use areas are likely disjunct, however, our methods were too course to detect differences.

Rut and winter use areas were similar in size and spatial orientation for all male social groups. This was likely because winter use areas included the rut period and males frequently made long-distance movements during this period to interact with female groups, greatly influencing both rut and winter use area estimates. When compared with annual use areas for neighboring female groups, ram groups appeared to expand their use areas during the rut period to encompass areas used by female groups. We hypothesized size and distribution of male seasonal use areas in our project area were primarily determined by breeding behavior (long-distance movements of males during the rut), proximity to female groups, selection of female groups visited during rut, and less influenced by seasons of the year. As an example, South Fork Rams displayed no difference in seasonal space use and home range size was consistently smaller than those of main stem groups. We speculate this is because (1) South Fork Rams, uniquely, did not travel extensively during rut to visit multiple female groups; instead focusing breeding behavior on the single female group in the South Fork (South Fork Ewes) and (2) South Fork Ewes were in proximity during rut as these 2 groups shared sympatric range year-round.

<u>Foray Movements and Social Group Fidelity</u>

Female Social Groups. Since space use for female groups was largely consistent year-round, foray movements were assessed based on annual group use area boundaries. Although members of all but the South Fork Ewe group made movements outside assigned home ranges, extra-home range movements were uncommon. Across all female groups 12 of 40 (30%) collared animals traveled $\geq$1 km from their use area boundary and 9 (23%) made forays inside neighboring female group use areas. From 2007–2015, 14 foray incidents into neighboring group use areas were recorded, averaging 0.4 incidents per year (about 1 foray incident every 3 years). The number of locations representing foray movements into neighboring use areas accounted for <2% of all locations collected for collared study animals.

Most forays were short-distance movements (70% <10 km, $\bar{x}$ = 4 km), within extreme ends of neighboring group use areas and outside of core use areas. Longer distance movements were rare, but notable as examples of potential capabilities of female bighorn sheep. Long distance foray movements were observed for 3 of 40 (8%) collared females, E50, E60, and E70, who had maximum recorded foray distances of 39, 37, and 13 river km, respectively. Movements by these study animals demonstrated the potential for extensive movements and their contributions to population connectivity, and disease spread.

E50 was collared as an adult member of the Jersey Creek female group in 2011 and fitted with a GPS satellite collar. The Jersey Creek female group was the upstream most group within the project area along the main stem reach. The Indian Creek female group was adjacent downstream along the main stem reach while the South Fork Ewe group was adjacent to the south along the South Fork reach. No known adjacent groups resided upstream along the main stem reach.

E50 spent the 2012–2013 winter in the traditional wintering area for this group between Mackay Bar and Jersey Creek until 11 January 2013, when she moved upstream to Rhett Creek, a common lambing area for this group (Fig. 18). She was observed from the air with a lamb on 31 May and remained in the lambing area until 24 July when she initiated a foray movement from Reed Creek upstream and outside of her group's use area. During a 17-day period between 24 July and 10 August, she moved continually (approximately 34 river km) upstream to the mouth of Sabe Creek. She localized her movement between Sabe Creek and Smith Gulch (5 km upstream of Sabe Creek, 39 river km from Reed Creek) from 10 August until 2 September, when her collar failed and contact was lost. Although the ultimate outcome of E50's foray is unknown, it is likely, given the abruptness and extent of her movements, she was in the process of leaving the Jersey Creek home range and exploring opportunities for joining another female group.

E60 was collared as an adult member of the newly established Manning Bridge Ewe group in January of 2013. Although her origin is unknown, she most likely was a member of the adjacent, upriver, Wind River group prior to recolonizing the Manning Bridge area. E60 conducted extra-use area movements throughout her monitoring period, placing her social group status in question. She was assigned to Manning Bridge because she spent the majority of her time, including the 2013 and 2014 lambing seasons with this group, although she did not produce a lamb in either year.

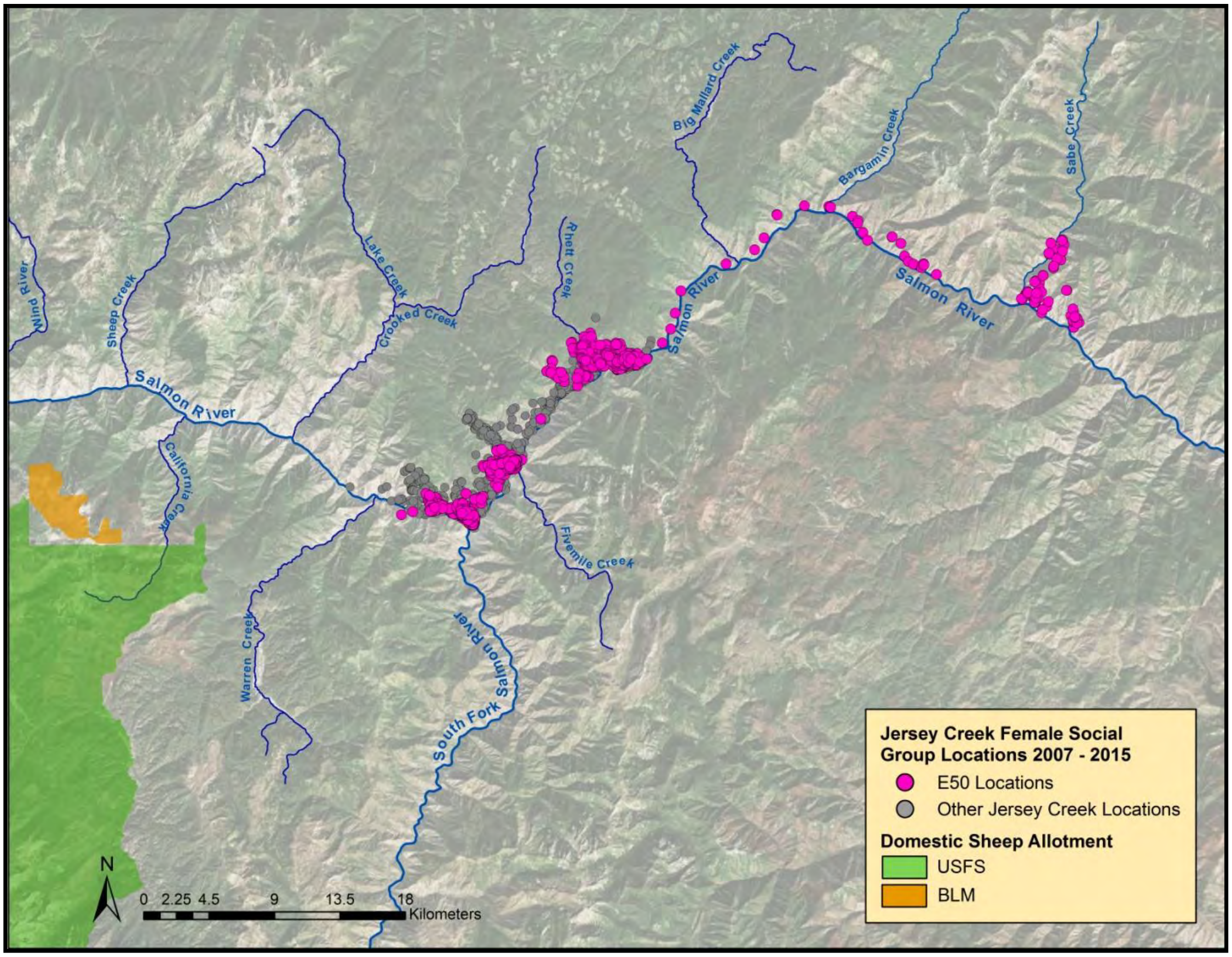

Figure 18. Foray movements of female radio-collared bighorn sheep E50 along the Salmon River, ID, USA, 2013.

E60 undertook 3 forays during her monitoring period, all terminating within Indian Creek's use area (a distance of 37 river km), and each was progressively of longer duration (Fig. 19). E60 conducted her first foray moving upstream past the adjacent Wind River group and into Indian Creek's use area in May of 2013, returning to her use area within 7 days. In 2014, E60 made 2 additional forays into Indian Creek's use area. The first occurred between February and May although duration of her stay could not be accurately determined as only 1 location was obtained within that period. In November, E60 was located once again within Indian Creek's use area from at least 1 January to 4 September 2015; a duration of over 8 months where she produced her first lamb.

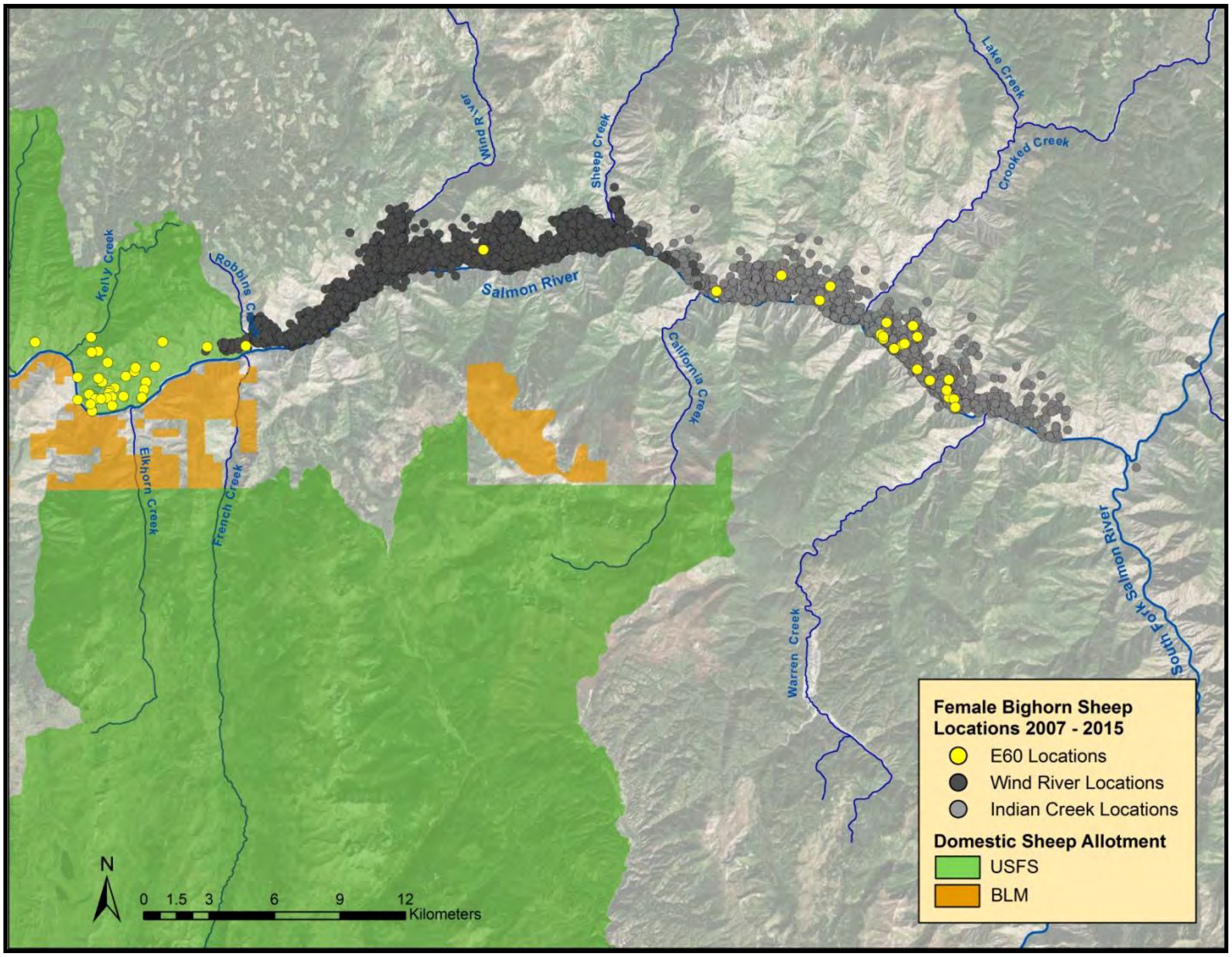

Figure 19. Foray movements of female radio-collared bighorn sheep E60 along the Salmon River, ID, USA, 2013–2014.

By 24 September 2015, E60 had returned to Manning Bridge Ewes' use area and remained there until the end of her monitoring period on 31 December 2015. It is unknown, but likely E60 was in the process of changing membership and joining Indian Creek, given time spent and the fact she produced a lamb in Indian Creek's use area. During E60's forays she was observed interacting with members of Wind River, Indian Creek, and Jersey Creek.

E70 was collared as an adult Indian Creek member in January 2013. E70 remained within her group use area through August 2014, when she initiated 4 separate forays into adjacent downstream Wind River's use area between August 2014 and December 2015 (Fig. 20). Foray distances ranged from 5–13 km and duration of time spent within Wind River's use area varied from 5–39 days. Similar to E60, E70's last foray was the longest in duration; she spent April through mid May within Wind River's use area.

Interactions between E70 and members of the Wind River group could not be verified as E70's locations were collected via a GPS collar. The project ended before E70's ultimate fate could be verified, although it is possible she was in the process of changing membership to Wind River, as her movements were unique among other members of her group.

Female groups exhibited strong group fidelity. We were unable to document a change in group membership for any of the 5 social groups. Although unequivocal evidence was lacking, we suspect E50 may have changed and E60 and E70 may have been in the process of changing group membership. If this were the case, the rate of membership change among the 40 collared females in our project was low (<8%). Considering the number of animal-years we monitored collared females (158 animal-years), the rate of membership change among study animals was 2% per year.

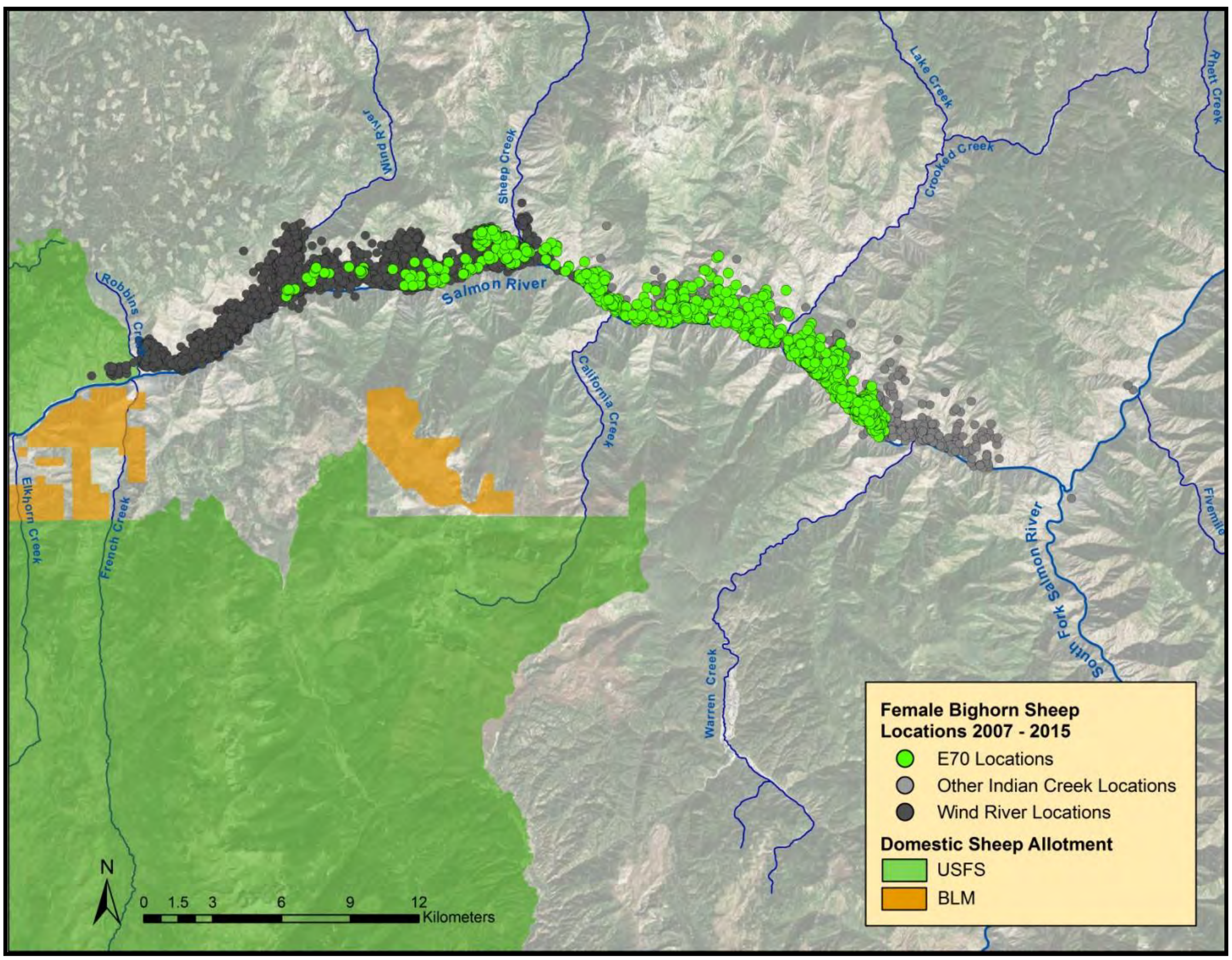

Figure 20. Foray movements of female radio-collared bighorn sheep E70 along the Salmon River, ID, USA, 2014–2015.

Male Social Groups. Adult male foray movements and membership fidelity were assessed during the non-rut season when male groups were discrete, disjunct, and more site- and group-fidelic than remaining times of year. Adult male forays were uncommon. Of 26 adult collared males associated with male groups, 2 (8%) made forays outside their non-rut seasonal use area. Male bighorn sheep R26 from Bull Creek and R3 from Blowout Creek each made a single foray (18 and 12 river km, respectively) of short duration (6 and 5 days, respectively). R26 traveled downstream bordering Manning Bridge Rams' use area, but it was unknown if he interacted with Manning Bridge Rams members. R3, from the upstream-most male group, traveled further upstream to the Mallard Creek area. It is unknown if he interacted with other bighorn sheep. The forays of these 2 males represent an average of 0.2 incidents per year (about 1 foray incident every 4.5 years) for adult collared male bighorn sheep during the course of the project. No males conducted foray movements outside of known female group distributions during other times of year, and no males were known to have changed their group membership during the course of this project. Our assessment of male foray movements was likely conservative, as we restricted our analysis to adult members of male groups and lacked collared juvenile male study animals more likely to conduct foray movements.

POPULATION CONNECTIVITY

Main Stem Female Social Groups. Population connectivity was less influenced by movements of females compared to those of males. Female groups along the main stem were interconnected, contributing to population connectivity through low-level, year-round female-female group interactions. Female groups were discrete and highly site and group fidelic year-round; behavioral characteristics discouraging female-female and female-male group interactions. Although groups were behaviorally discrete, their distribution throughout the project area was continuous rather than disjunct, with neighboring groups sharing adjacent or, in the case of Indian Creek and Jersey Creek, slightly overlapping boundaries. Continuous distribution and proximity of neighboring groups provided increased opportunities for inter-group interactions. Based on observed movements of collared bighorn sheep, main stem female groups were interconnected throughout the project area through interactions between neighboring groups (Wind River and Indian Creek, Indian Creek and Jersey Creek). Interactions likely occurred at low levels given (a) infrequent extra-use area foray movements, and (b) low level of estimated shared space use occurring at outer extremes of group use areas; areas less frequented outside of core use areas. Unlike males, female group use areas did not vary seasonally, and opportunity for interactions between main stem female groups was constant year round.

Main Stem Male Social Groups. Main stem male and female bighorn sheep social groups were well connected primarily due to movements of males during the rut. During the non-rut season ram groups were discrete and highly site- and group-fidelic; their distribution was disjunct through the project area, and groups did not interact with other male or female groups (Fig. 21). Although all male groups shared sympatric ranges with female groups during this time of year (Manning Bridge Rams and Manning Bridge Ewes, Bull Creek and Indian Creek, Blowout Creek and Jersey Creek, and South Fork Rams and South Fork Ewes; Wind River was the only female group not sharing space use with a male group), male and female groups remained temporally separated during the summer non-rut season. Adult mixed-sex groups were rarely observed during this time of year.

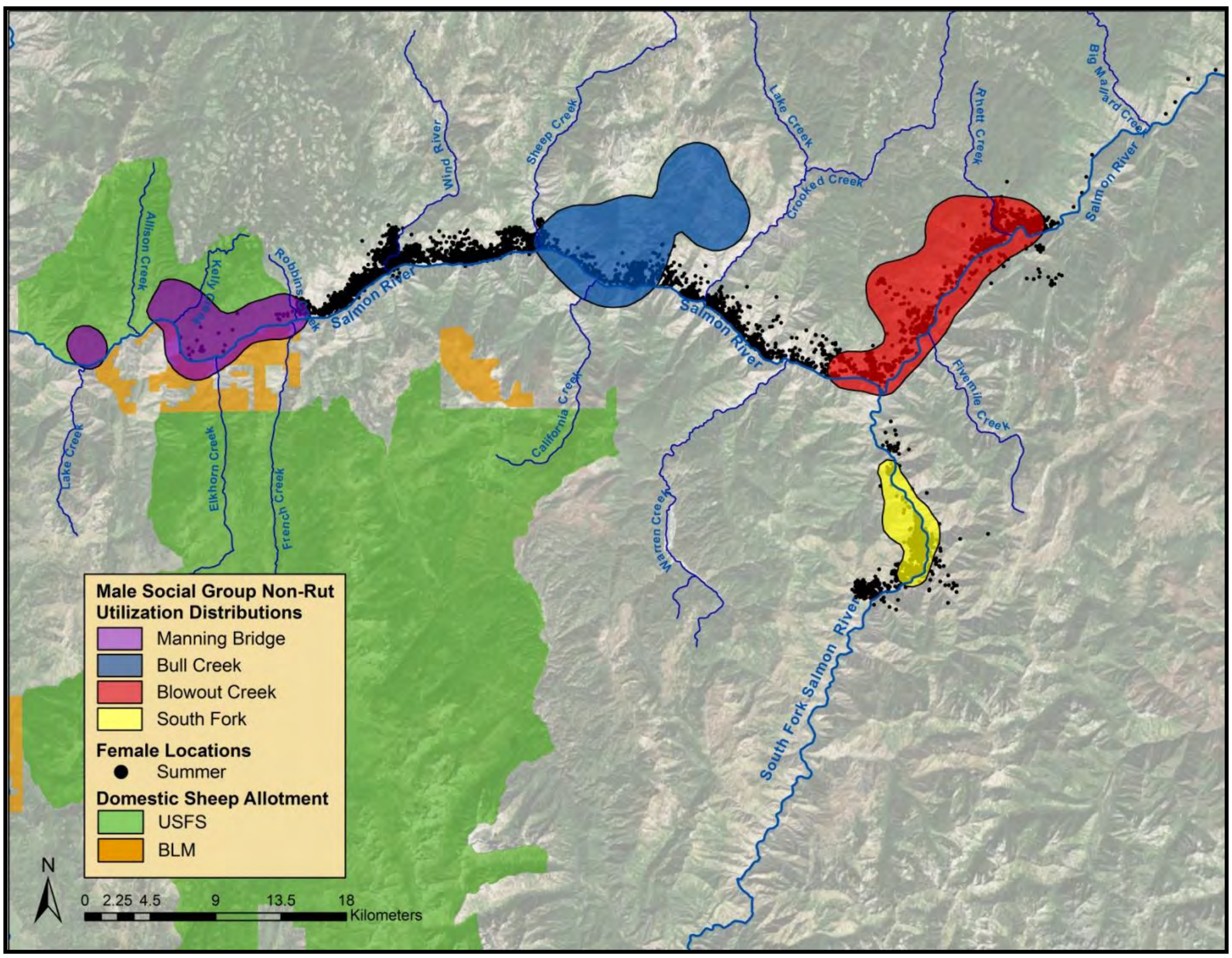

Figure 21. Non-rut (May–30 September) seasonal use area estimates for 4 male social groups and non-rut season locations for radio-collared female bighorn sheep in 5 female social groups along the Salmon River, ID, USA, 2007–2015. During the non-rut season, male social groups are highly site- and group-fidelic and occur in a disjunct distribution within the project area. Although male group use areas overlapped female use areas during the summer non-rut period, few mixed-sex groups were observed during this time period; temporal separation and avoidance resulted in lower levels of male-female interactions compared to the rut season.

During the rut season, main stem ram groups abandoned site and group fidelity, and traveled long distances in small groups or individually in search of female groups (Fig. 22). During the course of the rut season, males interacted with multiple female groups and members of multiple ram groups, providing a high degree of population connectivity among male and female groups throughout the main stem portion of the project area. Although members of ram groups were intermixed with members of multiple other ram groups during the rut, ram groups were highly group and site fidelic during the non-rut season, with the same members returning to the same use areas after the rut.

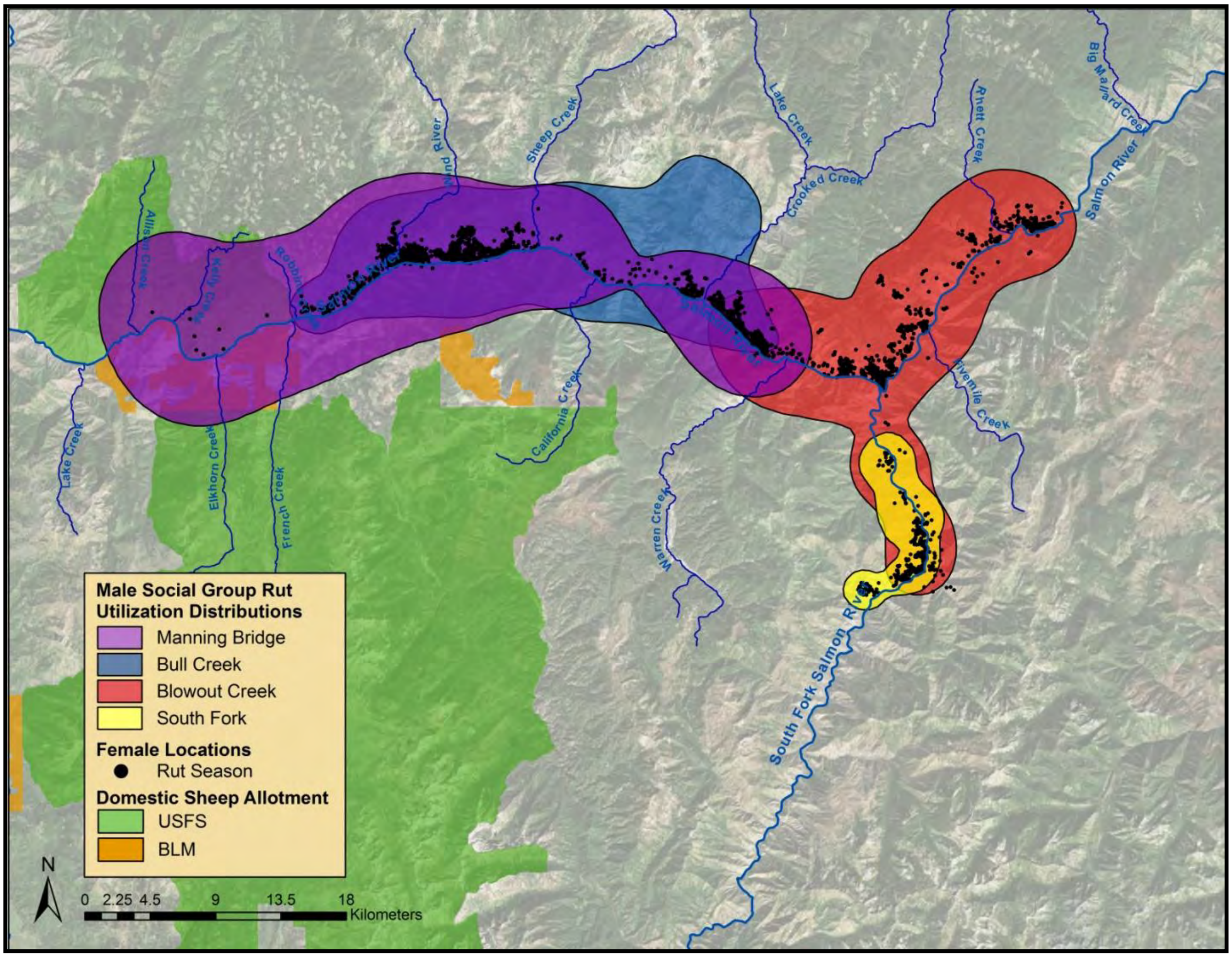

Figure 22. Rut (1 October–31 December) seasonal use area estimates for 4 male social groups and rut season locations of female radio-collared bighorn sheep in 5 female social groups along the Salmon River, ID, USA, 2007–2015. During the rut season males interact with multiple male and female social groups, resulting in a high level of population connectivity.

South Fork Social Groups. South Fork female and male groups appeared to be more isolated from main stem groups. Although South Fork Ewes shared an adjacent border with neighboring main stem Jersey Creek, we were unable to document interactions between these 2 groups based on movements of collared study animals (n = 17 animals). We suspect the Salmon River, may provide a behavioral barrier between these 2 groups. Likewise, we did not document collared South Fork Rams (n = 2) traveling to main stem ram or female groups, and only 1 of 10 adjacent Blowout Creek males interacted with the South Fork Ewes group during rut. Since South Fork groups share use area boundaries with adjacent main stem groups, some level of connectivity is likely albeit limited (given observed interactions of collared animals; 1 of 29,3%) compared to connectivity among main stem groups.

In a related project-sponsored study, Borg et al. (2017) evaluated behavioral connectivity of social groups within the project area to gain a better understanding of the potential for disease spread within the population. Borg et al. used a multi-state mark-recapture model to estimate transition probabilities (probability that a bighorn sheep from one group would move to another adjacent group) for collared animals in the project area. Monthly transition probabilities were developed for each pair of adjacent groups. Results of Borg et al.'s model-based study were consistent with telemetry-based finding of this project. They found evidence of connectivity among groups of both sexes, with males generally having higher probabilities of transition than females. Female transition probabilities (0.05–0.24) did not change significantly through the year ($\overline{x}_{\text{summer}}$ = 0.09, $\overline{x}_{\text{winter}}$ = 0.07) and male transition probabilities (0.0–0.76) were nearly 4 times higher during rut ($\overline{x}_{\text{summer}}$ = 0.12, $\overline{x}_{\text{winter}}$ = 0.41). Monthly transition probabilities between South Fork groups and Blowout Creek/Jersey Creek were low, ranging from 0.00–0.01 for females and 0.00–0.05 for males. Borg et.al concluded female groups did interact, but to a lesser degree than ram and female groups; male movements during the rut were the primary drivers of population connectivity within the project area; and main stem male and female groups were well connected, but connectivity between South Fork groups and main stem groups was limited.

Population connectivity can have important consequences for disease spread with higher levels of connectivity facilitating spread of disease. High level of connectivity between social groups observed in the project area would likely facilitate disease spread throughout the population. The potential for contact between domestic and bighorn sheep sharing overlapping range in the western portion of the project area was a concern for disease transmission and consequent spread throughout the population. Observed levels of connectivity between groups would also facilitate maintaining chronic disease within the population.

GENETIC STRUCTURE, DIVERSITY, AND CONNECTIVITY

Bighorn sheep in the Salmon River drainage represent the last remaining native populations in Idaho. Their genetic uniqueness is of management and cultural importance. Multiple bighorn sheep populations are generally recognized within the Salmon River drainage and modeled bighorn sheep habitat is continuous facilitating a metapopulation structure, but population boundaries and the extent on connectivity remained unknown. Whether populations are structured in a larger regional metapopuation is of importance as the degree of connectivity can have important management and demographic implications by influencing vital rates, spread of disease, and probability of persistence across multiple populations and regional landscapes.

In a project-sponsored study, Borg (2014) used genetic methods to identify population boundaries, level of connectivity among populations, and relative contribution of females and males to connectivity for bighorn sheep within the Salmon River Drainage.

Borg employed nuclear DNA microsatellite analysis to identify populations based on genetic relatedness and mitochondrial DNA sequencing and haplotype mapping to determine population boundaries. Connectivity among populations was assessed using a combination of methods: (a) comparing differences in genetic structure (reflecting the amount of gene flow) among populations using a fixation index, (b) identifying migrants (animals found in populations other than the one they originated from) using genetic assignment tests, and (c) quantifying number of shared haplotypes (individuals of common ancestry) among populations. Gender-specific contributions to population connectivity were assessed by comparing relative gene flow among populations attributed to males vs. females.

Genetic samples, including horn shavings, blood, fecal pellets, tissue, and hair, were collected from adjacent bighorn sheep populations occurring to the west (downstream) and east (upstream) of the Lower Salmon River population. Samples were collected from the Idaho portion of Hells Canyon metapopulation along the Snake River to the west and the Salmon River drainage and tributaries upstream to Sunbeam, ID, including the Lemhi, Lost River, and Beaverhead mountain ranges.

Based on genetic analysis, Borg identified 4 populations; from west to east (downriver to upriver) they were Hells Canyon, Lower Salmon, Upper Salmon, and Lost River (Fig. 23). The Lower Salmon River population was geographically more isolated from Hells Canyon than from Upper Salmon River, although geographic separation from Upper Salmon River was recognized above Mallard Creek despite continuous modeled habitat. Borg speculated observed geographic separation between these 2 populations may be due to variation in habitat quality and/or behavioral barriers.

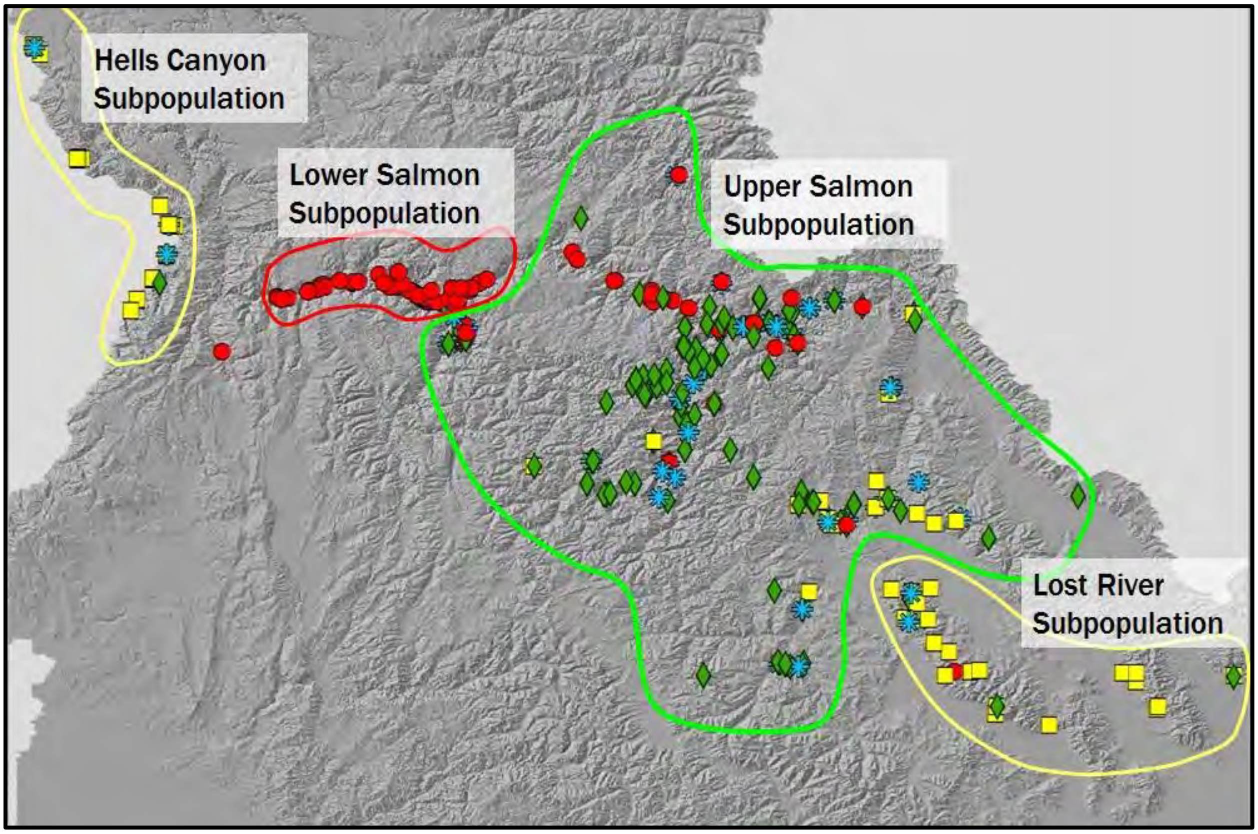

Figure 23. Four subpopulations across central Idaho as defined by program STRUCTURE. From west to east, Hells Canyon, Lower Salmon, Upper Salmon, and Lost River. Asterisks are individuals with mixed ancestry. Figure Courtesy of Borg 2014.

The Lower Salmon River population appeared to be more genetically isolated than other populations. Genetic diversity was lower relative to other populations but not to the point of concern over population fitness or impacting demographic rates. Borg speculated genetic diversity in this population may be normal for native populations and other Salmon River populations may have artificially high genetic diversity due to translocations of bighorn sheep from multiple disparate source populations outside the Salmon River drainage.

Borg found moderate to high levels of genetic connectivity among populations. Connectivity was lowest between the Lower Salmon River population and Hells Canyon based on estimates of gene flow and he did not detect migrants into or out of Hells Canyon. Connectivity was higher among the 3 Salmon River drainage populations and 10 migrants were detected moving among all 3 populations. One migrant from the Lower Salmon River population was genetically detected in the upriver-most Lost River population, an estimated distance of 200 km. Estimates of genetic connectivity were higher than published for other desert or Rocky Mountain bighorn sheep populations despite greater geographic distances. Borg speculated higher degree of connectivity in the Salmon River drainage was due to contiguous habitats with little anthropogenic impacts compared to other studies. Alternatively, high levels of observed genetic connectivity despite geographic distance may be, in part, an artifact of translocation history; the relative influence of habitat and anthropogenic factors on observed genetic connectivity is unknown. Interestingly, Borg proposed evidence for higher levels of historic connectivity, identifying one haplotype widespread among the 3 Salmon River populations that suggested historic connectivity throughout the Salmon River drainage. Borg speculated past disease-related die-offs and drainage-wide population reductions may explain, at least in part, current geographic distribution and separation, and resulting genetic differences and connectivity among Salmon River populations.

Bighorn sheep in the South Fork reach of the project area were genetically grouped with (most closely genetically related to) the Upper Salmon River population and were identified as the next most genetically distinct group. Borg's findings agree with our findings based on collared animals that female and male groups in the South Fork reach have little interaction with main stem groups despite sharing use area boundaries. Borg was not able to include a spatial parameter to his findings, confounding some results, as inter-population connectivity may and likely has changed through time. For example, the proposed current behavioral isolation between adjacent South Fork and main stem groups has likely not been static and will likely not persist indefinitely. Additionally, given close proximity some level of contemporary interchange is expected. We documented 1 collared male from the adjacent Blowout Creek group interacting with South Fork groups during the rut season. Borg et al. (2017), using data from this project, estimated the transition probability of an animal moving from an adjacent main stem group to a South Fork group to be <5%, and Borg detected 4 migrants between main stem and South Fork groups, providing evidence of some, albeit low, level of contemporary connectivity.

Based on degree of genetic relatedness, Borg suggested connectivity among populations may be mediated by both females and males for distances up to 30 km but predominantly male mediated for greater distances up to 50 km. These conclusions agree well with telemetry-based findings, but suggest females and males can interact over greater distances than documented by collared study animals.

OVELAP AND RISK OF CONTACT WITH DOMESTIC SHEEP

METHODS

Spatial and Temporal Overlap

Spatial overlap between domestic and bighorn sheep was assessed by overlaying group use areas and active allotment boundaries (permitted use in 2007) in ArcMap. Spatial overlap was quantified by calculating the percentage of bighorn sheep use areas overlapped by active allotments. Temporal overlap was assessed by correlating times of year when domestic sheep were present on allotments to temporal use patterns of bighorn sheep within the allotments.

Risk of Contact

Risk of contact between domestic and bighorn sheep was investigated by the PNF during development of the 2010 FSEIS (USFS 2010*a*). This effort amended the Forest Plan to address bighorn sheep viability on the Forest. In the FSEIS, risk of contact modeling was described in Appendix L: Modeling and Analysis Technical Report, and results presented in Chapter 3 – Affected Environment. A brief summary of this work is presented here.

RESULTS

Spatial and Temporal Overlap

Federal lands domestic sheep allotments administered by the BLM, PNF, and NPCNF occurred in the western portion of the project area (Fig. 2). Two allotments, Allison Berg administered by the NPCNF and Partridge Creek administered by the BLM overlapped all or portions of 3 bighorn sheep social group use areas (Figs. 13 and 15). These allotments, located within the breaks of the Salmon River canyon, encompassed a large contiguous block of habitat separated by the Salmon River; the Allison Berg allotment on the north side and Partridge Creek allotment on the south side of the river. Both allotments included substantial amounts of mapped bighorn sheep source habitat. The 150 km2 Allison Berg allotment included 53 km2 of summer and 49 km2 of winter bighorn sheep habitat while the 37 km2 of BLM ownership within the Partridge Creek allotment included 12 km2 of summer and 11 km2 of winter bighorn sheep habitat.

A small (1%) western-most portion of the Wind River ewe group use area overlapped the Allison Berg allotment. Although Wind River members were located within the allotment infrequently (<1% of locations) they were detected within the allotment in 4 of 8 monitored years. Manning Bridge Rams' non-rut season use area was almost completely overlapped by the Allison Berg (69%) and Partridge Creek (21%) allotments and all but a very minor portion of the remaining area, under private ownership, was also grazed by domestic sheep. Members of the Manning Bridge Rams group spent the majority of the non-rut season within the Allison Bert allotment; 98% of non-rut season locations were within the allotment and members were detected within the allotment during all monitored years. Members were located within the Partridge Creek allotment infrequently (<1% of locations) but in 4 of 8 monitored years. Manning Bridge Ewes became established within the Manning Bridge area in 2013 and were located within the Allison Berg allotment year-round. We did not have sufficient data to construct a use area, but all telemetry locations and observations of this group were within the Allison Berg allotment.

In 2007, prior to the start of this project, both allotments permitted extended summer and winter grazing seasons. Domestic sheep were present on these allotments for most of the year from April through July during the summer and from October through November (Partridge) or March (Allison Berg) during the winter. Temporal overlap between domestic and bighorn sheep within allotments was high as bighorn sheep were documented using areas within (Allison Berg) or within or adjacent to (Partridge Creek) allotments during all permitted grazing months.

Risk of Contact

The PNF developed a risk-of contact model to assess potential contact between bighorn and domestic sheep during the summer domestic sheep grazing season (O'Brien 2014). The model had 3 main components: (1) a core herd home range (CHHR) analysis, (2) a foray analysis, and (3) the bighorn sheep source habitat model described above (see Habitat Modeling section). The CCHR analysis developed summer core herd home ranges for 12 previously identified bighorn sheep populations in the Hells Canyon metapopulation and 3 in the Salmon River drainage including the Lower Salmon River population. Telemetry locations collected from these populations were used to develop 95% utilization distributions using a fixed kernel home range estimator with Home Range Extension version 1.1 in ArcGIS (ESRI, Redlands, CA).

Foray movements outside the CHHR were modeled based on movements of collared bighorn sheep in the Hells Canyon metapopulation. The foray analysis predicted average frequency and distance (up to 35 km, the greatest foray distance recorded in the dataset) of summer foray movements for female and male bighorn sheep.

The source habitat model was used to develop a resource selection function that classified habitat proportional to the probability of its use by bighorn sheep. All areas within 35 km of a CHHR were assigned to one of three habitat classes: source habitat, connectivity area, and non-habitat. Relative preference for each habitat class was evaluated using the distribution of telemetry locations of collared animals, relative to each habitat class.

Model elements were combined to estimate the probability of a bighorn sheep from any CHHR moving into any active domestic sheep allotment on the forest (Fig. 24). Contact between domestic and bighorn sheep was assumed if (a) CHHR and active allotment boundaries overlapped or (b) a bighorn sheep traveled into an active allotment.

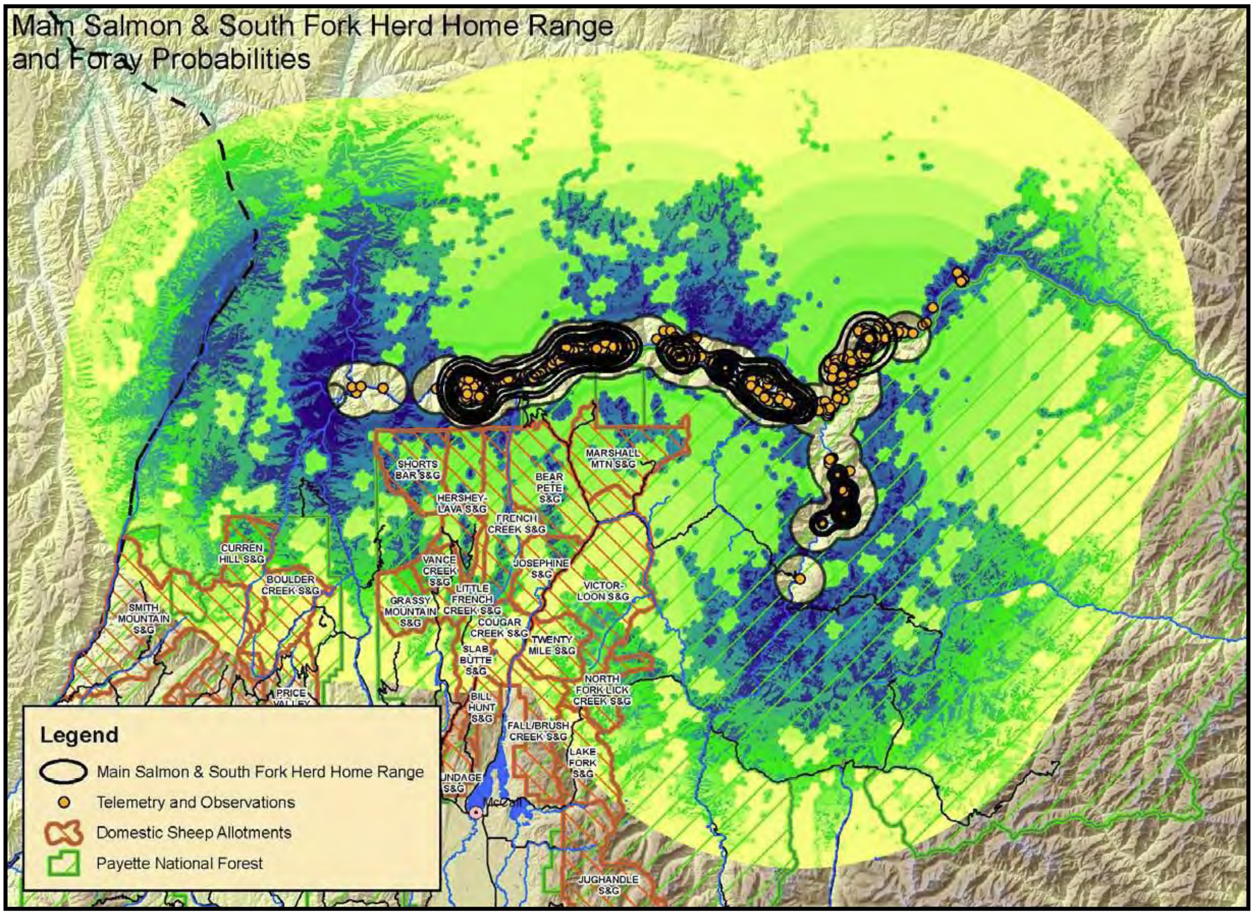

Figure 24. Modeled risk of contact probability for bighorn sheep in the Salmon River, ID, USA 2010. Figure courtesy of the USFS Payette National Forest, McCall, ID, USA (USFS 2010). Darker shading denotes greater probability of risk of contact between domestic and bighorn sheep.

The model based risk of contact solely on movements of bighorn sheep contacting domestic sheep. The model did not account for movements of stray domestic sheep coming into contact with bighorn sheep. Straying domestic sheep can move long distances from assigned allotments and can persist on the landscape after permitted seasons of use (Coggins 2002, WAFWA 2012). Straying domestic sheep are commonly reported for bands grazing in the project area, posing an additional risk of contact with bighorn.

The PNF developed a disease model using @RISK (@RISK 2009, Palisade Corporation, Ithaca, NY, USA) to make inferences about disease transmission from domestic to bighorn sheep and bighorn sheep population persistence (Carpenter 2014). The model included 4 bighorn sheep components: (1) probability of moving into an active domestic sheep allotment, (2) probability of contracting respiratory disease within an allotment and initiating an outbreak in the CHHR of origin, (3) projected population growth of the CHHR of origin depending on disease status (disease-free or infected), and (4) the magnitude and duration of a disease outbreak. Probability of a bighorn sheep encountering an active allotment was modeled by the risk-of-contact model. Due to a lack of empirical data, probability of contracting disease given contact, and initiating a disease outbreak was modeled for a range of values between 5–100%. A minimum viable population size of >30 animals was used. Magnitude and duration of a disease outbreak was modeled using disease data from the Hells Canyon metapopulation and the literature. Model simulations were run for a 100 year time frame. Modelers recognized a high degree of uncertainty in modeled results because of a lack of empirical data on bighorn sheep disease mechanisms and the wide range of observed disease-caused impacts in free ranging bighorn sheep populations.

Under domestic sheep grazing management direction prior to the 2010 Forest Plan amendment, the PNF estimated bighorn sheep in the Lower Salmon River population had a high (100%) probability of annual contact with active allotments on the PNF and a high (37-100%) probability of extirpation. The 2010 ROD (USFS 2010*c*) finalized the Forest Plan amendment and implemented new management direction for domestic sheep grazing. The PNF projected new management direction would decrease risk of contact to 4% and probability of extirpation to 2–29%.

The BLM and NPCNF administered domestic sheep grazing allotments are closer in proximity to Lower Salmon River bighorn sheep range relative to those administered by the PNF. As part of a cumulative effects analysis, the PNF applied their modeling approach to estimate a 149% probability of annual contact between Lower Salmon River bighorn sheep and active BLM and NCNF allotments, including other smaller private farm flocks under management direction prior to this project. The PNF concluded the Lower Salmon River population would have a low probability of persistence without a regional effort to address risk of contact across BLM, NCNF, and PNF administered allotments.The BLM Cottonwood office conducted a similar analysis while amending their Management Plan (BLM 2016*a*). Under grazing management conditions prior to the amendment process, their analysis predicted a 113% chance of annual contact between bighorn sheep and at least 1 of 4 BLM allotments analyzed, primarily due to close proximity between occupied bighorn sheep range and the Partridge Creek allotment. The amended Management Plan was adopted in 2017. New management direction, which included discontinuing domestic sheep grazing on the Partridge Creek allotment, was projected to reduce risk of contact to <1%.

POPULATION DEMOGRAPHICS

Given the history of pneumonic respiratory disease in our study population, we assessed population performance to provide baseline measures for future monitoring. We assessed population health; lamb production, survival, and recruitment; adult mortality and survival; and population size as measures of population performance.

POPULATION HEALTH

Numerous bacteria, viruses, and parasites have been reported to cause disease in bighorn sheep, many of which have their origin in domestic livestock and are common diseases affecting primarily domestic sheep and cattle (Jessup 1985, Dubay et al. 2002). For many of these pathogens, significance to bighorn sheep health is poorly understood and inferred from studies on domestic livestock. While most are thought to have low morbidity in bighorn sheep by themselves, in combination, they may cause population level effects including reduced reproductive potential, mortality, and population decline. Respiratory disease, primarily pneumonia, has been implicated in west-wide population reductions and extirpations since the late 1800s and is widely viewed as the single most important hurdle to range-wide recovery in the western United States (see Disease Transmission section).

Health monitoring is important for interpreting and managing population performance at the local population or metapopulation level; planning successful transplant operations when moving animals between jurisdictions, geographic locations, and populations; and obtaining a broader understanding of west-wide impacts of disease and potential for restoration. We tested for pathogens commonly found, tested-for, and/or implicated in bighorn sheep diseases across the western states in coordination with the Western Association of Fish and Wildlife Agencies' Wildlife Health Committee 2014 Bighorn Sheep Herd Health Monitoring Recommendations (WAFWA 2015).

Methods

Health samples were collected from adult bighorn sheep during capture and collaring operations. Most animals appeared in good health based on external physical assessment. Body condition scores were obtained for about half of the captured animals (42 of 82 captures) and 69% were considered to be in good to excellent health with body condition scores $\geq$2.5. Health samples were transported to the IDFG Wildlife Health Laboratory, Caldwell, ID and were assigned unique identification numbers. Blood samples were centrifuged and serum and plasma were separated and placed into sterile cryovials.

Serum samples were sent to the Idaho State Department of Agriculture Animal Health Laboratory, Boise, ID, for serological tests for a variety of bacterial and viral pathogens and to the Washington Animal Disease Diagnostic Laboratory (WADDL), Pullman, WA, for serological testing for the bacteria *Mycoplasma ovipneumoniae*.

Samples were tested for antibodies to bacterial diseases including Anaplasmosis using a competitive enzyme linked immunosorbent assay (cELISA), for *Brucella ovis* (*B. ovis*) using a direct ELISA assay, and for Leptospirosis using a microscopic agglutination test. Samples were tested for viral diseases including bovine viral diarrhea (BVD), bovine respiratory syncytial virus (BRSV), infectious bovine rhinotracheitis (IBR), and parainfluenza 3 (PI3) using a serum neutralization test; bluetongue (BTV) using cELISA (2007–2012 samples) and agar gel immunodiffusion (AGID, 2013 samples) assays; for epizootic hemorrhagic disease (EHD) using AGID diagnostic tests; and for ovine progressive pneumonia (OPP) using a direct ELISA test.

Samples were tested for antibodies to *M. ovipneumoniae* using 2 tests, passive hemagglutination for samples collected from 2007-2008 and cELISA assays for samples collected form 2008–2013. Although both tests allowed quantification of antibody levels within samples their units of measure were not comparable. Therefore we recoded results into 3 broad categories – detected, indeterminate, and not detected – to allow comparison of results across tests. Samples collected in 2008 were tested using both methods to calibrate standardized category intervals for each method.

Fecal samples and ear swabs were sent to WADDL for endo- and ectoparasite identification. Fecal samples were tested using saturated sugar floatation to detect eggs of *Capillaria spp.*, strongyles, *Nematodirus spp.*, *Skrjabinema spp., Trichuris spp and coccidia*. Feces were tested using a Baerman test to detect *Protostrongylus spp. and e*ctoparasites were identified from ear swabs.

Plasma and whole blood samples were sent to WADDL for trace mineral analyses. We tested levels (ug/g or ppm) of calcium, copper, iron, magnesium, phosphorus, zinc, and selenium. We tested differences in mean concentrations between sexes using a two-sample *t*-test for each element except selenium, for which a Mann-Whitney U test was used due to data normality issues. Because of data normality and small sample size issues, a Kruskal-Wallace test was used to determine differences among social groups for each element. Low sample size precluded Manning Bridge Ewes ($n = 1$) and South Fork Rams ($n = 2$) from this analysis. P values <0.05 were considered significant for all tests. We compared our test results to reference ranges developed for Rocky Mountain (Puls 1994) and desert bighorn sheep in California (Poppenga et al. 2012).

Nasal and oro-pharyngeal swab samples were sent to the University of Idaho Caine Veterinary Teaching Center (CVTC), Caldwell, ID for bacterial identification with emphasis on bacteria thought to be associated with pneumonic epizootics in bighorn sheep. Bacteria in the Pasteurellacae group were identified by growth characteristics on blood agar plates and biochemical tests to *Bibersteinia trehalosi*, *Mannheimia haemolytica*, and *Pasterella multocida*. Nasal and oro-pharyngeal swabs were cultured for *Mycoplasma spp. at CVTC. S*amples were also tested by various polymerase chain reaction (PCR) methods to detect *Mycoplasma spp*., *M. arginini*, and *M. ovipneumoniae*. Testing by PCR was conducted at CVTC and WADDL.

<u>Results</u>

We tested blood samples from 79 study animals (41 females, 38 males) from 2007–2013. Not all animals were tested for all pathogens; sample sizes ranged from 72–79 animals per test.

Sampled study animals had either no or low detected exposure rates to most of the pathogens we tested and no temporal pattern of prevalence was observed across sampled years (Table 20). We found no antibodies against IBR or OPP in our sample, and low prevalence rates for EHD (1%), B. ovis (3%), BT (3%), BVD (4%), BRSV (14%), and Leptospirosis (14%). Pathogens with low prevalence rates were not detected every year (1 to 3 of 7 sampled years).

No spatial pattern in seropositive animals was evident for these pathogens although B. ovis, Leptospirosis and BRSV (found in 2–6 groups distributed throughout the project area) appeared to be more widespread than BVD (found only in downstream Manning Bridge Rams group) or BT and EHD (found only in the upstream Jersery Creek group, Table 21). All Leptospirosis serovars except *Leptospira bratislava* were detected, but titers were low ($\leq$200) suggesting insignificant infection rates for this disease. All BVD seropositive samples came from 3 Manning Bridge males sampled in 2010 with titers ranging from 32–128. Although only one study animal (R6, Blowout Creek, upper-main stem) tested seropositive for BRSV in 2007, titers (256) indicated a possible recent exposure. Interestingly all animals seropositive for BRSV in 2012 were from the lower-main stem Manning Bridge male and Wind River female groups. All tested females and 1 of 3 tested males had titer levels (256) indicating possible recent exposure. Home ranges of these groups were within and adjacent to an active cattle allotment.

Antibodies against Anaplasmosis were detected in all but 1 year (2012) of testing. No temporal or spatial pattern in prevalence was detected but exposure appeared widespread. Detection occurred in all groups except Manning Bridge Ewes and South Fork Rams, although only 1–2 animals were tested during a single year for these 2 groups. Prevalence rates ($\overline{x}$ = 41%) were below the mean rate for all groups except Indian Creek (85%) and Blowout Creek (67%).

Table 20. Number of animals sampled (n) and prevalence (% pos) of antibody titers to bacterial and viral diseases in adult bighorn sheep along the Salmon River, ID, USA, 2007-2013.

	Mycoplasma Ovipneumonia		Anaplasmosis		BRSV[a]				PI3[a]			
YEAR	*n*	% pos[b]	*n*	% pos	*n*	% pos	Titer $\bar{x}$	Titer Range	*n*	% pos	Titer $\bar{x}$	Titer Range
2007	10	100	9	56	10	20	256	256 - 256	9	44	27	16 - 64
2008	20	90	20	35	21	0	-	-	21	91	66	8 - 256
2009	1	100	3	33	3	100	16	8 - 32	3	100	64	32 - 128
2010	11	100	11	27	11	0	-	-	11	100	88	32 - 128
2011	11	100	13	62	13	0	-	-	13	0	-	-
2012	6	100	6	0	7	86	74	4 - 256	7	100	43	16 - 128
2013	13	100	14	50	14	0	-	-	14	86	102	4 - 256
All Years	72	97	76	41	79	14	60	4 - 256	78	72	68	4 - 256

Table 20. (cont...)

	Leptospirosis		*B. ovis*[a]		BVD[a]		IBR[a]		BT[a]		EHD[a]		OPP[a]	
YEAR	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos
2007	9	11	9	0	9	0	9	0	9	0	9	0	9	0
2008	20	15	21	5	21	0	21	0	20	0	20	0	20	0
2009	3	0	3	0	3	0	3	0	3	0	3	0	3	0
2010	11	0	10	10	11	27	11	0	11	0	11	0	11	0
2011	13	8	13	0	13	0	13	0	13	15	13	8	13	0
2012	7	0	7	0	7	0	7	0	7	0	7	0	7	0
2013	14	43	13	0	14	0	14	0	14	0	14	0	14	0
All Years	77	14	76	3	78	4	78	0	77	3	77	1	77	0

[a] BRSV = bovine respiratory syncytial virus, PI3 = parainfluenza 3 virus, *B. ovis* = *Brucella ovis* bacteria, BVD = bovine viral diarrhea virus, IBR = infectious bovine rhinotracheitis virus, BT = bluetongue virus, EHD = epizootic hemorrhagic disease virus, OPP = ovine progressive pneumonia virus.
[b] % pos = percent of sero positive test results

Table 21. Sample size (years and animals), and prevalence (percent of seropositive test results) of antibody titers to bacterial and viral diseases in adult bighorn sheep belonging to 9 social groups and 1 wandering yearling male (R16) along the Salmon River, ID, USA, 2007–2013.

Social Group / AID	No. Years sampled	No. Animals sampled	*M. ovi*[a]	Ana[a]	BRSV[a]	PI3[a]	Lepto[a]	*B. ovis*[a]	BVD[a]	IBR[a]	BT[a]	EHD[a]	OPP[a]
Manning Br. Ewes	1	1	100	0	0	100	0	0	0	0	0.	0	0
Manning Br. Rams	4	9	100	21	20	93	0	7	20	0	0	0	0
Wind River	6	10	100	18	27	91	9	0	0	0	0	0	0
Bull Creek	6	6	100	38	22	75	38	0	0	0	0	0	0
Indian Creek	6	13	100	85	8	69	15	0	0	0	0	0	0
Blowout Creek	4	10	100	67	11	44	22	11	0	0	0	0	0
Jersey Creek	3	8	100	38	13	25	0	0	0	0	25	13	0
South Fork Ewes	2	10	100	33	0	78	33	0	0	0	0	0	0
South Fork Rams	1	2	100	0	0	100	0	0	0	0	0	0	0
R16	1	1	0	0	0	100	0	0	0	0	0	0	0

[a] M.ovi = *Mycoplasma ovipneumonia*, Ana = Anaplasmosis, BRSV = bovine respiratory syncytial virus, PI3 = parainfluenza 3 virus, Lepto = Leptospirosis, *B. ovis* = *Brucella ovis* bacteria, BVD = bovine viral diarrhea virus, IBR = infectious bovine rhinotracheitis virus, BT = bluetongue virus, EHD = epizootic hemorrhagic disease virus, OPP = ovine progressive pneumonia virus.

Seropositive results for PI3 were obtained for all years except 2011. Tested animals had high seroprevalence rates ($\overline{x}$ = 72%, range = 86–100%) for all years detected except 2007 (44%), and exposure to PI3 was widespread occurring across all groups. Except for 2011, when no seropositive animals were detected, antibodies against PI3 were detected in all groups for all years tested except for Bull Creek and Blowout Creek in 2007. Although seroprevalence was widespread and prevalence rates varied among groups, no strong temporal or spatial pattern was observed (Table 22). Although most groups had low titer levels, and no obvious spatial or temporal pattern was observed, some groups provided evidence of recent exposure with titer levels between 128 and 256. Observed maximum titers of 128 and 256 were scattered across years and groups with no discernible pattern. Annual geometric titer means across all animals varied ($\overline{x}$ = 69, range = 26.9–101.6) with a possible increasing trend for the 2007-2013 project period. All animals were seropositive for *M. ovipneumoniae* except R16, a wandering yearling male discovered along the Little Salmon River whose origin was unknown.

Table 22. Geometric means and ranges of antibody titers against parainfluenza 3 virus of sero positive adults in 9 bighorn sheep social groups and 1 wandering yearling male (R16) along the Salmon River, ID, USA, 2007-2013.

	2007		2008		2009		2010		2011		2012		2013		All Years	
Social Group / AID	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range
Manning Br Ewes	-	-	-	-	-	-	-	-	-	-	256	n/a	-	-	256	n/a
Manning Br Rams	-	-	32	8 - 64	-	-	78	32 - 128	-	-	20	16 - 32	4	n/a	39	4 - 128
Wind River	64	n/a	81	64 - 128	-	-	128	n/a	-	-	76	64 - 128	256	n/a	91	64 - 256
Bull Creek	-	-	81	64 - 128	128	n/a	128	n/a	-	-	-	-	256	n/a	114	64 - 256
Indian Creek	23	16 - 32	64	64 - 64	32	n/a	128	n/a	-	-	-	-	91	64 - 128	54	16 - 128
Blowout Creek	-	-	81	32 - 256	-	-	64	n/a	-	-	-	-	-	-	76	32 - 256
Jersey Creek	16	n/a	-	-	64	n/a	-	-	-	-	-	-	128	n/a	51	16 - 128
South Fork Ewes	-	-	32	16 - 64	-	-	-	-	-	-	-	-	111	64 - 128	78	16 - 128
South Fork Rams	-	-	91	64 - 128	-	-	-	-	-	-	-	-	-	-	91	64 - 128
R16	-	-	256	n/a	-	-	-	-	-	-	-	-	-	-	256	n/a
All Groups	27		66	8 - 256	64	-	88	32 – 128	-	-	43	16 – 128	102	64 - 128	68	4 - 256

We tested fecal samples from 74 study animals (39 females, 35 males) and ear swabs from 77 study animals (40 females, 37 males) from 2007–2013. Not all animals were tested for all endoparasites; sample sizes ranged from 67 to 70 animals per test.

Eggs and larvae of various endoparasites were found in sampled study animals (Table 23). Ova of *Capillaria spp.*, *Skrjabinema spp.*, and *Trichuris spp.* were found in low prevalence and intensity (Table 24). Ova of *Capillaria spp.* and *Skrjabinema spp.* were detected in 1 (2007) and 2 (2007, 2008) sample years respectively, and both were detected in 2 groups (Wind River and Blowout Creek, and Manning Bridge Rams and Indian Creek respectively; Table 25). Ova of *Trichuris spp.* were more widespread detected in 4 of 7 sample years and occurring across all but Manning Bridge Ewes and Wind River. No temporal or spatial pattern was observed across years or groups.

Mean prevalence rates for coccidian (21%) and strongyles (43%) showed that both parasites were wide spread across most sample years and groups. Oocysts of Coccidia were found in low numbers for all years detected except 2007. Higher counts in 2007 were collected across multiple groups including male R3 from Blowout Creek with a coccidia count of 1480 oocysts/g feces. Strongyles eggs were found in low numbers. No temporal or spatial pattern in prevalence or numbers of these parasites was observed.

A high prevalence of *Nematodirus spp.* (73%) and *Protostrongylus spp.* (69%) was generally detected across all years and groups (Tables 21–23). Although prevalence was high, intensity rates of *Nematodirus* eggs and *Protostrongylus* larvae were low ($\overline{x}$ = 9.2 eggs/g feces and 30.2 larvae/g feces respectively). No temporal or spatial patterns were observed. Scabies mites (*Psoroptes spp*.) were found in ear swabs of 7 of 77 (10%) sampled animals and 4 of 9 (44%) social groups.

Table 23. Number of animals sampled (n) and prevalence (% pos, percent positive test results) of endoparasite larvae and eggs in feces and ectoparasite psoroptes mites in ears of adult bighorn sheep sampled during winter along the Salmon River, ID, USA, 2007-2013.

	Protostrongylus spp.		*Capilaria spp.*		Coccidia		Strongyles		*Nematodirus spp.*		*Skrjabinema spp.*		*Trichuris spp.*		*Psoroptes spp.*	
Year	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos
2007	9	78	6	33	6	83	6	33	6	68	6	33	6	17	11	0.0
2008	17	59	19	0	16	13	19	53	19	47	19	16	19	26	19	16
2009	1	0	1	0	1	100	1	0	1	0	1	0	1	0	3	33
2010	10	50	11	0	11	9	11	55	11	100	11	0	11	0	11	9
2011	12	92	13	0	13	23	13	31	13	69	13	0	13	15	13	15
2012	6	68	6	0	6	33	6	68	6	83	6	0	6	0	7	0
2013	13	77	14	0	14	0	14	29	14	93	14	0	14	21	13	8
All Years	68	69	70	3	67	21	70	43	70	73	70	7	70	16	77	10

Table 24. Mean intensity and range of endoparasite larvae and eggs found in winter feces of adult bighorn sheep along the Salmon River, ID, USA 2007-2013.

	Protostrongylus spp.		*Capillaria* spp.		Coccidia		Strongyles		*Nematodirus* spp.		*Skrjabinema* spp.		*Trichuris* spp.	
Year	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range
2007	6	1 - 24	3	2 - 3	430	30 - 1480	7	2 - 12	6	3 - 10	48	3 - 92	14	14 - 14
2008	92	4 - 334	-	-	1	1 - 2	9	1 - 30	11	1 - 24	16	3 - 36	7	1 - 20
2009	-	-	-	-	1	1 - 1	-	-	-	-	-	-	-	-
2010	42	3 - 140	-	-	1	1 - 1	14	2 - 54	12	2 - 25	-	-	-	-
2011	11	1 - 34	-	-	2	1 - 4	12	5 - 19	9	1 - 28	-	-	1	1 - 1
2012	8	3 - 18	-	-	2	1 - 3	24	3 - 81	6	1 - 12	-	-	-	-
2013	9		-	-	-	-	1	1 - 2	8	2 - 21	-	-	1	1 - 1
All Years	30	1 - 334	3	2 - 3	155	1 - 1480	11	1 - 81	9	1 - 28	29	3 - 92	5	1 - 20

Table 25. Number of animals sampled (n) and prevalence (% pos, percent positive test results) of endoparasite larvae and eggs in feces and ectoparasite psoroptes mites in ears of adult bighorn sheep in 9 social groups and 1 wandering yearling male (R16) sampled during winter along the Salmon River, ID, USA, 2007–2013.

	Protostrongylus spp.		*Capilaria spp.*		Coccidia		Strongyles		*Nematodirus spp.*		*Skrjabinema spp.*		*Trichuris spp.*		*Psoroptes spp.*	
Social Group / AID	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos	*n*	% pos
Manning Brdge Ewes	1	100	1	0	1	0	1	100	1	100	1	0	1	0	1	0
Manning Bridge Rams	13	54	13	0	13	8	13	54	13	92	13	15	13	8	14	21
Wind River	10	70	11	9	9	33	11	64	11	64	11	0	11	0	11	0
Bull Creek	7	100	7	0	7	29	7	29	7	71	7	0	7	14	9	22
Indian Creek	12	67	12	0	11	18	12	42	12	50	12	17	12	8	13	0
Blowout Creek	9	89	8	13	8	38	8	63	8	75	8	0	8	13	10	20
Jersey Creek	7	86	6	0	6	17	6	0	6	67	6	0	6	33	8	0
South Fork Ewes	7	43	9	0	9	11	9	22	9	100	9	0	9	33	8	13
South Fork Rams	2	0	2	0	2	50	2	50	2	50	2	0	2	50	2	0
R16	0	0	1	0	1	0	1	0	1	0	1	100	1	100	1	0
All Groups	68	6	70	3	67	21	70	43	70	73	70	7	70	16	77	10
Main Stem		75		3		21		46		70		9		12		11
South Fork		33		0		18		27		91		0		36		10

We tested blood samples for trace mineral concentrations. Samples were collected from 76 study animals (40 females, 36 males) during 2007–2013. Two of 76 animals (1 female, 1 male) were tested for Selenium only. When pooled across years and groups, mean concentrations of macroelements were within reference ranges given by Puls (1994) and Poppenga (2012), while those of microelements were below reference ranges of Puls but still within ranges given by Poppenga (except selenium concentrations which were generally below those reported by Poppenga; Table 26). This pattern held when comparing genders (Table 27).

Mean mineral concentrations were consistent across genders for all elements except copper. Copper levels were higher for males than females ($t_{42} = 4.58$, $P \leq 0.001$) primarily due to high concentrations in the male Bull Creek group.

Table 26. Number of animals sampled, and mean concentration, standard deviation, and range of trace minerals found in adult bighorn sheep along the Salmon River, ID, USA, 2007–2013.

Element	*n*	$\bar{x}$	SD	min.	max.	Range
Calcium	74	98.6	9.03	84.0	136.0	52.0
Copper[a]	74	0.90	0.29	0.50	1.90	1.40
Iron[a]	74	1.19	0.34	0.44	2.20	1.76
Magnesium	74	26.9	4.08	19.0	39.0	20.0
Phosphorus	74	54.2	11.73	28.2	77.6	49.4
Selenium[a]	76	0.08	0.06	0.02	0.47	0.46
Zinc[a]	74	0.69	0.19	0.40	1.80	1.40

[a] Mean concentration below UIASL reference range

Table 27. Number of animals sampled, and mean concentration, standard deviation, and range of trace minerals found in adult female and male bighorn sheep along the Salmon River, ID, USA, 2007–2013. Concentrations did not differ between sexes except for copper.

	Females						Males					
Element	*n*	$\bar{x}$	SD	min.	max.	Range	*n*	$\bar{x}$	SD	min.	max.	Range
Calcium	40	97.8	8.53	84.0	120.0	36.0	34	99.4	9.64	84.0	136.0	52.0
Copper[ab]	40	0.78	0.15	0.50	1.20	0.70	34	1.05	0.34	0.62	1.90	1.28
Iron[a]	40	1.24	0.34	0.44	2.20	1.76	34	1.14	0.33	0.60	2.00	1.40
Magnesium	40	27.4	3.88	21.0	37.0	16.0	34	26.4	4.30	19.0	39.0	20.0
Phosphorus	40	53.4	12.14	28.7	77.6	48.9	34	55.2	11.33	28.2	73.3	45.1
Selenium[a]	41	0.09	0.08	0.02	0.47	0.45	35	0.08	0.05	0.02	0.19	0.18
Zinc[a]	40	0.64	0.14	0.40	0.96	0.56	34	0.74	0.24	0.40	1.80	1.40

[a] Mean concentration below UIASL reference range
[b] Copper concentrations higher for males than females

When assessed across social groups, mineral levels varied more widely than across years or between genders. Median social group concentrations differed for all elements except iron although no clear pattern among groups was observed. Mean concentrations were within ranges provided by Poppenga but below reference ranges provided by Puls for copper, iron, selenium, and zinc for all social groups except serum copper in Bull Creek and whole blood selenium in Manning Bridge Ewes and Wind River (Table 28).

Table 28. Number of animals sampled, and mean concentration, standard deviation, and range of trace minerals found in adult bighorn sheep belonging to 9 bighorn sheep social groups and 1 wandering yearling male (R16) along the Salmon River, ID, USA, 2007–2013.

Social Group / AID	*n*	Ca	Cu[a]	Fe[b]	Mg	P	Zn[b]	Se[c]
Manning Bridge Ewes	1	110.0	0.96	1.40	32.0	68.9	0.75	0.23
Manning Bridge Rams	14	102.0	1.01	1.17	28.7	60.1	0.64	0.11
Wind River	11	100.5	0.73	1.10	28.1	55.3	0.60	0.14
Bull Creek	8	104.0	1.34	1.05	25.9	57.8	0.94	0.04
Indian Creek	12	96.3	0.82	1.48	25.1	52.2	0.65	0.05
Blowout Creek	9	93.2	0.90	1.22	23.3	45.8	0.74	0.06
Jersey Creek	8	88.3	0.69	1.14	25.5	43.5	0.60	0.10
South Fork Ewes	8	104.5	0.84	1.17	31.1	60.6	0.72	0.04
South Fork Rams	2	94.8	1.10	0.88	26.0	47.2	0.72	0.03
R16	1	92.0	0.69	1.20	26.0	65.0	0.59	0.06
All Sheep		98.6	0.90	1.19	27.2	54.2	0.69	0.08

[a] Mean concentration below UIASL reference range for all social groups except Bull Creek
[b] Mean concentration below UIASL reference range
[c] Mean concentration below UIASL reference range for all social groups except for Manning Bridge Ewes and Wind River

We tested 55 (29 female, 26 male) nasal and oro-pharyngeal swab samples from 49 unique sheep (28 females, 21 males) for Pasteurellacae, and 64 (34 female, 30 male) samples from 54 unique sheep (32 females, 22 males) for Mycoplasmatacea. Samples were collected during 5 years including 2008 and 2010–2013.

Bibersteinia trehalosi was commonly found in high prevalence across all sampled years and all groups (Tables 29 and 30). A small percentage (2 of 46, 4%) of *B. trehalosi* isolates were beta-hemolytic. Prevalence of *M. haemolytica* varied (range = 10–60%) across years and was widespread occurring in all groups except Manning Bridge Ewes, although only 1 animal was sampled from this group. Over a third (8 of 23, 35%) of *M. haemolytica* isolates were beta-hemolytic. Prevalence was higher for earlier samples (2008 and 2010; $\overline{x}$ = 60%) compared to later samples (2011–2013; $\overline{x}$ = 24%) and declined from a high of 60% in 2010 to a low of 10% in 2013. Four of 6 (67%) *M. haemolytica* positive animals sampled in 2010 were beta hemolytic. Prevalence of *B. trehalosi* was higher for South Fork groups compared to main stem groups, while *M. haemolytica* was equally prevalent between the 2 project reaches. We did not isolate *P. multocida* from our samples.

Bacteria of the genus *Mycoplasma spp*. were commonly detected by PCR from across all sample years and groups (Tables 29 and 30). Prevalence was moderate to high across years (50–92%) and groups (33–100%) and averaged 67%. For samples that were positive for *Mycoplasma spp*., by PCR, both *M. arginini* and *M. ovipneumoniae* were identified by PCR. However, *M. arginini* was more common and likely accounted for the detections at the genera level, as it was found at similar prevalence across years and groups. We detected the presence of *M. ovipneumoniae* in all sampled years but generally at low prevalence. We detected low (5%) prevalence in 2008, a 10-fold increase (50%) in 2010, and a gradual decline to (7%) by 2013. Study animals testing positive for *M. ovipneumoniae* in 2010 were widespread throughout the project area, associated with Manning Bridge Rams, Indian Creek, and Blowout Creek. *M. ovipneumoniae* was detected in 5 of 7 main stem social groups including Manning Bridge Rams, Wind River, Indian Creek, Blowout Creek, and Jersey Creek; but was not detected in the South Fork groups. Mean prevalence was consistent across exposed groups (range = 20–33%).

Table 29. Percent prevalence of Pasteurellacaea and Mycoplasmataceae bacteria isolated from nasal and oro-pharyngeal swabs sampled from bighorn sheep along the Salmon River, ID, USA, 2007–2013.

	Pasteurellaceae Culture				Mycoplasmataceae PCR			
Year	*n*	*B. trehalosi*	*M. haemolytica*	*P. multocida*	*n*	*M. spp.*	*M. arginini*	*M. ovipneumoniae*
2007	0				0			
2008	20	85	60	0.0	20	50	50	5
2009	0				0			
2010	10[a]	90	60	0.0	10	90	50	50
2011	10	100	40	0.0	13	92	92	23
2012	6[b]	75	20	0.0	7	57	43	43
2013	10	90	10	0.0	14	57	57	7
All Years	55[c]	89	44	0.0	64	67	69	20

[a] $n_{P.\ \mathrm{multocida}} = 9$

[b] $n_{B. trehalosi} = 4$; $n_{M.\ haemolytica} = 5$

[c] $n_{B. trehalosi} = 54$

Table 30. Percent prevalence of Pasteurellacaea and Mycoplasmataceae bacteria isolated from nasal and oro-pharyngeal swabs sampled from bighorn sheep belonging to 9 social groups and 1 wandering yearling male (R16) along the Salmon River, ID, USA, 2007–2013.

	Pasteurellaceae Culture				Mycoplasmataceae PCR			
Social Group / AID	*n*	*B. trehalosi*	*M. haemolytica*	*P. multocida*	*n*	*M. spp.*	*M. arginini*	*M. ovipneumoniae*
Manning Bridge Ewes	1	100	0	0	1	100	100	0
Manning Bridge Rams	14[a]	77	62	0	15	73	60	27
Wind River	8[b]	100	38	0	10	70	60	20
Bull Creek	4	75	75	0	5	60	40	0
Indian Creek	6	83	17	0	9	78	78	33
Blowout Creek	5	80	60	0	6	67	50	33
Jersey Creek	6	100	17	0	6	83	83	33
South Fork Ewes	9	100	33	0	9	33	33	0
South Fork Rams	2	100	100	0	2	100	100	0
R16	1	100	0	0	1	0	0	0
Main Stem	45[c]	86	43	0	53	72	62	25
South Fork	11	100	46	0	11	46	46	0

[a] $n_{B. trehalosi} = 13$; $n_{M.\ haemolytica} = 13$

[b] $n_{B. trehalosi} = 7$

[c] $n_{B. trehalosi} = 43$; $n_{M.\ haemolytica} = 44$

Discussion

Bighorn sheep in our area were exposed to similar pathogens as reported for other populations in Idaho and across the west (M. Drew, IDFG, personal communication). Based on serologic tests, bighorn sheep in our project area appeared to have low exposure rates to many of the pathogens we assessed. Cassirer (2006) reported mean prevalence of antibodies to several viral and bacterial diseases for 8 herds from 1997–2006 in the Hells Canyon metapopulation. This author reported similar low prevalence for OPP (3%), EHD (2%), BT (1%), and BVD (4%), comparable higher prevalence for PI3 (68%), but lower prevalence for Anaplasmosis (14%) and BRSV (4%) than found in our project.

Although mean prevalence for Anaplasmosis found in our project area was higher than reported by Cassirer, observed range of prevalence across years in Salmon River bighorns sheep (0–62%) were similar to those reported for Hells Canyon (0–75%). As with our project, anaplasmosis in Hells Canyon was second to PI3 in prevalence and distribution. Anaplasmosis is a tick-borne disease considered widespread but thought to pose little direct health risk to bighorn sheep (Jessup et al. 1993, Dubay et al. 2002).

Bovine Respiratory syncytial virus (BRSV) is a common viral respiratory disease in cattle causing lung infections and mortality. It is also found in domestic sheep and is common in bighorn sheep populations range wide. Although BRSV is thought to cause low morbidity as a primary agent, it has been identified as a potential pathogen in bighorn sheep and isolated from pneumonia epizootics in Alberta, CA, Hells Canyon, and Montana (Miller et al. 2012, Dubay et al. 2002). Elevated levels of antibodies to BRSV found in our project area relative to those reported for Hells Canyon, and the potential pathogenicity of this virus as a co-determinant is of concern and warrants continued monitoring. Although we were not able to recapture animals at regular intervals, all recaptured animals that changed status (4 of 11 recaptures) with respect to BRSV changed from seronegative to seropositive.

PI3 is a common virus found in bighorn sheep populations and is considered of low pathogenicity alone but has been isolated in combination with other pathogens during respiratory pneumonia epizootic events. Elevated prevalence and titers against PI3 found in Salmon River bighorn sheep, combined with observed prevalence of *Mycoplasma ovipneumoniae*, is of concern and may be indicative of on-going chronic respiratory disease.

Bighorn sheep host a number of endo- and ectoparasites which can act as either primary pathogens or increase the susceptibility of infected animals to other diseases (Garde et al. 2005, Miller et al. 2012). Some parasites may be endemic while many others are thought to have originated through transmission from domestic livestock. Parasites may cause chronic low-intensity infections with subclinical symptoms; clinical but recoverable infections; or may act as primary or secondary agents causing epizootic outbreaks and mortality. As susceptibility to disease is often determined by a complexity of environmental determinants including changing habitat conditions, adverse weather events, and other pathogenic agents, the relationship between parasite fauna and its direct association with morbidity and mortality is not well understood (Miller et al. 2012, Hoberg et al. 2001). In addition, fecal counts of parasite eggs or larvae are indirect measures of infection intensity and the actual number of parasite infecting a host (Wilson et al. 2002).

Parasites we sought to identify in our sampled bighorn sheep include those reported pathogenic to either bighorn sheep or domestic livestock commonly sharing sympatric range with bighorn sheep (e.g., cattle, domestic sheep, and domestic goats). Although *Capillaria spp.* and *Skrjabinema spp.* were rarely detected, other endoparasites were commonly found across years and groups in the project area. No temporal patterns across years or spatial patterns across groups were observed for any parasite. Coccidia is a protozoan parasite causing coccidiosis, a disease in domestic sheep and goats and has been reported in bighorn sheep populations (Uhazy et al. 1971, Honess 1942). Strongyles include a group of common parasites of North American ruminants with many species found in bighorn sheep populations (Hoberg et al. 2001, Kistner et al. 1977). Trichuris is a common parasite of domestic sheep and goats that can be pathogenic to young of the year and some species are common in bighorn sheep (Garde et al. 2005). The pathogenicity of these parasites to bighorn sheep is either unknown or thought to be low as a primary agents, however, depending on infection intensity, they could predispose compromised animals to other diseases. Although prevalence was widespread for coccidia, strongyles and *Trichuris spp*., prevalence rates and intensities were low, suggesting low infection rates for these parasites during our sample period.

Protostrongylus spp and *Nematodirus spp* were found at high prevalence rates throughout the project area. *Protostrongylus spp*. (lungworm) are native endoparasites of bighorn sheep found range-wide except in extreme xeric habitats. These parasites commonly occur in high prevalence and have been associated with all-age die-offs (Miller et al. 2012; Festa-Bianchet 1988, 1991; Samson et al. 1987; Spraker and Hibler 1982; Kistner et al. 1977; Forrester 1971). Lungworm is thought to be a secondary agent predisposing infected animals to co-determinants such as viral or bacterial diseases (lungworm-pneumonia complex). They have caused die-offs reported in Colorado, Montana, and Alberta, CA. *Protostrongylus spp*. was widespread in high prevalence in our project area, similar to that reported in other studies. Intensity of this parasite in our project was intermediate from values reported elsewhere. Samson et al. (1987) reported mean intensity of winter pellets for a bighorn sheep population in Alberta, CA of 743 LPG, and Rogerson et al. (2008) reported high prevalence (90–97%) and median infection intensities of 13– 171 LPG for adults in 2 populations of bighorn sheep in northern Utah. Researchers reported prevalence rates between 13% and 42% for 9 herds with mean intensity ranging between 1 and 8 LPG for the adjacent Hells Canyon metapopulation in

Idaho, Oregon, and Washington (Cassirer 2006, HCI 2010). Although *Protostrongylus spp*. was widespread, intensity was low in our project area.

Nematodirus spp. is a pathogenic parasite in domestic livestock including cattle, sheep, goats, and llamas. *N.battus* can cause clinical outbreaks and mortality in domestic sheep lambs (Fox 2014, Garde et al. 2005). *N. buttus* has not been reported for wild sheep, but several other species of *Nematodirus* are commonly reported throughout the western United States and western Canada (Garde et al. 2005, Hoberg et al. 2001). Pathogenicity of this parasite to bighorn sheep is unknown (Garde et al. 2005). Although *Nematodirus spp*. was widespread in high prevalence in our project area, intensity was low.

Psoroptes spp. are ectoparasites (mites) causing severe disease in domestic sheep, goats, and llamas. *Psoroptes spp.* causes psoroptic scabies in bighorn sheep and was associated with initial bighorn sheep die-offs in the 19th century during the settlement of the west and introduction of domestic sheep grazing on wild sheep range (Buechner 1960, Smith 1954, Jones 1950, Honess and Frost 1942, Grinnell 1904, Hornaday 1901). Scabies is highly contagious, can result in substantial population level morbidity and mortality, is reported range wide in the western United States, and continues to contribute to bighorn sheep die-offs in many western states (Miller et al. 2012, Garde et al. 2005, Dubay et al. 2002, Boyce et al. 1990). In our project area, *Psoroptes spp.* was only occasionally found in ear swabs of tested animals, indicating a low prevalence of this parasite. Although mites detected on ear swabs may underestimate actual numbers of mites infecting host animals (HCI 2010), we observed clinical evidenced of mild scabies in only 1 of 82 bighorn sheep captured.

Trace mineral surveillance can be helpful in evaluating population health. Unfortunately base line reference intervals for healthy populations have not been determined for many wildlife species, including bighorn sheep, making interpretation of detected mineral concentrations difficult. Although reference intervals are available for domestic sheep, and often used for bighorn sheep, the relationship of mineral requirements between domestic and wild sheep is mostly unknown. Species-specific reference intervals for healthy bighorn sheep would be helpful for interpreting measured mineral concentrations and assessing population health.

Our data was generally in agreement with data reported for other bighorn sheep populations although reported values varied across geographic areas and habitats. Consistent with our findings, concentrations of copper, iron, and zinc were lower than or on the lower end of reference ranges reported for other bighorn sheep populations in California (Poppenga et al. 2012), Hells Canyon (HCI 2010), Alberta CA (MacCallum 2006), and Colorado (Carpenter 2005).

Reported mean bighorn sheep selenium concentrations vary widely. Reported concentrations below reference levels consistent with our finding include populations from CA (Poppenga et al. 2012), OR (HCI 2010), WA (Coggins 2006) and Alberta, CA (Samson et al. 1989). Other studies have reported higher concentrations for populations in OR and WA (HCI 2010), Alberta CA (MacCallum 2006), CO (Carpenter 2005), and WY (Dean et al. 2002). Mean concentrations of all macroelements found in Salmon River bighorn sheep were within ranges reported by these studies.

The clinical value of trace mineral test results is complicated, as detected concentrations of seemingly healthy bighorn sheep vary between populations in differing geographic areas and habitats; among individuals of a single population; and within individuals depending on diet, season of year, and other physiological factors (Poppenga 2012). A single range-wide reference range may not be feasible for bighorn sheep and reference ranges developed on a regional basis, such as developed by Poppenga (2012) for desert bighorn sheep in CA, may be more productive. Our data provide a baseline for the Lower Salmon River population and will contribute to the growing information base for developing a reference range for bighorn sheep in our region.

Pasteurellacae species *B. trehalosi*, *M. haemolytica*, and *P. mulocita* have been isolated from pneumonic bighorn sheep; *M. haemolytica* has been identified as an important pathogen in pneumonic epizootic die-offs. *M. haemolytica* has been isolated from pneumonic sheep during outbreaks, has consistently caused fatal pneumonia in bighorn sheep under experimental conditions, and has been experimentally demonstrated to be transmitted from domestic to bighorn sheep (Lawrence et al. 2010, Foreyt and Silflow 1996, Foreyt et al. 1994, Foreyt 1998, 1990, Festa-Bianchet 1988, Onderka and Wishart 1988, Onderka et al. 1988). More recently, with improved bacterial isolation techniques, *M. ovipneumoniae* has also been identified as an important pathogen associated with epizootic respiratory disease in bighorn sheep and has caused fatal pneumonia under experimental conditions (Rudolph et al. 2007; Besser et al. 2008; Dassanayake et al. 2010; Wolfe et al. 2010; Besser et al. 2012*a*, *b*; Besser et al. 2014). Although *M. haemolytica* and *M. ovipneumoniae* have been clearly shown to be pathogenetic to bighorns and associated with population limiting epizootics, their role as primary, predisposing, and/or opportunistic agents and the etiology of fatal respiratory disease in bighorn sheep is still unclear (Garrott et al. 2014, Miller et al. 2012, Dassanayake et al 2010). Recent research, however, suggests observed variation in morbidity, mortality rates, and isolated pathogens in bighorn sheep respiratory epizootics may be linked to a dynamic polymicrobial model for this disease.

Relative proportions of pasteurellacae bacteria found in our project were similar to those reported for pneumonic herds in Hells Canyon, although we report slightly higher levels for *M. haemolytica* and did not find evidence of *P. multocida*. Cassirer (2006) and HCI (2010) reported prevalence of *B. trehalosi* ($\overline{x}$ range = 72–81%), *M. haemolytica* ($\overline{x}$ range = 32–36%), and *P. multocida* ($\overline{x}$ range = 8–13%) for herds in the Hells Canyon metapopulation. Reported prevalence of *M. ovipneumoniae* was similar between the two populations ($\overline{x}$ this project 20%, $\overline{x}$ Hells Canyon 16%). Although sample size was low, concurrent high prevalence of *M. haemolytica* and *M. ovipneumoniae* observed in our project area in 2010 are of note; suggestive of a pneumonic event during that time period.

LAMB PRODUCTION SURVIVAL AND RECRUITMENT

<u>Methods</u>

We monitored lamb production and survival from 2009–2015 and lamb recruitment from 2008–2012. Lambing seasons, lamb production, and summer lamb survival (survival from date of birth through 1 October, or approximately 5 months of age at weaning) was assessed based on air and ground surveys conducted during May and June (spring surveys for production) and October and November (fall surveys for summer survival). Spring surveys were conducted just after the peak lambing period for our project area to minimize bias associated with pre-survey lamb mortality and post-survey births. Ground surveys along the main stem were conducted from either a jet boat or raft, depending on water flows and jet boat availability, over a 6–8 day period. A crew of 4–6 personnel using 12 power image-stabilized binoculars and spotting scopes surveyed the north side of the main stem between Robbins and Reed Creeks. Survey crews floated downstream glassing all observable terrain for bighorn sheep while monitoring for collared females. For larger viewscapes that could not be completely surveyed while floating past, crews stopped and completely surveyed the viewscape from the opposite river bank before proceeding downstream. Collared females were actively tracked on the ground to insure observations of all female study animals. For all collared and uncollared groups observed, location, composition (adult ewes, lambs, yearling ewes, Class I-IV rams), social group assignment, and health assessment data were recorded. In addition, lamb status was recorded for collared females. The main stem reach was divided into subunits based on social group use areas and each subunit was surveyed in one day to minimize double counting. Ground surveys along the South Fork were conducted on foot by hiking the river trail between Smith Creek downriver to Station Creek. Surveys were conducted unidirectional to reduce double counting. Survey duration, crew size, and protocol were the same as for the main stem surveys. Terrain in the South Fork reach was steeper, more rugged and inaccessible, and the river canyon narrower compared to main stem habitats. Consequently, the proportion of visible habitat was less and detecting bighorn sheep in visible habitat was more difficult. Aerial surveys immediately prior to, between, and after surveys provided recent location information to assist ground survey efforts and assisted in determining lamb status of collared females. Ground and aerial surveys were completed in as short a time period as possible to reduce double counting, minimize data loss due to bighorn sheep mortality during the survey period, and provided as close to an instantaneous estimate in time as possible.

Lambing season dates were assigned by estimating lamb birth dates as the midpoint between the first survey date a collared female was observed with her lamb and the most recent previous survey date she was observed without a lamb. Median annual lambing dates were calculated and compared across years to assess annual variation in lambing season dates. Synchronicity of lambing dates across groups was assessed by comparing median lambing dates for each group in a linear downstream-to-upstream direction.

Lamb production was estimated by the proportion of collared females observed with lambs during spring ground and aerial surveys, accounting for females with unknown lamb production status (produced lamb, did not produce lamb). Summer lamb survival was estimated by the proportion of lambs born to collared females that were observed during fall ground and aerial surveys; accounting for females with unknown lamb survival status (survived lamb, did not survive lamb). We did not determine pregnancy rates or directly measure neonatal mortality introducing an unknown bias in our production and survival estimates. Production and survival estimates were compared between years, project reach, and social groups using proportion tests in Minitab (Minitab Inc., State College, PA, USA).

Spring and fall age ratios (lambs:ewe) were obtained from ground surveys. Spring age ratios were used as a population productivity index and a summer lamb survival index was calculated by dividing fall age ratios by spring age ratios. The utility of age ratio-based estimates was assessed through comparison with estimates obtained from collared animals using Pearson's product-moment correlation tests in Minitab.

An index of lamb recruitment (survival from birth to 1 March of the following year, or approximately 10 months of age) was determined from lamb:ewe ratios obtained from helicopter surveys conducted in late February and early March. Helicopter surveys were conducted by IDFG as a companion study to develop a detection probability model and survey protocol for obtaining population estimates within the Lower Salmon River PMU. Surveys were conducted annually from 2009–2013 (2008–2012 biological years) and encompassed the project area including the north side of the main stem between Allison and Big Mallard Creek, the south side of the main stem between Mann and Little Fivemile Creeks, and along both sides of the South Fork upriver from its confluence to Porphyry Creek on the east side and Smith Creek on the west side. Starting from the river bank, 4 500' contours were surveyed from either a Bell 47 or Hiller 12E flying 40–50 knots, or a Hughes 500D flying 50–60 knots.

Results

The majority of lambing in our project area occurred within a relatively short 3-week period during the month of May. Collared females were estimated to have lambed as early as 7 May and as late as 9 Jun and 96% of collared females produced lambs by 1 June. Dates of birth for 2 lambs, 1 first observed on 24 June and the other on 4 July, could not be determined, and were censored from analysis.

Onset and duration of lambing appeared to be consistent across study years and groups with no temporal or spatial trends observed. Across all years, 2009–2015, the earliest estimated lambing date varied by 7 days (7–14 May) while the latest estimated lambing date varied by 12 days (28 May–9 June). On average, lambing in our project area occurred from 10 May to 1 June. Evaluated across all females for all study years, peak lambing dates varied by 8 days (13–21 May) with an average median lambing date of 16 May (Table 31).

Table 31. Earliest, latest, and median estimated date of birth (DOB) for lambs of radio-collared female bighorn sheep along the Salmon River, ID, USA, 2009–2015.

Year	Earliest Est. DOB	Latest Est. DOB	Median Est. DOB
2009	5/11	6/9	5/19
2010	5/12	5/31	5/14
2011	5/7	6/1	5/19
2012	5/11	6/6	5/14
2013	5/12	6/7	5/21
2014	5/14	5/28	5/18
2015	5/8	5/28	5/13
Min	5/7	5/28	5/13
Max	5/14	6/9	5/21
Range	7	12	8
Mean	5/10	6/1	5/16

Lamb production and summer lamb survival was determined for 37 collared females over a 7 consecutive year period during 2009–2015, totaling 123 animal-years (Table 32). Number of assessed females ranged from 13 to 26 and averaged 18 per year across the project area. Number of assessed females per social group ranged 1–8 and averaged 4 animals.

Table 32. Number of radio-collared female bighorn sheep assessed for production and summer lamb survival along the Salmon River, ID, USA, 2009–2015.

Social Group	2009	2010	2011	2012	2013	2014	2015	Total
Manning Bridge Ewes	0	0	0	0	1	1	1	3
Wind River	5	5	6	6	6	4	4	36
Indian Creek	4	5	6	6	6	6	2	35
Jersey Creek	1	2	2	6	5	2	2	20
South Fork Ewes	3	3	2	2	8	6	5	29
Totals	13	15	16	20	26	19	14	123

Females that produced lambs were 3 to 13 years old and were capable of maintaining high reproductive rates at older (11–13 years) ages (Fig. 25; Appendix H). Lamb production did not differ between prime aged (0.85; 2–7 years, Jorgenson et al. 1997) and older animals (0.78, 2 sample proportion test n_1 = 75, n_2 = 41, P = 0.341). Annual lamb production estimates varied from a high of 0.92 in 2009 to a low of 0.71 in 2010 and averaged 0.83 across 2009–2015 (Table 33, Appendix I). A slight downward trend was observed from 2009 (0.92) to 2015 (0.77), although low sample size did not provide sufficient power to detect a statistical difference (2-sample proportion test, n = 13, P = 0.133). Lamb Production estimates for 2010 were lower than any other year, although again our data lacked sufficient power to detect a statistical difference (2-sample proportion test, n_1 = 14, n_2 = 13, P = 0.140). Sample sizes of collared females were not sufficient to compare production among groups by year. When pooled across years, production rates were consistent among groups, ranging from 0.81 to 0.88. No differences between main stem and South Fork groups were observed (Table 33).

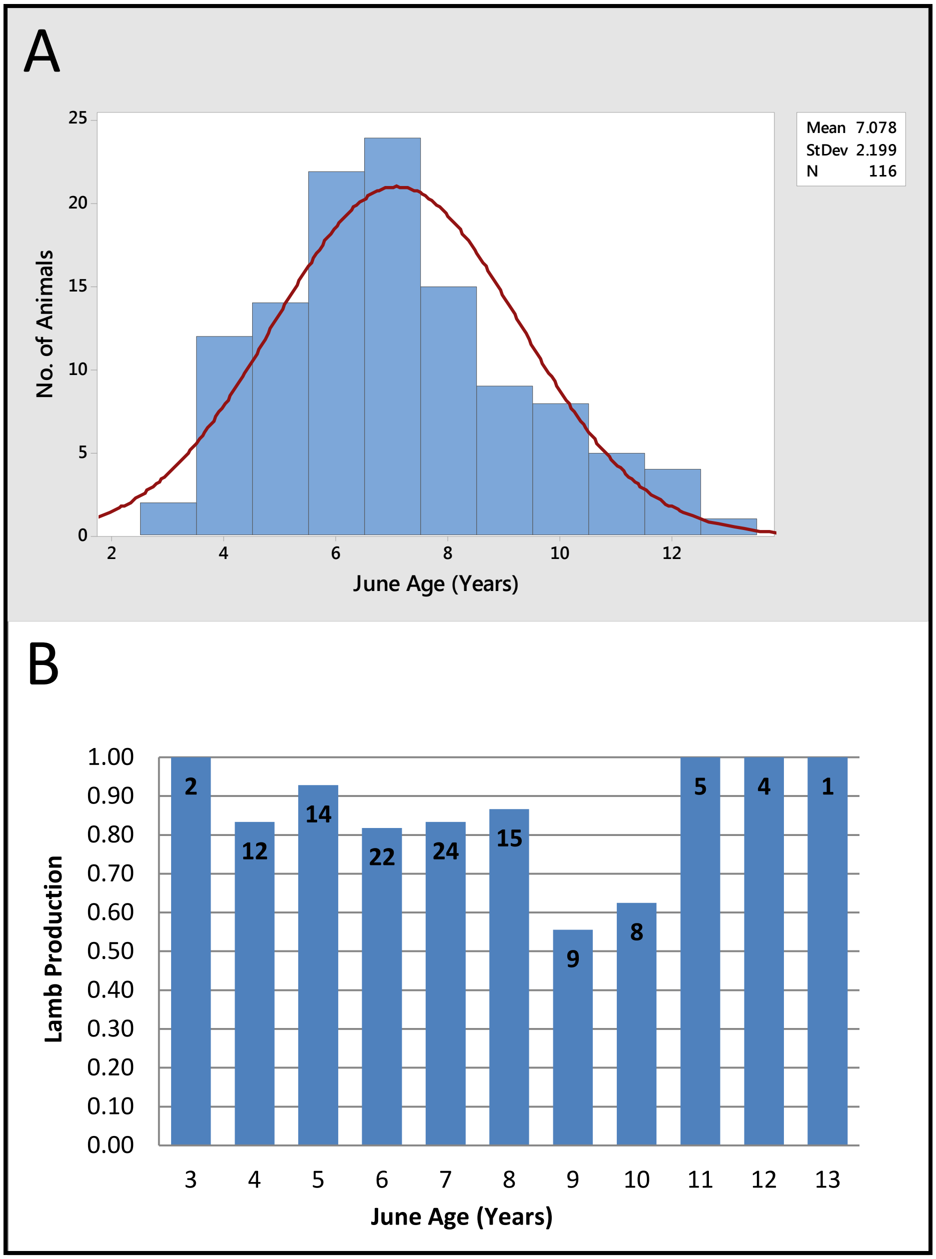

Figure 25. Age distribution (A) and age specific lamb production rates (B) of female radio-collared bighorn sheep along the Salmon River, ID, USA, 2009–2015. Data labels in B = sample size.

Table 33. Annual and social group lamb production estimates for female bighorn sheep along the Salmon River, ID, USA, 2009–2015.

Year / Social Group[a]	*n*	No. Lambs	Production	Lower 95% CI	Upper 95% CI
2009	13	12	0.92	0.640	0.998
2010	14	10	0.71	0.419	0.916
2011	13	12	0.92	0.640	0.998
2012	20	16	0.80	0.563	0.943
2013	25	22	0.88	0.688	0.975
2014	18	14	0.78	0.524	0.936
2015	13	10	0.77	0.462	0.950
All Years	116	96	0.83	0.746	0.891
Wind River	36	29	0.81	0.640	0.918
Indian Cr.	32	28	0.88	0.710	0.965
Jersey Cr.	20	17	0.85	0.621	0.968
South Fork	25	21	0.84	0.639	0.955
Main Stem	88	74	0.84	0.748	0.910
Project Area	113	95	0.84	0.760	0.903

[a] Analysis excluded Manning Bridge Ewes due to insufficient radio-collared members.

Summer lamb survival averaged 0.44 across all years and groups and ranged from 0.10–0.67 (Table 34). Lamb survival in 2010 was lower than in any other year (2-sample proportion test, n_1 = 10, n_2 = 9, *P* = 0.001). Only 1 of 10 collared female's offspring survived. A six-fold increase was observed from 2010 (0.10) through 2015 (0.60; 2 sample proportion test, n_1 = 10, n_2 = 10, *P* = 0.006). Lamb survival estimates were consistent between main stem groups (range = 0.40–0.43) and slightly higher for the South Fork Ewe group (0.53), although we could not detect a difference between main stem and South Fork estimates (2-sample proportion test, n_1 = 19, n_2 = 20, *P* = 0.213; Table 34). Survival estimates for South Fork Ewes during 2009–2012 were less reliable than those for main stem groups because of small sample sizes and difficult survey terrain. Estimates within this time period relied on 2 collared females, and no estimate was obtained for 2011 because the production status of these 2 females could not be determined. Age ratio-based data, considering all females and lambs observed during ground surveys, increased available sample sizes and indicated higher survival index values for South Fork compared to main stem groups for all years except 2013. Averaged across all survey years, age ratio-based data indicated nearly twice as large of a difference (44%) in summer lamb survival between South Fork and main stem groups than was detected from collared female-based estimates (23%).

Table 34. Annual and social group summer lamb survival estimates (Data of birth through 1 October) for female bighorn sheep along the Salmon River, ID, USA, 2009–2015.

Year / Social Group[a]	*n*	No. Lambs	Survival	Lower 95% CI	Upper 95% CI
2009	11	5	0.46	0.168	0.766
2010	10	1	0.10	0.003	0.445
2011	9	3	0.33	0.075	0.701
2012	15	8	0.53	0.266	0.787
2013	17	7	0.41	0.184	0.671
2014	9	6	0.67	0.299	0.925
2015	10	6	0.60	0.262	0.878
All Years	81	36	0.44	0.334	0.559
Wind River	27	11	0.41	0.224	0.612
Indian Cr.	20	8	0.40	0.191	0.640
Jersey Cr.	14	6	0.43	0.177	0.711
South Fork	19	10	0.53	0.289	0.756
Main Stem	61	25	0.41	0.286	0.543
Project Area	80	35	0.44	0.327	0.553

[a] Analysis excluded Manning Bridge Ewes due to insufficient radio-collared members.

Age ratio-based production indices were lower than but tracked trends of those derived from collared females for all sampled years, although the correlation between estimates was moderate (Pearson's correlation, $r_5 = 0.43$, $P = 0.338$; Fig. 26). Except for 2011, productivity indices were consistently between 30–36% lower than estimates derived from collared females. In 2011, 48 females and 11 lambs were observed between Jersey Creek and South Fork Ewes, influencing the low all-female ratio for that year. In contrast, both groups were represented by only 2 collared females that year, both of which survived their lambs, explaining the difference between the 2 estimates for 2011. Averaged across 2009–2015, the production index (0.53) was 36% lower than the estimate derived from collared females (0.83).

Fall age ratios based on all females and lambs observed were low for all study years ($\bar{x} = 0.30$, range = 0.10–0.44; Fig. 27). Although some annual estimates varied, trends from these estimates and age ratios derived from collared females generally agreed (Pearson's correlation $r_5 = 0.87$, $P = 0.010$). Age ratio-based summer survival indices were generally higher than estimates derived from collared females and results of both methods were strongly correlated (Pearson's correlation $r_5 = 0.85$, $P = 0.016$; Fig. 28).

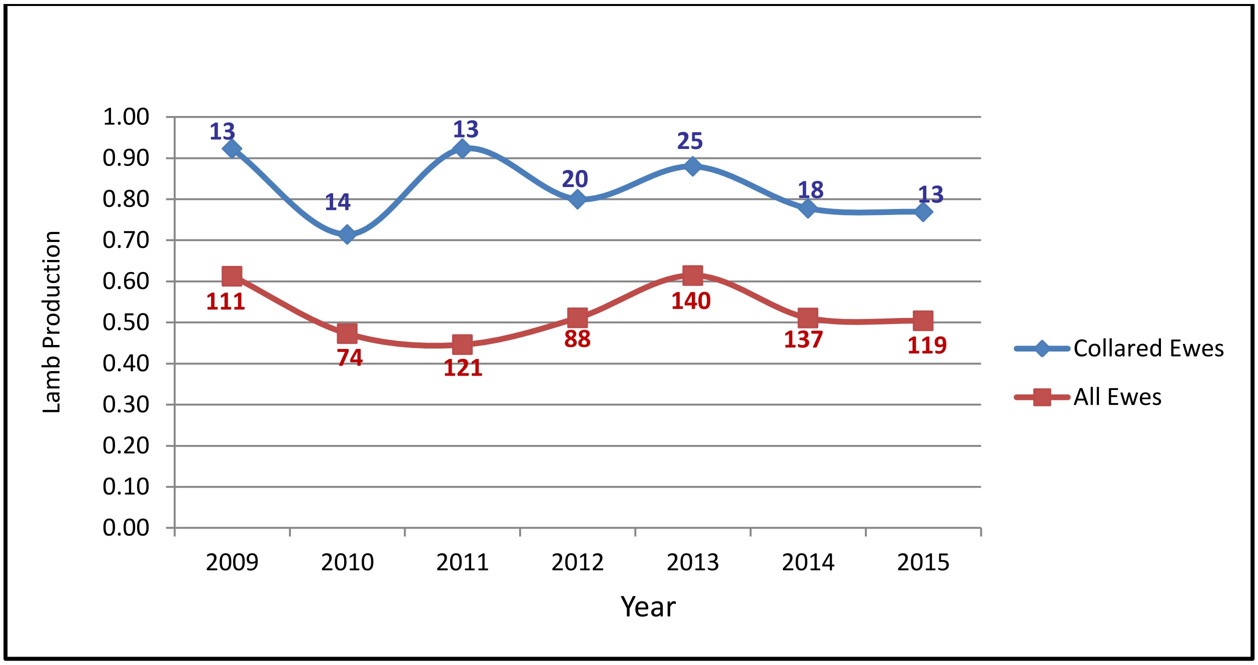

Figure 26. Comparison of lamb production estimates derived from (a) radio-collared bighorn sheep (Collared Ewes, blue line) and (b) lamb:ewe ratios (All Ewes, red line) for bighorn sheep along the Salmon River, ID, USA, 2009–2015. Lamb:ewe ratios were calculated based on all bighorn sheep observed during spring ground surveys. Data labels = sample size.

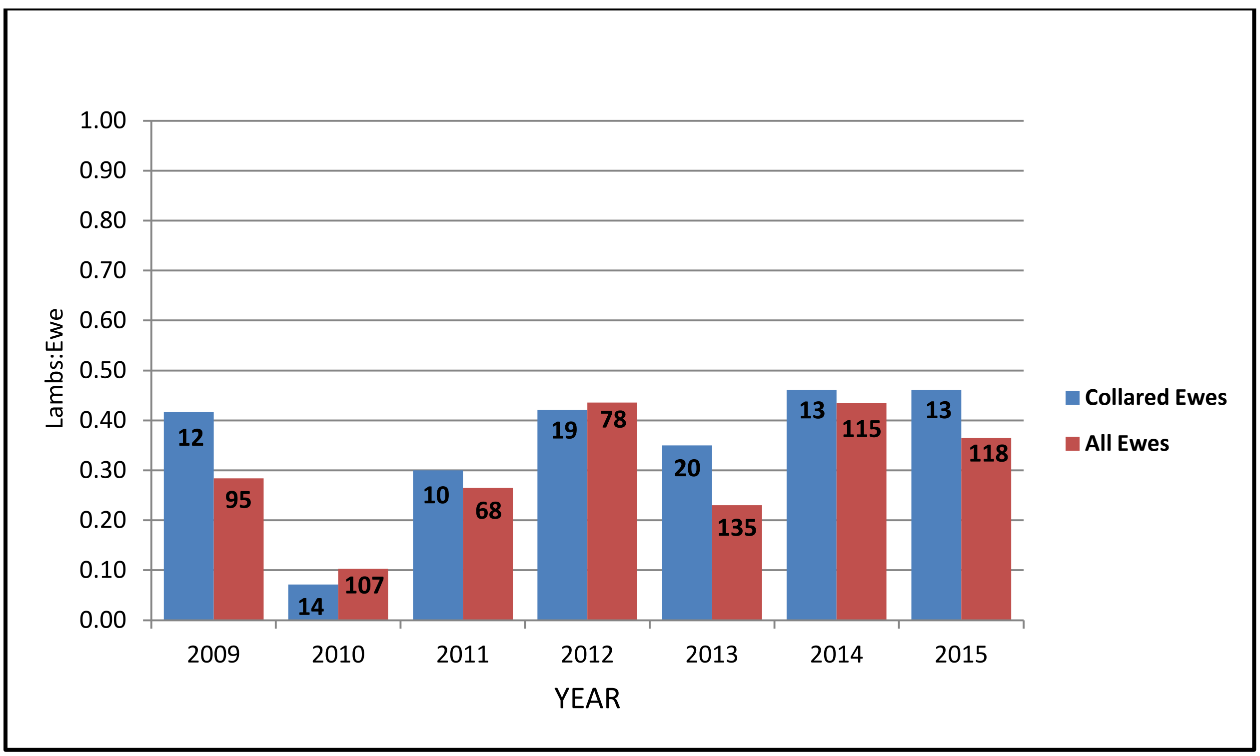

Figure 27. Fall lamb:ewe ratios for radio-collared (Collared Ewes, blue bars) and all (All Ewes, red bars) females observed during fall ground surveys along the Salmon River, ID, USA, 2009–2015.

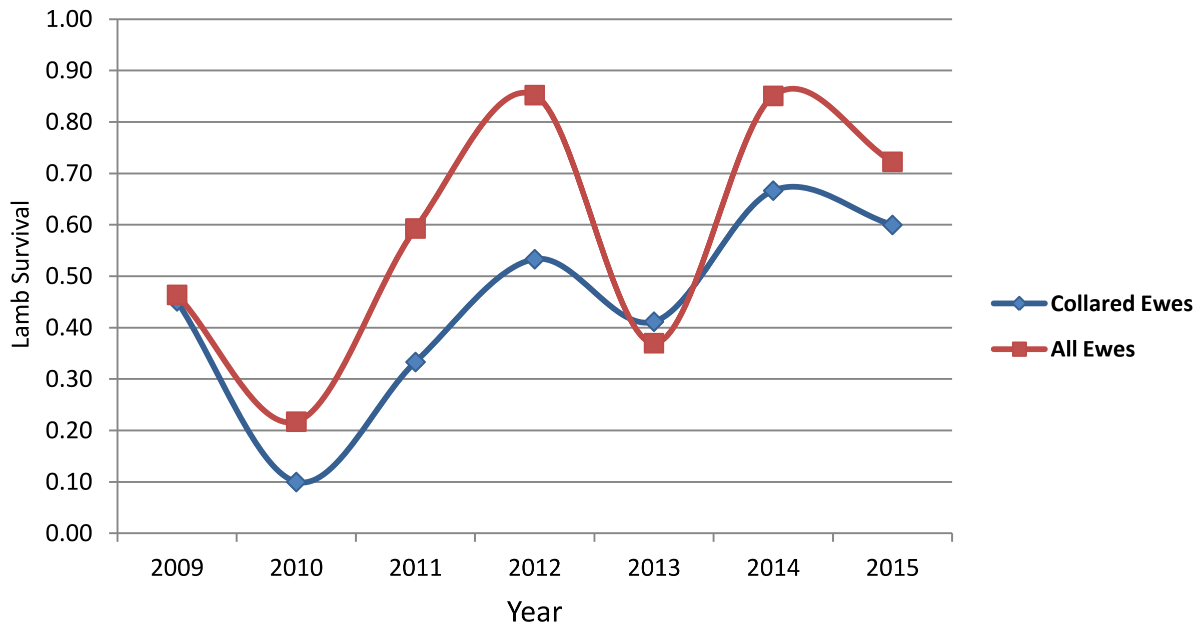

Figure 28. Comparison of summer lamb survival estimates derived from (a) radio-collared bighorn sheep (Collared Ewes, blue line) and (b) lamb:ewe ratios (All Ewes, red line) for bighorn sheep along the Salmon River, ID, USA, 2009–2015.

Recruitment estimates, indexed from winter age ratios data, were obtained for biological years 2009–2012. During this time frame, the South Fork reach of the project area was restricted to the west side of the river (no bighorn sheep were collared on the east side of the river). Although recruitment data from helicopter surveys included both west and east sides of the South Fork, data reported here was truncated to include only the west side of the river to coincide with the project area at that time and be more comparable to lamb production and summer survival estimates. Recruitment estimates obtained for the entire South Fork reach are provided in Appendix L.

Recruitment estimates averaged 0.21 across years and groups. An increasing trend was observed from biological year 2010 (0.13) through 2012 (0.30; 2-sample proportion test n_1 = 163, n_2 = 127, P = < 0.001; Table 35). This trend was significant for the main stem reach (2-sample proportion test n_1 = 120, n_2 = 102, P = < 0.001) but not for the South Fork reach (2-sample proportion test n_1 = 43, n_2 = 25, P = 0.155). Recruitment was lowest in 2010, primarily reflecting poor recruitment of main stem groups. Mean recruitment 2009–2012 was higher for South Fork Ewes (0.36) than main stem groups (0.16; 2-sample proportion test n_1 = 47, n_2 = 74,

$P = \leq 0.00$). Recruitment estimates for South Fork Ewes were higher compared to main stem groups for all years; differences were significant for all years except 2011.

Table 35. Age ratio recruitment index values for bighorn sheep along the Salmon River, ID, USA, 2009–2012. Main Stem = Project area excluding South Fork Salmon River, South Fork = South Fork Salmon River.

	Main Stem					South Fork[a]					Project Area[a]				
Bio Year	Adult Ewes	Lambs	Recruit L:E	Lower 95% CI	Upper 95% CI	Adult Ewes	Lambs	Recruit L:E	Lower 95% CI	Upper 95% CI	Adult Ewes	Lambs	Recruit L:E	Lower 95% CI	Upper 95% CI
2009[b]	100	10	0.10	0.049	0.176	27	9	0.33	0.165	0.540	127	19	0.15	0.093	0.224
2010[b]	102	9	0.09	0.041	0.161	25	8	0.32	0.150	0.535	127	17	0.13	0.080	0.206
2011	114	24	0.21	0.142	0.297	33	11	0.33	0.180	0.518	147	35	0.24	0.173	0.315
2012[b]	121	30	0.25	0.176	0.337	43	19	0.44	0.291	0.601	164	49	0.30	0.231	0.377
$\bar{x}$			0.16					0.36					0.21		

[a] Estimates for South Fork Salmon River include bighorn sheep on the west side of the river only to align with project area boundaries and be comparable with production and survival estimates 2009–2012.
[b] Recruitment for South Fork reach significantly higher than Main Stem reach.

Discussion

Although Rocky Mountain bighorn sheep lambing dates vary range-wide depending on population, latitude, and elevation (summarized in Foreyt 1988) lambing dates in our project area corresponded closely to those reported for other regional bighorn sheep populations (Foreyt 1988, Cassirer et al. 2013). Lambing dates in our project area were highly synchronized, punctuated, and predictable from year to year.

Our production estimates were biased as they did not account for pregnancy rates or an unknown level of early neonatal mortality. Pregnancy rates are commonly high ($\geq$90%) for bighorn sheep but can vary (77–100%) among populations (Thorne et al. 1979, Festa-Bianchet 1988, Schoenecker 2004, Cassirer and Sinclair 2007, Huwer 2015, Parr 2015). In-utero and/or neonatal loss determined by the proportion of females known to be pregnant but not observed with a lamb during the lambing season has been reported to be 0.09–0.16 for pneumonic populations (Schoenecker 2004, Cassirer and Sinclair 2007, Parr 2015). Early neonatal mortality can be substantive in some populations. Parr (2015) reported 0.75 of bighorn sheep lamb mortalities occurred within the first 3 days of life for a small (80 animals) population recovering from recent declines in South Dakota. Although the extent of bias in our estimates is unknown, we hypothesize it is low because we began monitoring collared females early, prior to the lambing season, continued monitoring frequently ($\geq$ once/week) during the lambing season, and our observed production rates were not substantially different than expected based on published pregnancy rates. Additionally, the utility of our estimates for long-term trend monitoring is not impaired by this bias.

The average lamb production rate we observed (0.83) was midrange of others reported for stable or declining populations suffering from disease (0.68–0.93; Parsons 2007, Schoenecker 2004, Cassirer and Sinclair 2007, Huwer 2015). Production rates we observed are not likely population limiting as production rates of 0.74 were found associated with a rapidly growing population of Sierra Nevada bighorn sheep in California (Wehausen 1986); although Jokinen reported a mean production rate of 0.80 which he thought was low and Singer et al. (2000*c*) reported production rates of 0.49 and 0.96 for declining and increasing populations respectively.

In the Hells Canyon metapopulation, summer lamb survival averaged 0.76 in the absence of pneumonia and 0.30 when pneumonia was detected, and pneumonic lambs were found in populations with summer lamb survival rates <50% (Cassirer and Sinclair 2007). More recently Cassirer et al. (2013) reported median summer survival of 0.83 during years when no pneumonia was detected across 14 populations. Summer lamb survival averaged .034 in a pneumonic population in Colorado (Huwer 2015). Singer et al. (2000*c*) reported late summer lamb survival rates of 0.37 and 0.66 for declining and increasing populations in Colorado, Utah, and South Dakota. Mean summer survival estimated for our project area (0.44) was lower than expected for healthy populations and more in line with those reported for pneumonic populations. Estimates for our project area indicated most lamb mortality occurred within the first 5 months of age, consistent with temporal patterns found for pneumonic lambs in Hells Canyon, South Dakota, and Colorado (Cassirer et al. 2013, Smith et al. 2014, Huwer 2015). Although we were rarely able to directly verify respiratory pneumonia in study animals, 2 uncollared lambs found opportunistically died of pneumonia and clinical signs of pneumonia in adults and lambs including coughing, lethargy, and nasal discharge were observed each year across all groups.

Lamb recruitment rates reported in the literature for pneumonic bighorn sheep populations are generally <20%. Smith et al. (2014) reported a mean recruitment rate of 4% for 3 populations in the Black Hills of South Dakota, where chronic pneumonia epizootics resulted in high summer lamb mortality. Mean fall lamb:ewe ratios were 0.19 for a pneumonic population in Colorado (Huwer 2015). Cassirer and Sinclair (2007) reported a mean recruitment rate, based on late winter lamb:ewe ratios, of 0.17 (range = 0.00–0.39) for 8 pneumonic populations in Hells Canyon; more recently, Cassirer et al. (2013) reported rates between 0.05–0.14 across 14 populations exhibiting pneumonia-caused lamb mortality. Butler (2013) summarized 30 years of late winter and early spring lamb:ewe ratios collected for 10 pneumonic bighorn sheep populations in Montana. Recruitment rates for ≤3 years after an all-age disease die-off averaged 0.15 (SD = 0.10, range = 0.00–0.36). George et al. (2008) reported lamb recruitment rates between 0.00-0.23 following pneumonic epidemics in 2 populations in Colorado and Jokinen et al. (2007) reported a mean recruitment rate of 0.18 for a stable to declining population in Alberta, Canada. Finally, Singer et al. (2000*c*) reported mean rates of 0.14 and 0.13 for declining populations in Colorado, Utah and Alberta.

In contrast recruitment rates for healthy populations have been reported between 46% and 100% (Festa-Bianchet 1988, Wehausen 1986, Singer et al. 2000*c*, George et al. 2008). Recruitment rates we observed during 2009–2012 were low, averaging 0.21 across the project area, and were influenced by low recruitment by main stem groups. Although an increasing trend was observed, recruitment among main stem groups remained low averaging 0.16 which was comparable to pneumonic populations. Recruitment in South Fork Ewes was higher and consistent among years, averaging 0.36.

ADULT MORTALITY AND SURVIVAL

Methods

Adult mortality and survival was based on collared study animals. All collars were equipped with a mortality sensor. A collar emitting a mortality signal was located from the air twice within 48 hours to eliminate collar failure as the cause for the mortality signal. If the collar's location did not change between flights a mortality event was suspected and the study animal was located from the ground as soon as access would allow. Standardized mortality and necropsy forms (Appendix J) were filled out to document and assess cause of death for each confirmed mortality event. A Kaplan-Meirer survival table was constructed to calculate annual mortality rates based on biological years (Pollock et al. 1989).

Results

Thirty two collared study animals (14 females, 18 males) died during 2007–2015; an additional 2 project-related mortalities were omitted from analysis (Appendix K). Mean estimated age of death was 8.3 and 9.2 years for females and males respectively (Fig. 29). Most females and males that died were past prime age (females = 71%, males = 67%). Bighorn sheep died in all months except January with no obvious temporal pattern (Fig. 30). Cause of death was difficult to determine, as most carcasses were too autolysed for diagnosis by the time we investigated, precluding field necropsy in some cases and tissue sampling in most. Causes of death could be determined for 5 females and included predation (*n* = 4), and trauma (fall, *n* = 1, Table 36). Known cause of death for 12 males included harvest (*n* = 5), trauma (*n* = 3), management (study animals lethally removed after likely contact with domestic sheep and goats, *n* = 2) and other natural causes (*n* = 2).

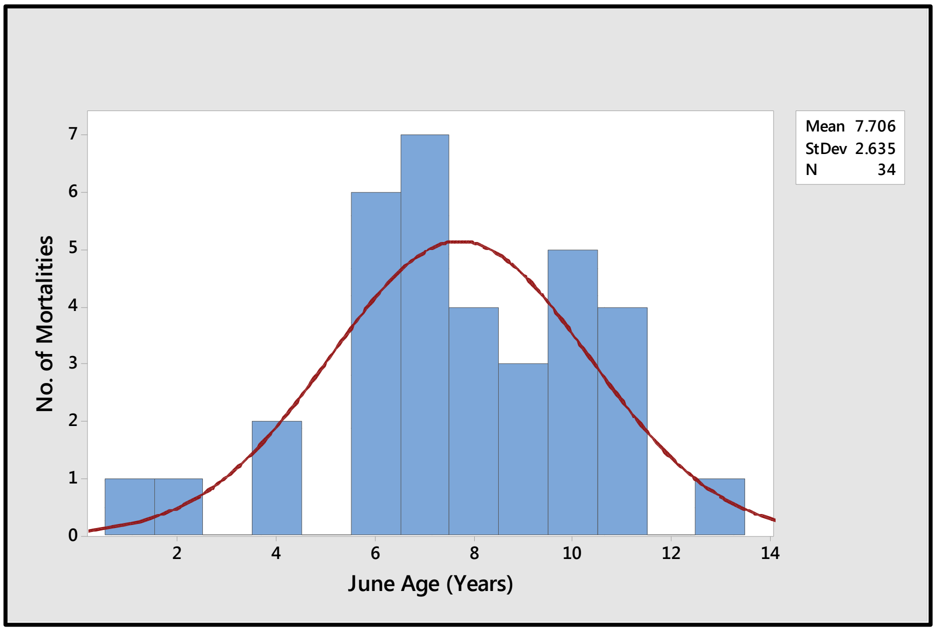

Figure 29. Mortalities by age of radio-collared bighorn sheep along the Salmon River, ID, USA, 2007–2015.

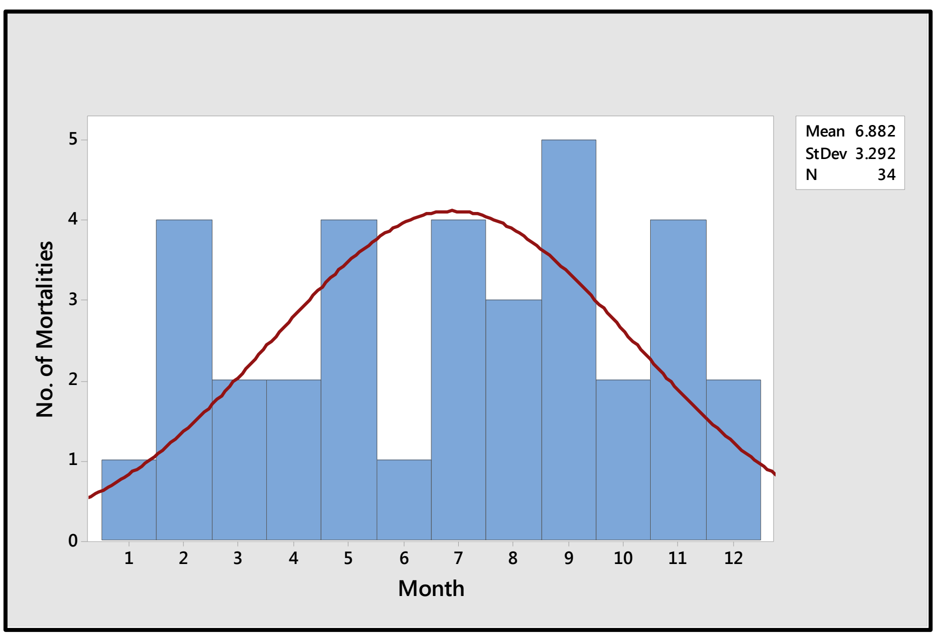

Figure 30. Mortalities by month of radio-collared bighorn sheep along the Salmon River, ID, USA, 2007–2015.

Table 36. Causes of adult bighorn sheep mortality along the Salmon River, ID, USA, 2007–2015.

Mortality Cause	Female	Male	Total
Natural			
Trauma	1	3	4
Predation	4	0	4
Other Natural	0	2	2
Human			
Harvest	0	5	5
Management	0	2	2
Unknown	9	6	15
Sum	14	18	32

Annual survival rates for adult females and males varied from 0.77–0.97, and averaged 0.86 across 2008–2015 (Table 37). Adult females generally had higher values of annual survival ($\bar{x}$ = 0.90) than adult males ($\bar{x}$ = 0.79) but we could not detect a statistical difference (2-sample t-test, n_{11} = 8, *t* = 1.21, *P* = 0.126). Compared to other study years, a noticeable drop in female survival was observed in 2011. Survival varied from year to year for both sexes and although no trend in female survival was observed, estimates indicated a downward trend in male survival from 2012 (1.00) to 2015 (0.40), although male sample size decreased markedly after 2013. Observed decrease in male survivorship after 2013 may reflect an older (>7 years) age distribution of collared males.

Table 37. Estimated annual survival for adult bighorn sheep along the Salmon River, ID, USA, 2008–2015. Survival rates based on biological years (May–April). No. of Monitored Animals = Number of collared study animals actively monitored or known to be alive sometime during the year.

	Ewes				Rams				All Sheep			
Bio Year	No. of Animals Monitored	No. Censored	No. Deaths	Annual Survival	No. of Animals Monitored	No. Censored	No. Deaths	Annual Survival	No. of Animals Monitored	No. Censored	No. Deaths	Annual Survival
2008	14	0	1	0.80	18	1	1	0.89	32	1	2	0.86
2009	15	0	0	1.00	21	0	1	0.94	36	0	1	0.97
2010	17	1	0	1.00	21	0	3	0.86	38	1	3	0.92
2011	28	2	5	0.73	20	4	3	0.83	48	6	8	0.77
2012	31	2	2	0.92	14	0	0	1.00	45	2	2	0.95
2013	27	4	4	0.84	14	2	3	0.76	41	6	7	0.81
2014	19	4	2	0.87	9	1	3	0.63	28	5	5	0.79
2015 [a]	13	2	0	1.00	5	0	3	0.40	18	2	3	0.82
Mean				0.90				0.79				0.86

[a] Partial year, May-December

Discussion

Mean annual adult female survival rate (0.90) estimated for this population was comparative (range = 0.83–0.95) to others reported in the literature (Festa-Bianchet 1988, Jorgenson et al. 1997, Singer et al. 2000*c*, Schoenecker 2004, Cassirer and Sinclair 2007, Huwer 2015, Parr 2015) and adult female survival can remain high even in diseased and/or declining populations. Singer et al. (2000*c*) reported consistent mean adult female survival rates between increasing (0.89) and declining (0.88) populations, and reduced survival (0.67) during active epizootics.

Although studies have reported adult male survival as either higher or lower than female survival, the range of reported survival rates for males (0.84–0.94) was similar to those reported for females. Our mean estimate of adult male survival (0.79) was lower than reported in the literature, but we suspect our estimate was biased low by an older age distribution of collared males during the last 2 years of the project. Excluding 2014–2015, our mean estimate for adult male survival increased to 0.88, within the range reported by other studies.

Cassirer et al. (2013) found the majority of pneumonia-caused adult mortalities occurred between October and February during the breeding season when mixed sex groups were most common. We did not observe this pattern in our project area where 34% of adult mortalities occurred during that time frame.

POPULATION COUNTS

Methods

Female social group counts were obtained during fall ground surveys. Male social group counts were obtained from late summer (pre-rut) aerial surveys. Population counts were compiled by combining female and male group counts. Estimates for group and population size were considered minimum fall counts.

South Fork Ewe counts were restricted to the west side of the South Fork River during 2009–2012 and South Fork Rams counts were only conducted on the west side of the river for all years. Population counts were compared to those obtained from IDFG helicopter surveys conducted during biological years 2010–2013 while developing the detection probability model.

Results

Estimated female group sizes varied among years for all groups, and mean group counts varied among groups (Table 38). Annual variation in group size was likely due to variation in annual detection rates rather than actual changes in numbers from year to year. South Fork Ewes had the largest mean groups size count (77 animals), while newly recolonizing Manning Bridge Ewes had the smallest (13 animals).

Mean male group size counts (7–17 animals) were smaller and more consistent than those of females. Annual variation in group size was likely due to variation in annual detection rates rather than actual changes in numbers from year to year. South Fork Rams counts were likely biased low, as no males were collared on the east side of the South Fork.

Annual population counts during 2009–2015, excluding the east side of the South Fork, were consistent between 187 and 204 animals, indicating a stable population trend (Table 39).

Table 38. Fall social group size counts for female and male social groups along the Salmon River, ID, USA, 2009–2015.

		Fall Social Group Size Counts							
Group Sex	Social Group	2009	2010	2011	2012	2013	2014	2015	$\bar{x}$
Female	Manning Bridge Ewes	N/A	N/A	N/A	N/A	12	12	16	13
	Wind River	33	31	29	30	28	28	26	29
	Indian Creek	65	48	43	51	48	44	39	48
	Jersey Creek	36	25	13	45	33	25	24	29
	South Fork Ewes [a]	11	29	13	8	70	78	83	77
Male	Manning Bridge Rams	8	14	11	11	9			11
	Bull Creek	9	19	10	6	9			11
	Blowout Creek	12	16	22	23	13			17
	South Fork Rams	9	8	6	7	6			7

[a] Incomplete counts 2009-2012, counts reflect west side of South Fork River only; $\bar{x}$ reflects 2013-2015 complete counts

Table 39. Population counts of bighorn sheep from ground and fixed-wing surveys along the Salmon River, ID, USA, 2009–2015. Counts exclude east side of the South Fork of the Salmon River.

Year	No. Ewes	No. Lambs	No. Rams	No. Unclassified	Total Sheep
2009	103	27	50	7	187
2010	114	11	51	16	192
2011	73	18	51	7	149
2012	88	34	68	1	191
2013	138	31	64	0	233
2014	124	50	59	6	239
2015	123	43	78	0	244

Counts for the same area obtained from helicopter surveys during biological years 2009–2012 were 9–40% higher and indicated an increasing (19%) trend (Fig. 31A, Appendix L). The discrepancy was primarily due to low ground counts in the South Fork reach where inaccessible and steep terrain made detecting bighorn sheep difficult (Fig. 31B). Population counts conducted after 2012 included west and east sides of the South Fork and a high population count of 244 sheep was obtain in 2015. The 2015 count, however, was lower than previous counts for the same area obtained by helicopter. Counts obtained from helicopter surveys indicated a steady annual increase from 248 bighorn sheep in biological year 2009 to 349 bighorn sheep in 2012 (Table 40).

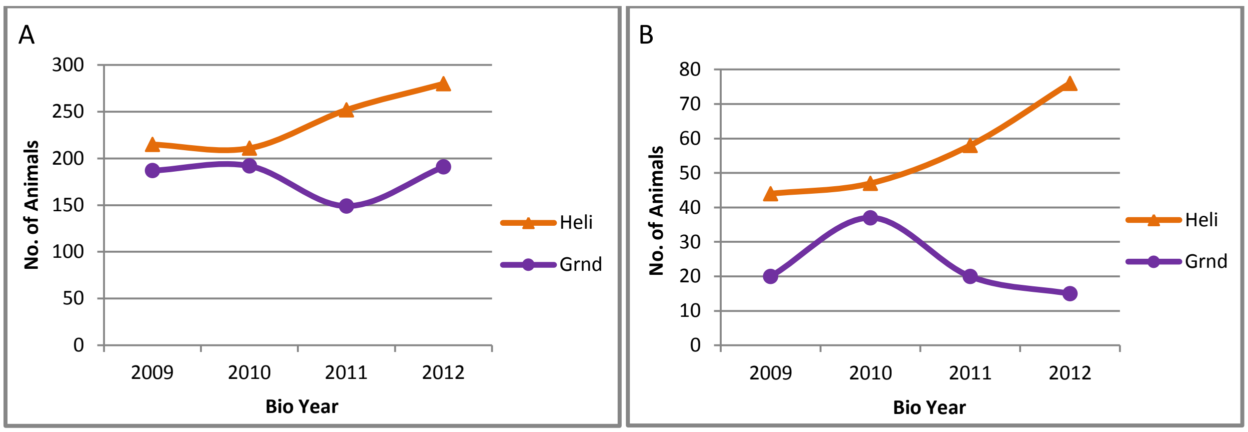

Figure 31. Bighorn sheep population counts conducted by ground (purple circles) and helicopter (orange triangles) in the Salmon River, ID, USA, 2009–2012. Differences in ground and helicopter counts for bighorn sheep within the main stem and west side of the South Fork reach (A) are primarily due to low ground counts obtained for the South Fork reach of the project area (B).

Table 40. Population counts of bighorn sheep from helicopter surveys within the Lower Salmon River Population Management Unit, ID, USA, 2009–2015. Data courtesy of Idaho Department of Fish and Game.

Biological Year	No. Ewes	No. Lambs	No. Rams	Total Sheep
2009	155	20	73	248
2010	173	40	72	285
2011	186	48	78	312
2012	210	62	77	349

<u>Discussion</u>

Prior to this project, bighorn sheep in the Lower Salmon River PMU were counted incidentally to elk surveys conducted by IDFG. Although not all game management units within the PMU were included during any one survey, the most recent surveys covering all units within the PMU were conducted in 2006–2007 and accounted for 139 bighorn sheep; continuing a downward trend (mean annual decline of 22%) in count results since 1987 (IDFG, unpublished data). Population modeling has shown small bighorn sheep populations below 100 animals exhibit higher extinction probabilities and may not be able to recover from stochastic events (Berger 1990). A near 3-fold decrease from 411 animals counted in 1987 and an apparent trend toward a small population size sparked concerns over the future persistence of this population.

More intensive ground counts and bighorn sheep-specific helicopter surveys conducted during this project documented substantially more (76–150%) sheep than previous incidental counts. Helicopter surveys consistently counted more sheep than ground survey and indicated an increasing population trend, while ground surveys indicated stable population numbers and generally were ineffective for the South Fork reach. Helicopter surveys provided the best counts indicating an average 12% increase during 2009–2012, primarily influenced by counts in the South Fork (25% increase) compared to the main stem (7% increase) reach.

Barring all-age die-offs, the highest population count of 347 obtained during the last helicopter survey conducted in 2013 should provide some level of resilience against demographic and environmental stochasticity. Although minimum viable populations for bighorn sheep have not been definitively defined, some studies have suggested populations above 100 are needed in the absence of disease to guard against stochasticity, and 250 animals or more are needed for long-term persistence for diseased populations (Berger 1990, Singer et al. 2001).

CONCLUSSIONS

Counts obtained during this project showed higher numbers of bighorn sheep in the Lower Salmon PMU than previously thought. A maximum count of 347 in 2013 was 2.5 times the number of animals thought to be present in 2007 and should provide for a greater degree of resilience. Increased numbers documented during the project compared to previous counts are largely due to a more intensive effort, but observed increasing trends in lamb survival, recruitment (particularly in the main stem reach), and population counts after 2010 provide evidence for a growing population.

Although lamb production and adult survival remained high during the term of the project and did not appear to be population limiting, low summer lamb survival and recruitment across the project area in 2010, a dip in female survival in 2011, and continued low recruitment within main stem groups is indicative of subpar population performance, warranting continued concern.

Although we were unable to quantify the extent of pneumonia and its impacts, health sampling, demographic patterns, and field observations taken together suggested respiratory pneumonia is likely a chronic condition in this population. Widespread and high prevalence of exposure to *M. ovipneumoniae* (97%) and PI3 (68%), and detected prevalence of *M. haeimolytica* (44%) and *M. ovipneumoniae* (20%) in the throat and nose of study animals is suggestive of a pneumonic population. High summer lamb mortality and adult mortality during fall/winter breeding season are demographic patterns indicative of pneumonic populations. We observed high summer lamb mortality but no increased adult mortality during fall/winter months, suggesting pneumonia is likely disproportionately affecting lambs in this population. Further health and demographic data point to a possible pneumonic event in 2010 when a 10-fold increase in the prevalence of *M. ovipneumoniae* (50%) and a high prevalence of *M. haemolytica* (60%) corresponded to the lowest summer lamb survival (0.10) and recruitment (0.13) recorded during the project.

Although most of the other diseases and parasites we tested for were found in study animals, low prevalence and/or infection rates suggested these were not primary agents affecting the population. Their role as opportunistic or predisposing agents, however, remains a concern and warrants continued health monitoring.

Because of the presence of pneumonia in this population, continued health and population monitoring is warranted. Although summer lamb survival and recruitment estimates appear to be trending upward, precision of our estimates is low, recruitment estimates within the main stem groups remain low, and continued upward trends are uncertain. Additional monitoring is required to more definitively determine the status and trend of this population.

Although continued monitoring of population heath and other demographic parameters we assessed would be ideal, in practical terms, a less intensive but long-term monitoring should be designed to fit within existing agency budgets and workloads. We recommend focusing on a narrower, but the most meaningful, set of demographic parameters. Further, although telemetry-based data provides the most precise information, cost and effort precludes this data collection method for long-term population monitoring.

Given realities of available funding and effort, we recommend a long-term monitoring strategy based on winter helicopter surveys conducted every 3 to 5 years to assess trends in recruitment and population size. Population recruitment will necessarily be indexed on resulting age ratios, and we recommend the population estimation metric be based on the Lower Salmon River bighorn sheep detection probability model currently being developed by IDFG. We recommend more intensive (2–3 year) telemetry-based efforts every 10 to 15 years or whenever monitoring results highlight a management concern. Short-term telemetry studies can gather more fine-scale data to better understand population status and provide timely management intervention if needed.

We do not recommend ground-based methods for long-term monitoring. Although ground-based age ratio data correlated reasonably well with telemetry-based data along the main stem, they consistently underestimated lamb production and overestimated lamb survival. More importantly, our ground-based efforts were assisted by the presence of radio-collared animals, increasing overall detection of bighorn sheep. Whether ground-based efforts without the assistance of collared animals would provide similar quality data is unknown, but unlikely given the difficulty in observing bighorn sheep in the project area. Ground-based surveys in the South Fork are unlikely to be effective without the assistance of collared animals. Steep terrain, a narrow canyon, and limited access prevent visualizing much of the available bighorn sheep habitat. In addition, the ruggedness of the terrain makes detecting sheep much more difficult than along the main stem. Ground-based efforts also consistently under-counted numbers of sheep across the project area and failed to detect an apparent trend in population number. Until an unaided ground-based method can be validated or a protocol developed providing statistical certainty in observed trends, we feel this method would not provide data with sufficient precision needed to detect meaningful trends.

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APPENDIX A

MEMORANDUM OF UNDERSTANDING

BETWEEN

THE NEZ PERCE TRIBE

USDA FOREST SERVICE PAYETTE NATIONAL FOREST

USDA FOREST SERVICE NEZ PERCE NATIONAL FOREST

BUREAU OF LAND MANAGEMENT COEUR D’ALENE DISTRICT

IDAHO DEPARTMENT OF FISH AND GAME

FS Agreement No. 07-MU-11041200-009
Cooperator's No. ____________

MEMORANDUM OF UNDERSTANDING

Between

The Nez Perce Tribe
USDA Forest Service Payette National Forest
USDA Forest Service Nez Perce National Forest
USDI Bureau of Land Management Coeur D'Alene District
Idaho Department of Fish and Game

In support of a study of bighorn sheep distribution, movements, and habitat use along the Main Stem Salmon River

This **MEMORANDUM OF UNDERSTANDING** (MOU) is entered into by the Nez Perce Tribe through its Wildlife Management Program (Tribe), the USDA Forest Service through its Payette (Payette Forest) and Nez Perce (Nez Perce Forest) National Forests, USDI Bureau Land Management through its Coeur D'Alene District Office (BLM), and the State of Idaho through its Department of Fish and Game (IDFG); hereafter referred to as the "parties".

A. PURPOSE:

The purpose of this MOU is to cooperatively identify and implement research needs on bighorn sheep within the main stem Salmon River. This MOU establishes an interagency Salmon River Bighorn Sheep Project Committee (Committee) responsible for overseeing identified research needs and provides guidelines for carrying out those responsibilities. This MOU will also facilitate the development of and progress towards long-term population and management goals and objectives for bighorns in the Salmon River canyon.

Specific purposes of this MOU are to:

1. Establish a collaborative partnership between the parties committed to developing and implementing identified research needs as described in the attached Study Plan (Appendix A).

2. Identify co-investigators representing the parties to serve on the Committee and who are responsible for implementing identified research.

3. Identify resource-sharing opportunities and coordinate related activities among the parties to improve cost effectiveness and operational efficiencies.

4. Identify funding opportunities and strive to identify funding mechanisms to fully support this effort.

B. STATEMENT OF MUTUAL BENEFIT AND INTERESTS:

In response to an appeal of the 2003 Payette National Forest Plan lodged by the Nez Perce Tribe, Hells Canyon Preservation Council and others, a March 9, 2005 decision by the Chief of the Forest Service, (Appendix B), found: "As documented in the Final Environmental Impact Statement (FEIS) and relevant scientific literature, without immediate removal of domestic sheep from occupied bighorn sheep habitat, bighorn sheep within that habitat are likely at risk of extirpation." (Page 14, paragraph 2). The appeal decision directed the Regional Forester for Region Four of the USDA Forest Service to "...do an analysis of bighorn sheep viability in the Payette National Forest commensurate with the concerns and questions discussed above, and amend the SW Idaho Ecogroup FEIS accordingly." (Page 15, paragraph 3).

Following direction provided by the appeal decision, the Payette Forest completed a risk analysis of disease transmission between domestic and bighorn sheep on the Forest. This analysis, among other findings, identified a lack of data on bighorn distribution and movements relative to domestic sheep allotment (allotment) boundaries within the Salmon River canyon as a key factor hindering risk assessment. The Parties wish to develop and implement a collaborative, multi-year research effort to better understand bighorn sheep distribution, movements, and habitat use along the main stem Salmon River as outlined in the attached Study Plan (Appendix A) to fully comply with the appeal decision's directive, more accurately assess the risk of contact between domestic and bighorn sheep, and foster effective and agreeable long-term management solutions to this controversial and important issue.

C. OBLIGATIONS COMMON TO ALL PARTIES:

1. Each party will cooperate through active participation to fulfill the terms and conditions of this MOU and support successful completion of identified projects objectives and goals.

2. Each party will assign one representative co-investigator to the Salmon River Bighorn Sheep Project Committee. This committee will be responsible for implementing identified research as outlined in the Study Plan, coordinating project activities with all parties, and working in a collaborative fashion to fulfill the terms and conditions of this MOU. Curt Mack will serve on behalf of the Tribe, Pattie Soucek for the Payette Forest, Mellany Glossa for the Nez Perce Forest, Craig Johnson for the BLM, and Pete Zager for the IDFG. The Committee will coordinate presentation of interim study findings to the signatories of the MOU at appropriate intervals, but not less than once yearly for the life of the study.

3. The committee will elect a chair person, for a one year term, to coordinate Committee activities.

4. The parties agree the Study Plan, as outlined in Appendix A, will guide initial research efforts for this term of this MOU.

5. The parties recognize study implementation will be dynamic and agree implementation decisions will be made using a consensus based decision-making process.

6. Each party will participate, through the Committee, in the development, attainment, evaluation, and modification of initial and future research goals, objectives, and study designs.

7. Each party will participate, through the Committee, in preparation, review, and publication of an annual report detailing tasks, expenditures, and results of activities completed.

8. The parties agree to joint ownership and timely sharing of all original research data collected in the field or compiled from other sources (Project data). Prior existing data owned by a party, or other government, agency, or organization (Prior proprietary data) provided in support of this project will be used only with the expressed permission from and will remain in the sole ownership of the party, government, agency, or organization providing the data.

9. The parties will collaborate, through the Committee, on all scientific peer reviewed articles prepared and submitted from results and findings of this project.

10. Each party will provide effective, timely, and accurate communication with all parties involved, and between representatives of the Committee and their respective government, agency, or organization.

11. Each party will attempt to identify and provide in-kind contributions to increase project cost effectiveness and operational efficiencies.

12. Each party will seek opportunities to collaboratively solicit funds, above agency budgets, from granting agencies. All funding requests from and between governments, agencies, and organizations will be reviewed by the Committee.

D. THE TRIBE SHALL:

1. Solicit funding through U.S. Fish and Wildlife Service Tribal Wildlife Grants to support this effort and will develop and submit multiple tiered grants.

2. Pending successful solicitation of grants, provide one full time Research Assistant, to work under the guidance and on behalf of the Committee. Research Assistant will be responsible for finalizing project design; all aspects of project implementation including data collection, management, summary, and analysis, and report writing; and coordinating project activities with the Committee.

3. Provide staff time, equipment, vehicles and field assistance, as available, for operations, including bighorn sheep capture, data collection and other activities.

E. THE PAYETTE AND NEZ PERCE FORESTS SHALL:

1. Provide 18 radio collars.

2. Provide logistical, administrative, GIS analysis, and field support as available.

F. THE BLM SHALL:

1. Provide logistical, administrative, and field support, as available.

G. THE IDFG SHALL:

1. Provide staff time, equipment, vehicles and filed assistance, as available, for filed operations, including bighorn sheep capture, data collection and other filed activities.

2. Provide funding, as available, to support project operational costs.

H. IT IS MUTUALLY AGREED AND UNDERSTOOD BY ALL PARTIES THAT:

1. FREEDOM OF INFORMATION ACT (FOIA). Any information furnished to the Forest Service under this instrument is subject to the Freedom of Information Act (5 U.S.C. 552).

2. PARTICIPATION IN SIMILAR ACTIVITIES. This instrument in no way restricts the Forest Service or the Cooperator(s) from participating in similar activities with other public or private agencies, organizations, and individuals.

3. COMMENCEMENT/EXPIRATION/TERMINATION. This MOU takes effect upon the signature of the parties, Tribe, Payette National Forest, Nez Perce National Forest, BLM, and IDFG, and shall remain in effect for a minimum of five years from the date of execution. The MOU shall remain in force unless amended for a longer time period, or

completed/terminated in a shorter period of time as allowed herein. This MOU may be extended or amended upon written request of either party and the subsequent written concurrence of the other parties. Any party may withdraw from this MOU with a 90-day written notice to the other parties.

4. RESPONSIBILITIES OF PARTIES. The parties and their respective agencies and offices will handle their own activities and utilize their own resources, including the expenditure of their own funds, in pursuing these objectives. Each party will carry out its separate activities in a coordinated and mutually beneficial manner.

5. PRINCIPAL CONTACTS. The principal contacts for this instrument are:

Tribal Project Contact	Payette Forest Project Contact
Curt Mack	Pattie Soucek
Nez Perce Tribe	Payette National Forest
1000 Mission St.	800 West Lakeside
McCall, ID 83638	McCall, ID 83638
Phone: 208-634-1061	Phone: 208-634-0812
FAX: 208-634-3231	FAX: 208-634-0744
E-Mail: cmack@nezperce.org	E-Mail: psoucek@fs.fed.us

Nez Perce Forest Project Contact	BLM Project Contact
Mellany Glossa	Craig Johnson
Nez Perce National Forest	Cottonwood Area Office
1005 Highway 13	1 Butte Drive
Grangeville, ID 83550	Cottonwood, ID 83522
Phone: 208-799-5010	Phone: 208-962-3688
FAX: 208-983-4099	FAX: 208-962-3275
E-Mail: mglossa@fs.fed.us	E-Mail: craig_johnson@blm.gov

IDFG Project Contact
Pete Zager
Idaho Department of Fish and Game
3316 16th St.
Lewiston, ID 83501
Phone: 208-799-5010
FAX: 208-799-5012
E-Mail: pzager@idfg.idaho.gov

6. NON-FUND OBLIGATING DOCUMENT: Nothing in this MOU shall require either the parties to obligate or transfer any funds. Specific work projects or activities that involve the transfer of funds, services, or property among the various agencies and offices of the Department of Agriculture and any other party will require execution of separate agreements and be contingent upon the availability of appropriated funds. Such activities must be independently authorized by appropriate statutory authority. This MOU does not provide such authority. Negotiation, execution, and administration of each such agreement must comply with all applicable statues and regulations. Terms and conditions of this agreement are predicated on timing and amount of available funding and other unforeseen study constraints.

7. ESTABLISHMENT OF RESPONSIBILITY. This MOU is not intended to, and does not create, any right, benefit, or trust responsibility, substantive or procedural, enforceable at law or equity, by a party against the United States, its agencies, its officers, or any person.

8. MODIFICATION. The terms of this MOU shall not be waived, altered, modified, supplemented or amended, in any manner whatsoever, except by written instrument signed by all parties. This agreement may be amended at any time by mutual consent of the parties involved in writing and signed by each of them. Upon agreement of all parties, additional cooperators may be added to this MOU in the future provided terms of this MOU are not waived, altered, modified, supplemented, or amended unless as specified within this MOU.

9. AGREEMENT TERMINATION. This MOU will remain valid through the identified term, or until terminated as provided herein. This MOU may be terminated by mutual written consent signed by all parties, or by any party upon 90 days written notice, delivered by certified mail or in person, the other parties. Termination of the MOU by a single party does not prohibit the reauthorization of a similar agreement among remaining or other collaborators with and interest in continuing work with bighorn sheep in the Salmon River drainage. If any provisions of this MOU are held invalid, the remaining provisions shall not be affected and shall remain in full force and effect.

10. AUTHORIZED REPRESENTATIVES. By signature below, the cooperators certify that the individuals listed in this document, as representatives of the cooperator, are authorized to act in their respective areas for matters related to this instrument.

11. DISCLAIMER AND COMPLIANCE WITH TRIBAL, STATE, AND FEDERAL LAWS. Nothing in this MOU commits or binds any party to conduct activities outside of their government or agency's legal framework. The parties will comply with all policies, regulations, and laws, applicable to them in the implementation of this agreement.

FS Agreement No. ____________
Cooperator's No. ____________

THE PARTIES HERERTO have executed this instrument

Signed :

for Rebecca A. Miles, Chairman, — 1-29-07 Date
Nez Perce Tribal Executive Committee

Brooklyn Baptiste, Secretary, — 1-29-07 Date
Nez Perce Tribal Executive Committee

Suzanne Rainville, Supervisor, — 1/22/07 Date
Payette National Forest

for Jane Cottrell, Supervisor, — 1/26/07 Date
Nez Perce National Forest

Lewis Brown, District Manager, — 1/16/07 Date
Bureau of Land Management Coeur D'Alene District

Cal Groen, Director, — 1/27/07 Date
Idaho Department of Fish and Game

APPENDIX B

SALMON RIVER BIGHRON SHEEP PROJECT

PROJECT COMMITTEE

Salmon River Bighorn Sheep Project Committee

Bighorn sheep within the project area ranged across multiple federal and state jurisdictions having common domestic-bighorn sheep management concerns. A collaborative interagency effort was the most efficient and effective approach for addressing these management concerns. The Salmon River Bighorn Sheep Project was a cooperative interagency research effort among the Idaho Department of Fish and Game; Nez Perce Tribe; USDA Payette and Nez Perce Clearwater National Forests; and the USDI Bureau of Land Management, Cottonwood Field Office. The Project Committee, comprised of representatives of each cooperating agency, was established to facilitate communication, resource sharing, and securing funding needs; set project direction; and guide project activities. Committee members advocated for project support and funding, and often provided field assistance from their respective agencies. Project Committee members included:

Idaho Department of Fish and Game

- Frances Cassirer, Wildlife Research Biologist, Lewiston, ID;
- Jay Crenshaw, Regional Wildlife Manager, Lewiston, ID;
- Jeff Rohlman, Regional Wildlife Manager, McCall, ID;
- Mike Scott, Regional Wildlife Biologist, McCall, ID;
- Pete Zager, Principal Wildlife Research Biologist, Lewiston, ID

Nez Perce Tribe

- Curt Mack, Project Leader, McCall, ID;
- Keith Lawrence, Wildlife Management Division Director, Lapwai, ID

USDA Forest Service – Nez Perce - Clearwater National Forest

- Joanne Bonn, District Wildlife Biologist, White Bird, ID;
- Dan Davis, Forest Wildlife Biologist, Orofino, ID;
- Darcy Pederson, District Ranger, Grangeville, ID;
- Rema Sadak, Wildlife Program Manager, Kamiah, ID

USDA Forest Service – Payette National Forest

- Ana Egnew, Forest Wildlife Biologist, McCall, ID;
- Chris Hescock, District Wildlife Biologist, McCall, ID;
- Pattie Soucek, Forest Planner, McCall, ID

USDI Bureau of Land Management – Idaho Cottonwood Field Office

- Craig Johnson, Fisheries and Wildlife Biologist, Cottonwood, ID

APPENDIX C

SALMON RIVER BIGHORN SHEEP PROJECCT

STUDY PLAN

Bighorn Sheep Movements, Distribution, and Potential for Contact with Domestic Sheep Along the Main Stem Salmon River Within the Nez Perce and Payette National Forests

Research Study Plan

A Cooperative Research Effort between:

Nez Perce Tribe

Idaho Department of Fish and Game

U.S.D.A. Forest Service

U.S.D.I Bureau of Land Management

January 2007

Introduction

Rocky Mountain bighorn sheep (*Ovis Canadensis canadensis;* bighorn) were once common and widespread throughout the western states including the mountainous regions of Idaho (Smith 1954, Buechner 1960). Since the mid 1800s, bighorns across the west and in Idaho have been reduced to remnant isolated populations from a variety of factors including disease outbreaks, overharvest, habitat loss, and competition with domestic livestock (Honess and Frost 1942, Smith 1954, Jessup 1981, Goodson 1982, Valdez and Krausman 1999). Of these many factors, disease, primarily respiratory diseases, has been identified as the single most important mortality factor influencing bighorn populations for the past several decades (Jessup 1981). Extensive all age die-offs from pneumonia have occurred in every western state (Martin et al. 1996). Bacteria in the genera *Pasteurella* and *Mannheimia*, especially M. haemolytica, are thought to be the most important respiratory pathogen in these pneumonia outbreaks in bighorn sheep (Foreyt et al. 1994). It has been suggested that disease outbreaks in bighorn populations can be caused by a variety of environmental factors, and it has been demonstrated that bighorn populations are highly susceptible to disease and resulting die-offs stemming from close contact with domestic sheep (Geist 1971, Onderka and Wishart 1988, Foreyt 1989, Foreyt 1990, Foreyt 1992, Jaworski et al. 1993, Foreyt et al. 1994, Martin et al. 1996, Singer et al. 2000, Singer et al. 2001, Garde et al. 2005). Pneumonia outbreaks can have significant long-term impacts on bighorn populations because outbreaks commonly result in high mortality across all age classes within a herd and can also depress recruitment (and therefore population growth and recovery) for years after the outbreak (Foreyt 1990, Coggins and Matthews 1992, Ward et al. 1992, Foreyt 1995). Recruitment may be depressed even in the absence of large-scale die-offs (Cassirer and Sinclair 2007). Wildlife professionals, veterinarians, and federal land management and western state fish and game agencies have concluded that domestic and bighorn sheep are not compatible when occupying the same range and the most effective management approach is to separate the two species in space or time (Hunt 1980, Jessup 1980, Foreyt and Jessup 1982, Goodson 1982, Jessup 1982, Kistner 1982, Wishart 1983, Onderka 1986, Coggins 1988, Onderka and Wishart 1988, Foreyt 1989, Desert Bighorn Council 1990, Foreyt 1990, Callan et al 1991, Coggins and Matthews 1992, Foreyt 1992, USDI Bureau of Land Management 1992, Foreyt 1994, Foreyt et al. 1994, Pybus et al. 1994, Foreyt 1995, USDA Forest Service 1995a, USDA Forest Service 1995b, Martin et al. 1996, USDI Bureau of Land Management 1998, Schommer and Woolever 2001, USDI Fish and Wildlife Service 2001, USDI Fish and Wildlife Service 2003, Wyoming State-wide Bighorn/Domestic Sheep Interaction Working Group 2004).

The future of bighorn populations in the portions of the Snake and Salmon river canyons that occur on and adjacent to the PNF and the Nez Perce national forest (NPNF) is still uncertain, because domestic and bighorn sheep ranges overlap, providing continued risk of disease outbreaks and bighorn die-offs. Although bighorns were historically abundant in the adjacent Hells Canyon area of the Snake River, numbering around 10,000 sheep in the early 1800s, they were extirpated from this area by the 1940s primarily from competition for forage with domestic livestock, introduced diseases, and unregulated hunting (Hells Canyon Bighorn Sheep Restoration Committee 2005). Extensive restoration efforts and studies of bighorn subpopulations have been conducted within the Hells Canyon area since 1971 (Hells Canyon Bighorn Sheep Restoration Committee 1997, 2004). Disease, primarily pneumonia has been identified as the most important factor limiting bighorn restoration efforts in Hells Canyon (Hells Canyon Bighorn Sheep Restoration Committee 2004).

Bighorns were also historically abundant in the Salmon River canyon. Although bighorns were not extirpated from this area, current population levels remain low. Disease related die-offs were reported as early as the 1870s (Smith 1954), and have continued to be documented or implicated in different subpopulation die-offs since then (Akenson and Akenson 1992; Idaho Department of Fish and Game 2004, 2005). To date, no intensive research effort has been conducted on the Salmon River canyon bighorn subpopulations within the Payette and Nez Perce national forests to better understand bighorn distribution and movements, and potential overlap and risk of contact with domestic sheep.

In response to appeals of the 2003 Payette National Forest Plan, the Chief of the Forest Service, through the Regional Forester, instructed the Payette National Forest (PNF) to conduct an analysis of bighorn sheep population viability to address concerns and questions about the threat to bighorn sheep populations resulting from diseases transmitted from domestic sheep grazed on the PNF (USDA Forest Service 2005). In response to this direction, the PNF, in 2005, completed a risk analysis of disease transmission between domestic and bighorn sheep on the PNF (USDA Forest Service 2006a). This analysis, among other findings, identified a lack of data on bighorn distribution and movements relative to domestic sheep allotment (allotment) boundaries within the Salmon River canyon as a key factor hindering risk assessment. In 2006, the PNF convened a Science Panel to review the findings of the PNF's risk analysis. Among other conclusions, the Science Panel reiterated the need for additional data on bighorn sheep along the Salmon River and suggested it would be prudent to manage bighorn and domestic sheep to prevent contact between these species (USDA Forest Service 2006b).

Detailed information on bighorn distribution, movements, and temporal and spatial use patterns along the main stem Salmon River is needed to more accurately assess the risk of contact between domestic and bighorn sheep. This information may then be used to foster effective long-term management solutions to this controversial and important issue.

Because diverse regional and national interests view this as an important issue, finding long-lasting and workable solutions for managing domestic and bighorn sheep in the Salmon River canyon is a priority for local land and wildlife managers including the PNF, NPNF, Bureau of Land Management (BLM), Idaho Department of Fish and Game, and the Nez Perce Tribe. Due to the diversity of interests and viewpoints, a local collaborative process has the best chance of finding successful solutions to this issue.

Study Area

The proposed study area includes the main stem Salmon River corridor from the confluence of the Little Salmon River at Riggins, Idaho, upstream to the mouth of Big Mallard Creek, just upstream from the confluence of the South Fork Salmon River; and the upper Payette River drainage within the PNF (Figure 1). The study area includes the north central portion of the PNF south of the main stem Salmon River, the southern end of the NPNF bordering the north side of the main stem Salmon River, and a 200 mi^2 rectangle of BLM land situated north of Marshall Mountain on the south side of the main stem Salmon River. The study area includes the Main Stem and South Fork bighorn subpopulations and 3 operators graze domestic sheep on 20 National Forest and BLM allotments.

Bighorn Sheep Populations

Today, occupied bighorn range is thought to be contiguous within the main stem Salmon River drainage from the confluence of the Little Salmon River upstream to its headwaters (USDA Forest Service 2006a). Throughout this area, bighorns are distributed in a metapopulation structure, or a network of discrete local subpopulations interconnected by movements of individuals between these subpopulations. Bighorn subpopulations extending upstream from the confluence of the Little Salmon River in and adjacent to the NPNF and PNF are found along the lower main stem of the Salmon River (Main Stem subpopulation), lower South Fork Salmon River (South Fork subpopulation), Big Creek (Big Creek subpopulation), and the Middle Fork of the Salmon River (Middle Fork subpopulation) drainages. Of these, the Main Stem and South Fork subpopulations occur within the study area, and the Main Stem subpopulation is located farthest downstream closest to active allotments. Interactions between individuals from discrete

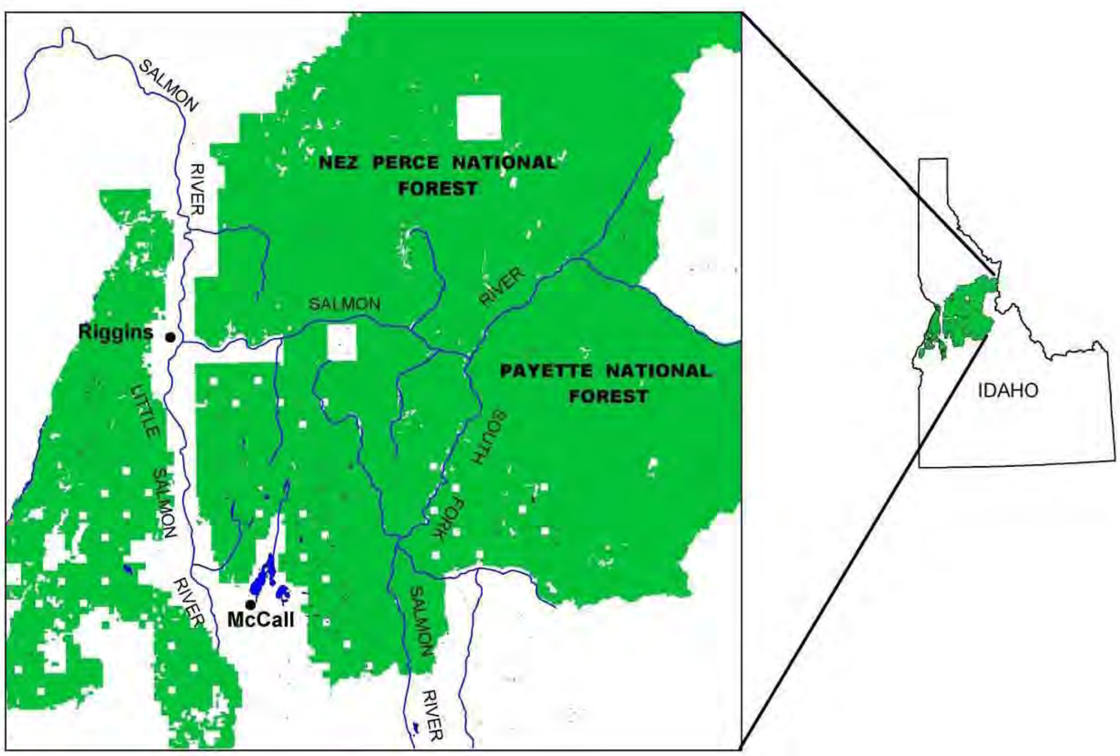

Figure 1. Salmon River Bighorn Sheep Study Area

subpopulations facilitate the spread of disease between subpopulations, potentially impacting large areas (Akenson and Akenson 1992).

South Fork subpopulation estimates have fluctuated, gradually decreasing from a high of 92 bighorns in 1986 to a low of 33 between 1996 and 2002, then increasing again to a high of 78 in 2006 (Idaho Department of Fish and Game unpublished data). Reasons for this fluctuation are not known. Other than regular winter counts, little is known about this subpopulation.

The Main Stem subpopulation gradually increased to 319 bighorn sheep by 1986, then steadily declined to 101 in 2001 (Idaho Department of Fish and Game 2004). Reasons for this decline are not known, however, a 68% decline in total bighorns in Game Management Unit (GMU) 20 between 1987 and 1993, and a 43% decrease in total bighorns between 1989 and 1992 followed by very low lamb:ewe ratios in 1992 and 1993 in GMU 19 suggests a possible disease related die-off in this subpopulation (Idaho Department of Fish and Game 2004). Other than periodic winter surveys, little is known about this subpopulation.

Domestic Sheep Grazing

Three domestic sheep producers are permitted to graze 15,931 dry ewes and 12,115 ewe/lamb pairs on 19 PNF and 1 BLM allotments within the study area (USDA Forest Service 2006a; Dean Huibregtse, personal communication). In addition, one producer is permitted to graze around 2,400 dry ewes and 1,632 ewe/lamb pairs on one allotment along the north side of the main stem Salmon River within the NPNF (Don Sorensen, personal communication). These allotments are located within the lower end of the main stem Salmon River and upper North Fork Payette River drainages. Current known bighorn range abuts the NPNF Allison-Berg allotment along the downstream end, or east side, of the study area, mapped bighorn habitat overlaps all allotments within the study area, and 2 incidental observations of bighorns within active allotments were recorded in 2006 (US Forest Service 2006).

Research Goals and Objectives

The goal of this study is to develop baseline ecological information on bighorn subpopulations within the study area. It will supplement and complement similar on-going research in the Hells Canyon ecosystem (Hells Canyon Bighorn Sheep Restoration Committee 2004). The information will be used to assess the potential for contact between domestic and bighorn sheep and will serve as a basis for crafting effective solutions to manage domestic and bighorn sheep within the study area. This research effort is not designed to document or evaluate disease transmission between the two species. Documenting disease transmission would require a different study design, methodologies, and expertise, and is outside the scope and financial capabilities of this study. Rather, we assume, based on available science and management guidelines, that if the two species overlap, there is a risk of disease transmission. However, we will collect standard disease samples (swabs and blood) from all captured bighorns to further our general understanding of pathogens within bighorn sheep populations. Sampling protocols will follow those established by the Hells Canyon Bighorn Sheep Restoration Committee (2004).

Primary research objectives include:

1. Document spatial and temporal movements, distribution, and population boundaries of bighorn subpopulations within the study area.
2. Model and validate potential bighorn sheep habitat to predict bighorn sheep distribution within the study area.
3. Investigate extent of spatial and temporal overlap between allotments, domestic sheep, the Main Stem subpopulation, and bighorn habitat within the study area.
4. Assess potential risk of contact between bighorn and domestic sheep within the study area.

Secondary research objectives include:

5. Assess bighorn demographics and population dynamics in the Salmon River canyon.
6. Investigate genetic relatedness between Hells Canyon and Salmon River bighorn subpopulations as an index of subpopulation interchange.

Methods and Analysis

Data collection will rely on capturing, radio collaring, and radio tracking representative cohorts of the Main Stem and South Fork bighorn subpopulations. A minimum of 10 ewes and 10 rams will be fitted with VHF and GPS radio transmitters (Advanced Telemetry Systems, Isanti MN) respectively, in the Main Stem subpopulation. An additional minimum of 10 ewes and 5 rams will be fitted with VHF and GPS radio transmitters respectively, in the South Fork subpopulation. Bighorns will be captured from October – December of each study year and standard capture, handling, and sampling protocols will be adopted (Foster 2004, Hells Canyon Bighorn Sheep Restoration Committee 2004). Age, sex, body condition, morphologic measurements, capture location, radio collar frequency and type, and number and type of samples taken will be recorded for each animal captured. Body condition will be estimated through palpation at the withers, ribs, and rump on a score of 1 (emaciated) to 5 (obese) (Gerhart et al 1996, Cook et al. 2001a, 2001b). Blood, pharyngeal and ear swabs, and fecal samples will be obtained for genetic, disease, and parasite analysis. One pharyngeal swabs will be submitted to the University of Idaho Caine Veterinary Teaching Center, Caldwell, ID for culture of *Pasteurella* and *Mannheimia* spp. Bacteria, a second will be archived at -20 C. Blood serum will be submitted to the Idaho State Bureau of Animal Health Laboratory, Boise, ID for testing for exposure to respiratory viruses. Fecal samples and ear swabs will be submitted to the Washington Animal Disease and Diagnostic Laboratory, Pullman, Washington for analysis of internal and external parasites. Blood samples will be archived for potential future genetic analyses. Vital signs will be monitored and recorded to insure the health and safety of animals processed (Foster 2004).

1. Spatial and Temporal Movements and Distribution of Bighorn Sheep

Spatial and temporal distribution of bighorn sheep subpopulations will be described in terms of seasonal ewe and ram ranges, migration corridors, population boundaries, and ram movements. This information will be used to assess overlap and potential for contact with domestic sheep, and potential for interchange between bighorn subpopulations.

Documenting Seasonal Ranges, Migration Routes, and Subpopulation Boundaries. During the initial year of the study, radio-collared (VHF and GPS) bighorn ewes and rams will be monitored from the air at a minimum frequency of once per week to document bighorn summer and winter ranges. Frequency of aerial monitoring flights will be increased to 1 flight per 2-3 days during May and November to document travel routes between seasonal ranges. Flight frequency will be reevaluated and adjusted, if need be, depending on data needs beyond the first year. Flight frequency may also be increased during the domestic sheep grazing season if seasonal bighorn ranges are near allotment boundaries, to more closely monitor bighorn movements and survival.

Study animal identification, bighorn subpopulation identification, date, location coordinates, and visual observations (bighorn group size, sex/age composition, behavior, etc; proximity to domestic sheep; and domestic sheep group size, composition, location, etc.) will be recorded for each radiolocation obtained. Summer range, winter range, seasonal migration routes, and population boundaries of each marked subpopulation will be delineated using Adaptive Kernel home range analysis (ESRI Animal Movement Extension, Redlands, CA). Seasonal ranges (summer, winter, and domestic sheep grazing seasons), migration routes, and population boundaries (seasonal ranges and migrations routes combined) will be mapped and quantified using Geographic Information System (GIS; ESRI ArcGIS, Redlands, CA) analysis.

Documenting Movements of Bighorn Rams and Assessing Subpopulation Overlap. GPS satellite fixes of radio-collared bighorn rams will be used to document movements and distribution of this cohort and assess potential for subpopulation overlap. GPS collars will obtain multiple locations per day to document frequency, timing, and distance of bighorn ram movements. Study animal identification, bighorn subpopulation identification, date, time of day, and location coordinates will be recorded for each satellite fix obtained. GPS collars will collect location data over a 13-month period, obtaining an average of 2 locations per day during the non-domestic sheep grazing period (grazing period) from December-April, and 4 locations per day during the rut and grazing period from May-November of each year.

Spatial and temporal (summer, winter, grazing season, etc…) movements of individual radio-collared bighorn rams will be quantified using Adaptive Kernel home range analysis (ESRI Animal Movement Extension, Redlands, CA). Potential for subpopulation overlap will be assessed using two methods: 1) a broad scale GIS buffer analysis and 2) a fine scale utilization distribution analysis.

Broad Scale GIS Buffer Analysis. Observed bighorn ram movements will be superimposed on subpopulation boundaries, as derived from ewe movements, as determined above, using GIS analysis. A "ram movement" buffer will be described beyond the population boundary. The width of this buffer will be determined from the longest documented distance moved by a radio-collared ram outside of its population boundary. Potential for subpopulation overlap will be assessed based on the amount of overlap between ram movement buffers of each subpopulation. Since we can not radio-collar all rams within the study area, and because ram movements between subpopulation are probably infrequent, it will be extremely difficult to actually document interpopulation movements during the course of this study. Recognizing this reality, this method is based on extrapolated maximum observed travel capabilities of radio-collared rams, not actual individual movements. Thus, this analysis will be helpful for assessing the theoretical potential for interchange between bighorn subpopulations on a broad scale, is not intended to document actual interpopulation movements of individual study animals, and will lack the resolution needed to identify site specific geographic areas of potential overlap.

Fine Scale Utilization Distribution Analysis. Subpopulation utilization distributions (GPS locations for all radio-collared rams within a subpopulation combined) will be constructed for each subpopulation using Adaptive Kernel home range analysis (ESRI Animal Movement Extension, Redlands, CA). Subpopulation overlap, if any, will be quantified based on amount of overlap between subpopulation utilization distributions. This analysis will assess observed overlap based on documented movements of individual study animals and will be helpful in identifying site specific geographic areas having high potential for overlap. It is recognized that failure to document interpopulation movements does not mean it does not occur (see discussion above).

Potential subpopulation overlap and potential for subpopulation interchange will be evaluated using the following data: 1) amount of overlap, if any, between subpopulation ram movement buffers/utilization distributions, 2) distance to nearest bighorn subpopulation, 4) extent and continuity of bighorn habitat between subpopulations, and 4) distance to nearest domestic sheep allotment.

2. Validating and Modeling Bighorn Sheep Habitat

The Hells Canyon bighorn habitat model (Hells Canyon model), developed by the Hells Canyon Bighorn Restoration Committee (Hells Canyon Bighorn Restoration Committee 2004) and subsequently modified by the PNF (US Forest Service 2006), will be validated for application to the study area using empirical field data. All locations of radio-collared bighorns will be superimposed on remotely sensed GIS data layers for habitat variables used in the Hells Canyon model including slope, forest cover, and habitat type. Remotely sensed data layers will be field validated using randomly selected survey plots. GIS analysis will be used to quantify observed bighorn habitat use within the study area in terms of the Hells Canyon habitat model parameters (slope, buffer from escape cover, minimum area, cover, and habitat type). Observed bighorn habitat use will be compared to existing Hells Canyon model parameter criteria to validate and/or modify the Hells Canyon model for use in the study area. The validated habitat model will be used to map bighorn habitat within the study area as a broad-scale indicator of potential bighorn range, potential for bighorn occurrence or occupancy, connectivity between subpopulations, and potential for overlap with domestic livestock.

3. Spatial and Temporal Overlap between Domestic Sheep Allotments, Domestic Sheep, and the Main Stem Subpopulation and Bighorn Habitat

Previous study objectives have been designed to gather and analyze bighorn data needed to assess spatial and temporal overlap between bighorn and domestic sheep within the study area. Overlap will be quantified by combining bighorn data (population boundaries, ram movements, and bighorn habitat) and domestic sheep data (allotment boundaries, grazing seasons, and historic and current grazing routes) in a GIS analysis. Potential risk of contact between bighorn and domestic sheep will be assessed by using these same data to develop a risk of contact probability model.

Spatial and temporal overlap will be quantified on broad and fine scales. Broad scale overlap will be quantified using a habitat and population approach. Spatial and temporal overlap will be analyzed by bighorn sex and age and domestic sheep band type (ewe/lamb band, ewe/buck band, dry ewe band, or stray sheep).

Broad Scale Habitat Approach. Potential overlap between bighorns and allotment boundaries will be quantified by overlaying modeled bighorn habitat and allotment boundaries using GIS analysis. This approach uses low resolution data and is most useful for assessing likelihood of contact between bighorn and domestic sheep on a broad scale. It also has application as a predictive planning tool for projecting likelihood of contact as a consequence of future management actions that may change the relative distribution of these two species.

Broad Scale Population Approach. Overlap between bighorns and domestic sheep will also be quantified using locations of radio-collared bighorns (ewes and rams), allotment boundaries, and grazing routes of domestic sheep (temporal use patterns of allotments). A utilization distribution for radio-collared bighorns will be constructed for the domestic sheep grazing season using Adaptive Kernel home range analysis (ESRI Animal Movement Extension, Redlands, CA). The utilization distribution will be superimposed on GIS data layers of allotment boundaries and grazing routes. Extent of overlap will be quantified using GIS analysis and assessed in terms of allotment boundaries, grazing routes, age/sex of bighorns, and seasonal bighorn movement patterns. This analysis documents observed overlap and assesses potential for future contact between bighorn and domestic sheep based on documented movements of specific individual radio-collared bighorns, existing allotment boundaries, and grazing routes under current habitat conditions, bighorn distribution, and domestic sheep management.

Fine Scale Approach. When radio-collared bighorns are located near active allotments during the grazing season, we will monitor those bighorns and the nearest domestic sheep from the ground on a daily basis. A minimum of 2 bighorn and domestic sheep locations per day will be attempted. Project technicians, working from the ground, will locate bighorns and domestic sheep using telemetry and visual observations respectfully, and locations will be recorded use hand help GPS units. Ground efforts will be augmented by aerial telemetry, as needed and feasible. Bighorn identification, allotment identification, domestic sheep band identification, domestic sheep band type, date, bighorn location coordinates, nearest domestic sheep location coordinates, and visual observations will be recorded for each ground and aerial radiolocation obtained.

Encounters between domestic sheep and individual bighorns will be recorded and quantified as the distance between location of bighorns and nearest location of domestic sheep based on ground and aerial radiolocations. Encounters will be categorized as 1) physical contact (0-10m), 2) associated with domestic sheep (11-100m), 3) in close proximity of domestic sheep (101m – 1km), 4) in proximity of domestic sheep (1.1-13.5km), and distant from domestic sheep (>13.5 km). Encounter rate, weighted mean rate, and encounter extent will be calculated for each allotment. Encounter rate will be calculated for each encounter category by summing all encounters within a category occurring within an allotment during one grazing season. Weighted mean encounter rate will be calculated for each allotment by averaging the weighted values for each encounter category. Encounter extent for each allotment will be calculated by constructing a 100% Minimum Convex Polygon (encounter polygon; ESRI Animal Movement Extension, Redlands, CA) using all bighorn locations, within and adjacent to an allotment and for which encounters with domestic sheep were recorded, then determining the percent overlap between the encounter polygon and the allotment boundaries using GIS analysis.

For all bighorns observed, visual signs of health and/or health problems will be recorded. Bighorns observed in close proximity to domestic sheep will be euthanized and disease samples taken.

4. Potential Risk of Contact

Risk of contact will be evaluated using a GIS spatial analysis approach (ESRI Spatial Analyst Extension, Redlands, CA). The ArcGIS Spatial Analyst extension will be used to construct a temporally-explicit risk of contact probability model for the study area. The model will incorporate bighorn population and habitat data and domestic sheep allotment and grazing route information. More specifically, the model will combining the following data: 1) distance/overlap between subpopulation(s), allotments, and grazing routes; 2) encounter rate and extent; 3) amount and continuity of modeled bighorn habitat within allotments/grazing routes and between allotments and the nearest bighorn subpopulation; and 4) allotment characteristics (grazing season, band size and type, grazing routes and patterns, grazing route flexibility, etc…). The model will be used to characterize and map risk of contact between domestic and bighorn sheep across the study area.

5. Subpopulation Demographics

Bighorn subpopulation productivity will be monitored by assessing population vital rates including sex specific adult survival, ewe productivity and lamb survival, and subpopulation growth. This effort will provide baseline data to determined population status and trends through time within the study area, and to compare vital rates with other bighorn sheep populations whose ranges are not in close proximity to domestic sheep.

<u>Sex Specific Adult Survival and Cause-Specific Mortality.</u> All VHF and GPS collars will include a mortality sensor to facilitate detection of adult bighorn mortalities and collection of carcasses. All dead bighorns will be necropsied and tested for disease using standard protocols (Hells Canyon Bighorn Sheep Restoration Committee 2004) at the Washington Animal Disease and Diagnostic Laboratory, Pullman, Washington. Sex, age, estimated date of death, and cause of death will be recorded for each adult mortality.

Survival rates will be calculated using program Capture (Otis et al. 1978) and compared between sexes, subpopulations, and years using standard *t* tests. Cause specific mortality will be compared between cause, sex, subpopulation, and year using standard X^2 tests (Pollock et al. 1989)

<u>Ewe Productivity and Lamb Survival.</u> Ewe productivity and lamb survival will be monitored through weekly aerial observations of radio-collared ewes during the lambing period (late April-early June) and a minimum of semi-monthly observations of radio-collared ewes through the remainder of the summer to track lamb survival. Based on aerial observations, opportunistic ground searches will be undertaken to locate suspected dead lambs. All dead lambs will be

necropsied, and tested for disease using standard protocols (Hells Canyon Bighorn Sheep Restoration Committee 2004), at the Washington Animal Disease and Diagnostic Laboratory, Pullman, Washington. Sex, age, estimated date of death, and cause of death will be recorded for each lamb mortality. For each ewe/lamb pair, lamb presence/absence will be recorded during each monitoring flight from April through October as an index of lamb survival. Winter ewe:lamb ratios will be calculated and compared between subpopulations and years.

Subpopulation Growth. Winter helicopter surveys to estimate population size and composition will be conducted by the Idaho Department of Fish and Game every 3 years using standard methodology (Unsworth et al. 1994). Data points will be collected to supplement and further develop a bighorn sheep sightability model. Surveys will be conducted between late January and early March. Population size and composition will be estimated by subppulation and year. Subpopulation growth rates will be estimated when data are adequate.

6. Genetic Relatedness

Blood and tissue samples collected from the Main Stem and South Fork subpopulations during this study and samples previously collected from the Big Creek subpopulation will be analyzed for genetic relatedness as another indicator of Salmon River subpopulation interchange. Salmon River subpopulation samples will be compared to those collected by the Hells Canyon Initiative from bighorn sheep in the Hells Canyon ecosystem to assess efficacy of using this technique to identify bighorn sheep interchange between Hells Canyon and Salmon River subpopulations.

Implementation and Time Line

This project will be completed over a 5.5-year time frame, from October 2007 through April 2013, as funding permits. This study proposal is endorsed by collaborators, but funding, to date, has not been secured. It is anticipated that substantial funding for this study must be secured through outside sources. The project will be conducted in 2 phases. Phase I will focus on project objective 1, documenting distribution and movements, within the Main Stem subpopulation, and secondarily, conducting a preliminary assessment of overlap between bighorn and domestic sheep (Table 1). Phase I will be completed within the first 1.5 years of the research project from October 2007 through April 2009 and include a 12-month field season(October 2007 through October 2008) and a 6-month data analysis, study design review, and reporting period (November 2008 through April 2009). Phase I will provide researchers with a better understanding of spatial and temporal distribution of bighorn ewe and ram groups and a preliminary assessment of potential overlap with allotment boundaries and domestic sheep. This preliminary information will be valuable for fine-tuning study designs for addressing remaining study objectives. In addition, the South Fork subpopulation boundary may be solely contained within the Frank Church River-of-No-Return Wilderness Area, complicating capture and collaring efforts. Capture experience and distribution information gained during phase I will be instrumental in designing an effective capture strategy for expanding the project to include the South Fork subpopulation.

Phase II will be implemented in October 2008, and will include annual capture and collar operations for the Main Stem and South Fork subpopulations during October through December, data analysis and reporting periods from January through May, and intensive field seasons during the grazing season from June through October of each study year (Table 2). Phase II will address all study objectives. Radio-collared bighorns will be monitored year-round from October 2007 through October 2012.

Reporting

Annual progress reports and a final project report will be developed and submitted to all collaborators and funding groups and agencies. Annual progress reports for Phase II will be completed by 31 May of each study year. A Phase I final report will be completed by 30 April 2009, and a Phase II final report will be completed by 30 April 2013. Collaborators will work together to prepare and submit research results for consideration in peer-reviewed publications.

Cooperators

Results of this study will be most effective in resolving domestic and bighorn sheep management concerns if research is conducted in a collaborative fashion and is supported by a broad spectrum of vested interest groups. This collaborative research project is supported by the US Fish and Wildlife Service, Foundation for North American Wild Sheep, National Wildlife Federation, the Wilderness Society, and Hells Canyon Preservation Council.

Table 1. Research timeline for Phase I of the Salmon River Bighorn Sheep Project, Idaho, 2007-2009.

Year/Month	Phase I Tasks
2007	
October – December	• Capture and radio collar Main Stem subpopulation • Data collection (Monitor bighorn distribution and movements)
2008	
January - May	• Data collection (Monitor bighorn distribution and movements) • Data collection (Develop/organize existing GIS layers) • Grants (develop grant proposals for needed project funding)
June - October	• Data collection (Monitor bighorn distribution and movements) • Data collection (Monitor overlap between domestic and bighorn sheep)
November - December	• Data analysis (Main Stem distribution/movements) • Data analysis (Bighorn/domestic sheep overlap) • Data analysis (Main Stem subpopulation demographics)
2009	
January - April	• Data analysis and reporting (Phase I final report by 30 April 2009)

Table 2. Research timeline for Phase II of the Salmon River Bighorn Sheep Project, Idaho, 2008-2013.

Year/Month	Phase II Tasks
2008	
October – December	• Capture and radio collar Main Stem and South Fork subpopulations) • Data collection (Monitor bighorn distribution and movements)
2009	
January - May	• Data collection (Monitor bighorn distribution and movements) • Data design and analysis (Prepare study design and GIS layers for habitat modeling and validation)
June - October	• Data collection (Monitor bighorn distribution and movements) • Data collection (Monitor overlap between domestic and bighorn sheep) • Data collection (Field validation of habitat model)
October - December	• Data collection (Monitor bighorn distribution and movements) • Capture and radio collar Main Stem and South Fork subpopulations
2010 -2011	
January - May	• Data collection (Monitor bighorn distribution and movements) • Data analysis (Ewe distribution and movements) • Data analysis (Ram movements and subpopulation overlap) • Data analysis (Bighorn/domestic sheep overlap) • Data analysis (Risk of contact probability model) • Data analysis (Habitat modeling; 2010 only) • Reporting (Annual progress report by 31 May)
June - October	• Data collection (Monitor bighorn distribution and movements) • Data collection (Monitor overlap between domestic and bighorn sheep)
October - December	• Data collection (Monitor bighorn distribution and movements) • Capture and radio collar Main Stem and South Fork subpopulations)

Table 2 (cont…). Research timeline for Phase II of the Salmon River Bighorn Sheep Project, Idaho, 2008-2013.

Year/Month	Phase II Tasks
2012	
January - May	• Data collection (Monitor bighorn distribution and movements) • Data analysis (Ewe distribution and movements) • Data analysis (Ram movements and subpopulation overlap) • Data analysis (Bighorn/domestic sheep overlap) • Data analysis (Risk of contact probability model) • Reporting (Prepare collaborative manuscripts for peer-reviewed publication) • Reporting (Annual progress report by 31 May)
June - October	• Data collection (Monitor bighorn distribution and movements) • Data collection (Monitor overlap between domestic and bighorn sheep)
November - December	• Data collection (Monitor remaining radio-collared study animals) • Data analysis (Ewe distribution and movements) • Data analysis (Ram movements and subpopulation overlap)
2013	
January - April	• Data analysis (Bighorn/domestic sheep overlap) • Data analysis (Risk of contact probability model) • Reporting (Phase II final report by 30 April • Reporting (Prepare collaborative manuscripts for peer-reviewed publication

Budget

Total project budget for this 5.5 year research effort is estimated at $1,33,846, an average annual budget of $243,245. Total cost for Phase I, implemented between 2007-2009, is projected at $273,363, while total cost for Phase II, implemented between 2008-2013, is projected at $1,064,483. Primary expenditures include flight time (helicopter and fixed wing) for captures and monitoring flights, equipment for capture and radio collaring operations, salary for a full-time research biologist and two seasonal field technicians, and vehicles for transportation. The budget incorporates an annual 3% inflationary adjustment for salary and flight costs. Annualized budgets for Phase I and Phase II are provided in Tables 3 and 4 respectively.

Table 3. Annualized project budget, Phase I, Salmon River Bighorn Sheep Project, Idaho, 2007-2009.

Year	Item	Description	Amount
2007	Salary	Research Biologist; 1 for 3 mos	$ 10,550
	Radio Collars	18 VHF @ $247; 10 GPS @ $ 1,900	$ 23,446
	Flight time (fixed wing)	Monitoring; 36 hrs @ $320/hr	$ 11,520
	Flight time (helicopter)	Capture; 8 hrs @ $1,350/hr	$ 10,800
	Jet boat and crew	Capture; 24 mandays @ $150/day	$ 3,600
	Travel	Vehicle; 1 for 3 mos	$ 1,500
	Operating	Supplies; Equipment; Travel	$ 5,000
	Indirect		$ 4,604
	2007 Subtotal:		**$ 71,020**
2008	Salary	Research Biologist; 12 mos	$ 42,200
	Salary	Field Technician; 1 for 4 mos	$ 10,300
	Salary	GIS Analyst; 1 for 3 mos	$ 10,550
	Flight Time (fixed wing)	Monitoring; 180 hrs @ $330/hr	$ 59,400
	Travel	Vehicles; 2 for 12 and 4 mos	$ 8,000
	Operating	Supplies; Equipment; Travel	$ 20,000
	Indirect and Administration	Includes Office Lease @ $ 9,900	$ 31,635
	2008 Subtotal:		**$ 182,085**
2009	Salary	Research Biologist; 2 mos	$ 7,244
	Salary	GIS Analyst; 1 for 3 mos	$ 10,867
	Indirect		$ 2,147
	2009 Subtotal:		**$ 20,258**
	Phase I Project Total:		**$ 273,363**

Table 4. Annualized project budget, Phase II, Salmon River Bighorn Sheep Project, Idaho, 2008-2013.

Year	Item	Description	Amount
2008	Radio Collars	VHF; 5 @ $265; GPS 15 @ $ 2,100	$ 32,825
	Flight Time and Crew (helicopter)	Capture; 8 hrs @ $1,391/hr	$ 11,128
	Jet Boat and Crew	Capture; 24 mandays @ $150/day	$ 3,600
	2008 Subtotal:		**$ 47,553**
2009	Salary	Research Biologist; 8 mos	$ 28,977
	Salary	Field Technicians; 2 for 4 mos	$ 21,218
	Radio Collars	VHF; 5 @ $265 GPS; 15 Refurb @ $ 1,260	$ 20,225
	Flight Time (fixed wing)	Monitoring; 180 hrs @ $340/hr	$ 61,200
	Flight Time and Crew (helicopter)	Capture; 8 hrs @ $1,433/hr	$ 11,464
	Jet Boat and Crew	Capture; 24 mandays @ $150/day	$ 3,600
	Travel	Vehicles; 3 for 12 mos	$ 18,000
	Operating	Supplies; Equipment; Travel	$ 20,000
	Indirect and Administration	Includes Office Lease @ $ 9,900	$ 35,481
	2009 Subtotal:		**$ 220,165**
2010	Salary	Research Biologist; ;12 mos	$ 44,770
	Salary	Field Technicians; 2 for 4 mos	$ 21,855
	Salary	GIS Analyst; 1 for 3 mos	$ 11,193
	Radio Collars	VHF 5 @ $265 GPS 15 Refurb @ $ 1,260	$ 20,225
	Flight Time (fixed wing)	Monitoring; 180 hrs @ $350/hr	$ 63,000
	Flight Time and Crew (helicopter)	Capture; 8 hrs @ $1,476/hr	$ 11,808
	Jet Boat and Crew	Capture; 24 mandays @ $150/day	$ 3,600
	Travel	Vehicles; 3 for 12 mos	$ 18,000
	Operating	Supplies; Equipment; Travel	$ 20,000
	Indirect and Administration	Includes Office Lease @ $ 9,900	$ 38,149
	2010 Subtotal:		**$ 252,600**

Table 4 (cont.). Annualized project budget, Phase II, Salmon River Bighorn Sheep Project, Idaho, 2008-2013.

Year	Item	Description	Amount
2011	Salary	Research Biologist; 12 mos	$ 46,113
	Salary	Field Technicians; 2 for 4 mos	$ 22,510
	Salary	GIS Analyst; 1 for 3 mos	$ 11,529
	Radio Collars	VHF; 5 @ $265 GPS; 15 Refurb @ $ 1,260	$ 20,225
	Flight Time (fixed wing)	Monitoring; 180 hrs @ $361/hr	$ 64,980
	Flight Time and Crew (helicopter)	Capture; 8 hrs @ $1,520/hr	$ 12,160
	Jet Boat and Crew	Capture; 24 mandays @ $150/day	$ 3,600
	Travel	Vehicles; 3 for 12 mos	$ 18,000
	Operating	Supplies; Equipment; Travel	$ 20,000
	Indirect and Administration	Includes Office Lease @ $ 9,900	$ 38,688
	2011 Subtotal:		**$ 257,805**
2012	Salary	Research biologist; 12 mos	$ 47,497
	Salary	Field Technicians; 2 for 4 mos	$ 23,185
	Salary	GIS Analyst; 1 for 3 mos	$ 11,875
	Flight Time (fixed wing)	Monitoring; 156 hrs @ $372/hr	$ 66,960
	Travel	Vehicles; 3 for 12 mos	$ 18,000
	Operating	Supplies; Equipment; Travel	$ 20,000
	Indirect and Administration	Includes Office Lease @ $ 9,900	$ 39,244
	2012 Subtotal:		**$ 226,761**
2013	Salary	Research Biologist; Data Analysis, Reporting; 4 mos	$ 16,308
	Salary	GIS Analyst; 1 for 4 mos	$ 16,308
	Operating	GIS Support; Analysis Support; Publication Costs	$ 10,000
	Indirect and Administration	Includes Office Lease @ $ 9,900	$ 17,003
	2013 Subtotal:		**$ 59,619**
	Phase II Project Total:		**$ 1,064,483**
	Phase I and II Project Total:		**$ 1,337,846**

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APPENDIX D

ACTIVE PUBLIC LANDS DOMESTIC SHEEP ALLOTMENTS

WITHIN AND ADJACENT TO THE

SALMON RIVER BIGHORN SHEEP PROJECT AREA 2006

Appendix D. Active domestic sheep allotments within and adjacent to Salmon River Bighorn Sheep Project Area, ID, USA, 2006. BLM = Bureau of land Management, NPCNF = Nez Perce Clearwater National Forest, PNF = Payette National Forest.

			Grazing Season		Permitted No. of Sheep	
Location/Agency	Allotment	Acres	On Date	Off Date	Class	Adults
Within Project Area						
BLM [a]	Partridge Creek	16029	4/11	7/15	Ewe/lambs	833
			10/15	11/30	Dry ewes	
	Marshall Mountain	4212	7/5	8/4	Ewe/lambs	815
	Hard Creek	5210	6/15	7/15	Ewe/lambs	1050
NPCNF [b c]	Allison-Berg	37249	4/16	7/7	Ewe/lambs	1600
			12/20	3/1	Dry ewes	2450
PNF [d]	Hershey-Lava	20212	7/10	9/15	Ewe/lambs	1333
	French Creek	25922	7/7	10/7	Ewe/lambs	833
	Bear Pete	34282	7/7	10/7	Ewe/lambs	833
	Marshall Mountain	28621	7/7	10/7	Ewe/lambs	834
	Vance Creek	7677	9/15	10/15	Dry Ewes	2666
	Little French Creek	4679	7/10	7/20	Dry Ewes	1333
	Josephine	14116	7/10	9/15	Ewe/lambs	1333
	Victor-Loon	43832	8/26	10/10	Dry Ewes	1500
	Grassy Mountain	16480	7/10	9/15	Ewe/lambs	1333
	Slab Butte	9909	7/10	9/15	Ewe/lambs	1333
	Cougar Creek	11591	7/10	9/15	Ewe/lambs	1333
	Twenty Mile	15006	7/10	9/15	Ewe/lambs	1333
	Brundage	8603	9/15	10/15	Dry Ewes	2666
	Bill Hunt	6937	9/15	10/15	Dry Ewes	2666
	Fall/Brush Creek	20365	7/1	8/25	Ewe/lambs	800
	North Fork Lick Creek	12037	8/25	8/25	Dry Ewes	1500
	Lake Fork	21740	7/1	8/25	Ewe/lambs	817
	Jughandle	42420	7/10	10/15	Dry Ewes	2000
Adjacent to Project Area						
PNF	Smith Mountain	84285	5/16	8/10	Ewe/lambs	1200
			8/17	10/15	Dry Ewes	1200
			6/18	8/10	Ewe/lambs	1900
			8/17	10/15	Dry Ewes	1900
	Curren Hill	16023	9/1	9/30	Dry Ewes	1925
	Boulder Creek	19635	6/16	8/31	Ewe/lambs	1000
	Price Valley	18320	6/16	8/31	Ewe/lambs	895

[a] BLM 2016a
[b] USFS 2007*b*
[c] USFS 2006*c*
[d] USFS 2006*a*

APPENDIX E

SALMON RIVER BIGHORN SHEEP PROJECT

BIG HORN SHEEP CAPTURE OPERATIONS

2007-2013

Appendix E. Sex, age, capture date and method, and radiocollar type (VHF = Very High Frequency, GPS = Global Positioning System) for bighorn sheep captured along the Salmon River, Salmon River Bighorn Sheep Project, ID, USA, 2007-2013.

Animal ID	Sex	Age Category	Age Years	Capture Date	Capture Method	Collar Type(s)
R2	M	Adult	5.5	11/7/2007	Ground Dart	VHF
R3	M	Yearling	1.5	11/7/2007	Ground Dart	VHF,GPS
R4	M	Adult	3.5	11/7/2007	Ground Dart	VHF,GPS
E1	F	Adult	4.5	11/8/2007	Ground Dart	VHF
E5	F	Adult	2.5	11/8/2007	Ground Dart	VHF
R6	M	Adult	3.5	11/14/2007	Ground Dart	VHF,GPS
R7	M	Adult	2.5	11/15/2007	Ground Dart	VHF,GPS
E8	F	Adult	5.5	11/15/2007	Ground Dart	VHF
R9[a]	M	Adult	7.5	11/15/2007	Ground Dart	N/A
E10	F	Adult	4.5	11/16/2007	Ground Dart	VHF
E11	F	Adult	8.5	11/17/2007	Ground Dart	VHF
R12	M	Adult	6.5	2/18/2008	Drive Net	VHF,GPS
R13	M	Adult	3.5	2/18/2008	Drive Net	VHF
R14	M	Adult	6.5	3/14/2008	Net Gun	VHF,GPS
R15	M	Yearling	1.5	3/14/2008	Net Gun	VHF,GPS
R16	M	Yearling	1.5	3/14/2008	Net Gun	VHF
E17	F	Adult	5.5	11/13/2008	Ground Dart	VHF
E18	F	Adult	5.5	11/14/2008	Ground Dart	VHF
R19	M	Adult	4.5	11/19/2008	Ground Dart	VHF,GPS
E20	F	Adult	7.5	11/20/2008	Ground Dart	GPS
E21	F	Adult	3.5	11/20/2008	Ground Dart	VHF
R22	M	Adult	11+	11/20/2008	Ground Dart	VHF,GPS
R23	M	Yearling	1.5	11/21/2008	Ground Dart	VHF,GPS
R24	M	Adult	4.5	11/21/2008	Ground Dart	VHF,GPS
E25	F	Adult	2.5	11/21/2008	Ground Dart	VHF
R26	M	Adult	8	12/3/2008	Net Gun	VHF,GPS
E27	F	Adult	4.5	12/3/2008	Net Gun	VHF
R28	M	Adult	2.5	12/3/2008	Net Gun	VHF
E29	F	Adult	3.5+	12/3/2008	Net Gun	GPS
R30	M	Adult	4.5	12/3/2008	Net Gun	VHF,GPS
E31	F	Adult	6.5	12/3/2008	Net Gun	VHF
R32	M	Adult	6.5	12/3/2008	Net Gun	VHF,GPS
E33	F	Adult	2.5	12/3/2008	Net Gun	VHF
R34	M	Adult	4.5	12/3/2008	Net Gun	VHF,GPS
E35	F	Adult	3.5	11/18/2009	Ground Dart	VHF
R36	M	Adult	9.5	11/20/2009	Ground Dart	GPS
E37	F	Adult	7.5	11/20/2009	Ground Dart	VHF
R13[b]	M	Adult	5.5	2/5/2010	Net Gun	VHF,GPS
R15[b]	M	Adult	3.5	2/5/2010	Net Gun	VHF,GPS
R28[b]	M	Adult	4.5	2/5/2010	Net Gun	VHF
R38	M	Adult	9.5	2/5/2010	Net Gun	VHF,GPS
R39	M	Adult	5.5	2/5/2010	Net Gun	VHF,GPS
R40	M	Adult	4.5	2/5/2010	Net Gun	VHF,GPS
R41	M	Adult	2.5	2/5/2010	Net Gun	VHF
E43	F	Adult	6	11/18/2010	Ground Dart	VHF

Animal ID	Sex	Age Category	Age Years	Capture Date	Capture Method	Collar Type(s)
R4[b]	M	Adult	6.5	11/19/2010	Ground Dart	VHF
R42	M	Adult	3.5	11/19/2010	Ground Dart	VHF
E44	F	Adult	6	11/19/2010	Ground Dart	VHF
R45	M	Adult	5.5	11/7/2011	Ground Dart	VHF
E46	F	Adult	9.5	11/7/2011	Ground Dart	GPS
E47	F	Adult	6.5	11/8/2011	Ground Dart	GPS
E48	F	Adult	3.5	11/8/2011	Ground Dart	GPS
R22[b]	M	Adult	11.5	11/9/2011	Ground Dart	VHF,GPS
E49	F	Adult	11.5	11/9/2011	Ground Dart	GPS
E50	F	Adult	8.5	11/10/2011	Ground Dart	GPS
E51	F	Adult	6.5	11/10/2011	Ground Dart	GPS
E52	F	Adult	3.5	11/10/2011	Ground Dart	VHF
E53	F	Adult	3.5	11/11/2011	Ground Dart	VHF
E54	F	Adult	5.5	11/11/2011	Ground Dart	VHF
R55	M	Adult	2.5	11/11/2011	Ground Dart	VHF
E56[a]	F	Adult	6.5	11/11/2011	Ground Dart	VHF
R13[b]	M	Adult	9 or 10	3/14/2012	Net Gun	VHF
R15[b]	M	Adult	6	3/14/2012	Net Gun	VHF
E17[b]	F	Adult	6 or 7	3/14/2012	Net Gun	VHF,GPS
R40[b]	M	Adult	6	3/14/2012	Net Gun	VHF
E57	F	Adult	4 or 5	3/14/2012	Net Gun	VHF,GPS
E58	F	Adult	6 or 7	3/14/2012	Net Gun	VHF,GPS
E59	F	Adult	4	3/14/2012	Net Gun	VHF,GPS
R19[b]	M	Adult	7	1/29/2013	Net Gun	VHF
E27[b]	F	Adult	6	1/29/2013	Net Gun	VHF
R39[b]	M	Adult	8	1/29/2013	Net Gun	VHF
E60	F	Adult	4	1/29/2013	Net Gun	VHF
E61	F	Adult	6	1/29/2013	Net Gun	VHF
E62	F	Adult	5	1/29/2013	Net Gun	VHF,GPS
E63	F	Adult	5	1/29/2013	Net Gun	VHF
E64	F	Adult	7	1/29/2013	Net Gun	VHF
E65	F	Adult	6+	1/29/2013	Net Gun	VHF
R66	M	Yearling	1	1/29/2013	Net Gun	VHF
E67	F	Adult	3+	1/29/2013	Net Gun	VHF
E68	F	Adult	6+	1/29/2013	Net Gun	VHF
E69	F	Adult	5	1/29/2013	Net Gun	VHF
E70	F	Adult	4+	1/29/2013	Net Gun	VHF,GPS

[a] Capture Mortality
[b] Recapture

APPENDIX F

SALMON RIVER BIGHORN SHEEP PROJECT

AVERAGE CROSS-YEAR AREA AND OVERLAP INDEX VALUES

FOR INDIVIDUAL COLLARED ANIMALS AND

SOCIAL GROUPS

Appendix F. Average percent overlap of annual individual home ranges and groups use areas, and average difference from mean annual home range and use area size for radio-collared bighorn sheep along the Salmon River, ID, USA, 2007-2015.

Sex	AID	No. of Complete Study Years	Overlap Range (%)	$\bar{x}$ Overlap (%)	Area Range (km^2)	$\bar{x}$ Area (km^2)	$\bar{x}$ Difference from $\bar{x}$ Area (%)
Females	E1	4	31.9 - 100.0	77.5	66.28 - 205.09	121.65	34.29
	E10	3	49 - 100.0	76.9	17.84 - 35.64	28.07	24.31
	E17	3	54.7 - 99.3	75.7	88.23 - 157.01	113.00	25.96
	E18	3	58.8 - 100.0	82.8	67.22 - 125.17	100.04	18.44
	E20	2	67.4 - 99.4	83.4	55.35 - 81.42	68.39	19.06
	E21	4	58.5 - 97.4	84.0	30.72 - 50.13	41.59	13.86
	E25	4	19.2 - 100.0	71.1	23.11 - 133.19	68.91	50.00
	E27	5	25.4 - 100.0	72.4	33.66 - 129.54	79.86	44.52
	E31	4	68.7 - 94.1	81.1	53.28 - 71.05	63.74	10.51
	E33	4	41.0 - 100.0	80.6	38.75 - 93.34	59.82	28.02
	E35	3	50.7 - 100.0	81.9	39.74 - 165.48	96.46	47.70
	E37	2	69.8 - 89.2	79.5	171.46 - 219.15	195.31	12.21
	E5	3	51.4 - 88.3	69.4	63.47 - 102.09	84.90	16.83
	E52	2	34.8 - 100.0	67.4	26.03 - 73.88	49.95	47.89
	E53	2	80.7 - 95.3	88.0	89.51 - 105.59	97.55	8.24
	E57	2	76.2 - 89.9	83.1	49.14 - 58.63	53.89	8.80
	E58	3	42.2 - 100.0	78.2	56.93 - 133.14	90.29	31.63
	E59	3	75.8 - 86.3	82.3	33.93 - 35.46	34.45	1.94
	E61	2	29.6 - 100.0	64.8	24.42 - 80.85	52.64	53.61
	E62[1]	2	75.8 - 85.5	80.6			
	E63	2	84.1 - 100.0	92.1	278.58 - 331.02	304.80	8.60
	E65	2	74.9 - 99.3	87.1	260.65 - 347.16	303.90	14.23
	E67	2	70.9 - 94.5	82.7	260.65 - 347.16	303.90	14.23
	E70	2	18.9 - 100.0	59.4	36.56 - 189.6	113.08	67.67
	E8	3	54.7 - 97.2	79.3	38.1 - 67.01	48.34	25.75
	All Females	71	18.9 - 100.0	78.46	17.84 - 347.16	107.27	26.18
Males	R12	3	31.3 - 100.0	73.8	147.64 - 468.63	291.30	40.58
	R13	5	7.2 - 100.0	61.7	70.6 - 990.17	449.87	76.79
	R15	6	12.4 - 100.0	68.1	39.73 - 312.94	168.70	55.97
	R19	4	44.1 - 96.3	76.9	112.49 - 535.22	307.10	39.85
	R22[1]	2	63.5 - 92.2	77.8			
	R23	4	46.1 - 100.0	78.7	132.64 - 286.16	192.59	26.24
	R24	3	25.8 - 100.0	66.3	75.94 - 280.82	189.93	35.18
	R26	2	27.9 - 100.0	64.0	136.47 - 484.71	310.59	56.06
	R3	3	23.0 - 100.0	63.4	113.2 - 488.62	259.94	58.65

Appendix F (cont…)

Sex	AID	No. of Complete Study Years	Overlap Range (%)	$\bar{x}$ Overlap (%)	Area Range (km^2)	$\bar{x}$ Area (km^2)	$\bar{x}$ Difference from $\bar{x}$ Area (%)
	R30	4	19.8 - 100.0	70.9	194.3 - 979.95	491.11	49.77
	R32	4	55.4 - 94.6	81.3	46.45 - 75.23	58.76	15.38
	R34[1]	2	41.2 - 100.0	84.9			
	R39	4	60.7 - 99.6	85.8	220.23 - 348.08	293.32	17.22
	R4	5	8.8 - 100.0	64.2	19.45 - 214.36	120.17	54.09
	R40	3	26.4 - 100.0	69.8	111.31 - 421.64	237.94	38.60
	R41	2	37.0 - 100.0	68.5	153.21 - 411.34	282.28	45.72
	R42	2	67.9 - 89.1	78.5	361.55 - 474.31	417.93	13.49
	R45	2	71.3 - 96.1	83.7	188.02 - 253.22	220.62	14.78
	R7	3	61.7 - 91.0	72.4	46.96 - 164.02	113.05	38.97
	All Males	63	7.2 - 100.0	73.2	19.45 - 990.17	259.1	39.8

Sex	Social Group	No. of Complete Study Years	Overlap Range (%)	$\bar{x}$ Overlap (%)	Area Range (km^2)	$\bar{x}$ Area (km^2)	$\bar{x}$ Difference from $\bar{x}$ Area (%)
Females	Indian Creek	9	25.3 - 100.0	76.21	39.00 - 154.00	103.00	26.91
	Jersey Creek	9	38.3 - 100.0	73.99	67.00 - 170.00	121.86	26.39
	South Fork	7	21.7 - 100.0	76.19	49.00 - 227.00	87.86	25.21
	Wind River	9	59.9 - 100.0	85.50	62.00 - 104.00	78.57	15.90
	All Female Groups	34	21.7 - 100.0	78.27	39.00 - 227.00	97.82	23.60
Males	Blowout	8	39.1 - 100.0	78.70	146.00 - 374.00	217.88	24.60
	Bull	5	39.4 - 98.4	65.94	202.00 - 333.00	265.60	20.15
	Manning	6	7.9 - 100.0	67.44	74.00 - 378.00	247.33	34.59
	South Fork	5	38.9 - 100.0	79.47	32.00 - 74.00	53.40	20.37
	All Male Groups	24	7.94 - 100.0	73.53	32.00 - 378.00	200.92	25.29

APPENDIX G

SALMON RIVER BIGHORN SHEEP PROJECT

PERCENT OF TELEMETRY LOCATIONS OVERLAPPING

SOCIAL GROUP BOUNDARIES

Appendix G. Percent of telemetry locations occurring within neighboring female and male social group use areas calculated for radio-collared animals along the Salmon River, ID, USA, 2007–2015. Values indicate the number and percent of locations for groups in column B occurring within use areas of groups in column A. Insufficient data excluded the Manning Bridge Ewe group from the analysis.

Females

	A	B			
Total Number of Locns		Indian Creek n (%)	Jersey Creek n (%)	South Fork n (%)	Wind River n (%)
9505	Wind River	264 (7.5%)	0 (0.0%)	0 (0.0%)	-
3519	Indian Creek	-	276 (7.1%)	0 (0.0%)	3 (0.03%)
3899	Jersey Creek	74 (2.1%)	-	0 (0.0%)	0 (0.0%)
2419	South Fork	0 (0.0%)	0 (0.0%)	-	0 (0.0%)

Males

	A	B							
		Blowout Creek		Bull Creek		Manning Bridge		South Fork	
Total Number of Locns		All Locns[a] n (%)	Locns Rut[b] n (%)	All Locns n (%)	Locns Rut n (%)	All Locns n (%)	Locns Rut n (%)	All Locns n (%)	Locns Rut n (%)
7928	Manning Bridge	2 (0.04%)	0 (0%)	894 (39.3%)	664 (74.3%)	-	-	0 (0.0%)	0 (n/a)
2274	Bull Creek	748 (15.5%)	522 (69.8%)	-	-	1895 (23.9%)	1281 (67.6%)	0 (0.0%)	0 (n/a)
4817	Blowout Creek	-	-	57 (2.5%)	17 (29.8%)	92 (1.2%)	92 (100%)	700 (50.0%)	275 (39.3%)
1401	South Fork	152 (3.2%)	126 (82.9%)	0 (0.0%)	0 (n/a)	0 (0.0%)	0 (n/a)	-	-

[a] All Locns = all telemetry locations collected for a social group. Percentages represent proportion of all telemetry locations collected for a social group that overlapped another social group's use area.
[b] Locns Rut = telemetry locations collected during the rut season 1 October–31 December. Percentages represent proportion of all overlapping locations (All Locns) that occurred during the rut seasons.

APPENDIX H

SALMON RIVER BIGHORN SHEEP PROJECT

ANNUAL LAMB PRODUCTION AND SUMMER LAMB SURVIVAL

FOR FEMALE RADIO-COLLARED INDIVIDUALS

AND SOCIAL GROUPS

Appendix H. Annual lamb production and summer lamb survival for female radio-collared individuals and social groups along the Salmon River, ID, USA, 2009-2015.

		2009		2010		2011		2012		2013		2014		2015		No. Years	No. Years
Social Group	Ewe ID	Prod (Y/N)	Surv (Y/N)	Prod (Y/N)	Surv (Y/N)	Prod (Y/N)	Surv (Y/N)	Prod (Y/N)	Surv (Y/N)	Prod (Y/N)	Surv (Y/N)	Prod (Y/N)	Surv (Y/N)	Prod (Y/N)	Surv (Y/N)	Prod Lamb	Surv Lamb
Manning Bridge	E60									No	DNP	No	DNP	Yes	Yes	1	1
Wind River	E5	Yes	No	Yes	Yes	Yes	No									3	1
Wind River	E17	Yes	No	Yes	No	Yes	No									3	0
Wind River	E18	Yes	Yes	No	DNP	Yes	Unk	Yes	No	No	DNP	Yes	Yes	Yes	Yes	5	3
Wind River	E20	No	DNP	No	DNP	Yes	Unk									1	0
Wind River	E27	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes	7	2
Wind River	E44					No	DNP									0	0
Wind River	E49							Yes	No	Yes	No					2	0
Wind River	E57							Yes	Yes	Yes	No					2	1
Wind River	E58							Yes	Yes	Yes	No	No	DNP	No	DNP	2	1
Wind River	E59							Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	4	3
Indian Creek	E8	Yes	Yes	No	DNP	Unk	Unk	No	DNP			Yes	Unk			2	1
Indian Creek	E10	Yes	No	Yes	No	Yes	No	No	DNP	Unk	Unk	Yes	Unk			4	0
Indian Creek	E11															0	0
Indian Creek	E21	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Unk	Yes	Unk			6	2
Indian Creek	E25	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	Unk	Yes	Unk			6	1
Indian Creek	E35			No	DNP	Yes	No	Yes	Yes	Yes	No					3	1
Indian Creek	E43					Yes	Unk									1	0
Indian Creek	E47															0	0
Indian Creek	E48							Yes	Unk							1	0
Indian Creek	E56															0	0
Indian Creek	E68															0	0
Indian Creek	E69									Yes	Yes	Yes	Yes			2	2
Indian Creek	E70									Yes	Yes	Yes	No	Yes	No	3	1
Jersey Creek	E1	Yes	No	Yes	No	Yes	Yes									3	1
Jersey Creek	E37			Yes	No	Yes	No									2	0
Jersey Creek	E46							Yes	Yes	Yes	Unk					2	1
Jersey Creek	E50							Yes	Yes	Yes	Unk					2	1
Jersey Creek	E51							Yes	No							1	0
Jersey Creek	E52							Yes	No	Yes	No	Yes	Yes	No	DNP	3	1
Jersey Creek	E53							Yes	Yes	Yes	Yes	No	DNP	Yes	No	3	2
Jersey Creek	E54							No	DNP	Yes	Unk					1	0
South Fork	E29	Yes	Yes	Unk	Unk											1	1
South Fork	E31	Yes	Yes	Yes	No	Unk	Unk	Yes	No	Yes	No	Yes	Unk			5	1
South Fork	E33	Yes	Unk	Yes	No	Unk	Unk	No	DNP	Yes	Yes					3	1
South Fork	E61									Yes	No	Unk	Unk	Yes	No	2	0

Appendix H (cont…)

Social Group	Ewe ID	2009 Prod (Y/N)	2009 Surv (Y/N)	2010 Prod (Y/N)	2010 Surv (Y/N)	2011 Prod (Y/N)	2011 Surv (Y/N)	2012 Prod (Y/N)	2012 Surv (Y/N)	2013 Prod (Y/N)	2013 Surv (Y/N)	2014 Prod (Y/N)	2014 Surv (Y/N)	2015 Prod (Y/N)	2015 Surv (Y/N)	No. Years Prod Lamb	No. Years Surv Lamb
South Fork	E62									Yes	Yes	No	DNP	Yes	Yes	2	2
South Fork	E63									Yes	No	Yes	Yes	Yes	No	3	1
South Fork	E64									Yes	No					1	0
South Fork	E65									No	DNP	Yes	Yes	No	DNP	1	1
South Fork	E67									Yes	Yes	Yes	Yes	Yes	Yes	3	3
	No. Lambs	12	5	10	1	12	3	16	8	22	7	14	6	10	6	96	36
	n	13	11	14	10	13	9	20	15	25	17	18	9	13	10	116	81
	Rate	0.9231	0.4545	0.7143	0.1000	0.9231	0.3333	0.8000	0.5333	0.8800	0.4118	0.7778	0.6667	0.7692	0.6000	0.8276	0.4444
Manning Bridge	No. Lambs	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	n	0	0	0	0	0	0	0	0	1	0	1	0	1	1	3	1
	Rate	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.3333	1.0000
Wind River	No. Lambs	4	2	3	1	5	0	6	3	5	1	3	1	3	3	29	11
	n	5	4	5	3	6	3	6	6	6	5	4	3	4	3	36	27
	Rate	0.8000	0.5000	0.6000	0.3333	0.8333	0.0000	1.0000	0.5000	0.8333	0.2000	0.7500	0.3333	0.7500	1.0000	0.8056	0.4074
Indian Creek	No. Lambs	4	1	3	0	5	2	4	2	5	2	6	1	1	0	28	8
	n	4	4	5	3	5	4	6	3	5	3	6	2	1	1	32	20
	Rate	1.0000	0.2500	0.6000	0.0000	1.0000	0.5000	0.6667	0.6667	1.0000	0.6667	1.0000	0.5000	1.0000	0.0000	0.8750	0.4000
Jersey Creek	No. Lambs	1	0	2	0	2	1	5	3	5	1	1	1	1	0	17	6
	n	1	1	2	2	2	2	6	5	5	2	2	1	2	1	20	14
	Rate	1.0000	0.0000	1.0000	0.0000	1.0000	0.5000	0.8333	0.6000	1.0000	0.5000	0.5000	1.0000	0.5000	0.0000	0.8500	0.4286
South Fork	No. Lambs	3	2	2	0	0	0	1	0	7	3	4	3	4	2	21	10
	n	3	2	2	2	0	0	2	1	8	7	5	3	5	4	25	19
	Rate	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.5000	0.0000	0.8750	0.4286	0.8000	1.0000	0.8000	0.5000	0.8400	0.5263
Reach																	
Main Stem	No. Lambs	9	3	8	1	12	3	15	8	15	4	10	3	6	4	75	26
	n	10	9	12	8	13	9	18	14	17	10	13	6	8	6	91	62
	Rate	0.9000	0.3333	0.6667	0.1250	0.9231	0.3333	0.8333	0.5714	0.8824	0.4000	0.7692	0.5000	0.7500	0.6667	0.8242	0.4194
South Fork	No. Lambs	3	2	2	0	0	0	1	0	7	3	4	3	4	2	21	10
	n	3	2	2	2	0	0	2	1	8	7	5	3	5	4	25	19
	Rate	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.5000	0.0000	0.8750	0.4286	0.8000	1.0000	0.8000	0.5000	0.8400	0.5263
Project Area	No. Lambs	12	5	10	1	12	3	16	8	22	7	14	6	10	6	96	36
	n	13	11	14	10	13	9	20	15	25	17	18	9	13	10	116	81
	Rate	0.9231	0.4545	0.7143	0.1000	0.9231	0.3333	0.8000	0.5333	0.8800	0.4118	0.7778	0.6667	0.7692	0.6000	0.8276	0.4444

[1] Greyed cells indicate years animal was not monitored
[2] nsd = Not sufficient data to include in calculations
[3] DNP = Did not produce

APPENDIX I

SALMON RIVER BIGHORN SHEEP PROJECT

LAMB PRODUCTION AND SUMMER SURVIVAL

SUMMARY TABLES

Appendix I. Lamb production and summer survival (through 1 October) estimates from radio-collared females (Table 1) and age ratios (lamb:ewe; Table 2) obtained during ground surveys of bighorn sheep along the Salmon River, ID, USA, 2009-2015.

Table 1. Estimates based on fates of lambs born to radio-collared females

Year	Female Group	Spring Lamb Production			Fall Age Ratios			Over Summer Lamb Survival		
		No. Ewes	No. Lambs	Prod[a] Rate	No. Ewes	No. Lambs	L:E[b] Ratio	No. Lambs Spring	No. Lambs Fall	Surv[c] Rate
2009	Wind River	5	4	0.80	5	2	0.40	4	2	0.50
	Indian Creek	4	4	1.00	4	1	0.25	4	1	0.25
	Jersey Creek	1	1	1.00	1	0	0.00	1	0	0.00
	South Fork	3	3	1.00	2	2	1.00	2	2	1.00
	Main Stem	10	9	0.90	10	3	0.30	9	3	0.33
	All Groups	13	12	0.92	12	5	0.42	11	5	0.45
2010	Wind River	5	3	0.60	5	1	0.20	3	1	0.33
	Indian Creek	5	3	0.60	5	0	0.00	3	0	0.00
	Jersey Creek	2	2	1.00	2	0	0.00	2	0	0.00
	South Fork	2	2	1.00	2	0	0.00	2	0	0.00
	Main Stem	12	8	0.67	12	1	0.08	8	1	0.13
	All Groups	14	10	0.71	14	1	0.07	10	1	0.10
2011	Wind River	6	5	0.83	4	0	0.00	3	0	0.00
	Indian Creek	5	5	1.00	4	2	0.50	4	2	0.50
	Jersey Creek	2	2	1.00	2	1	0.50	2	1	0.50
	South Fork	0	N/A	N/A	0	N/A	N/A	Unk	N/A	N/A
	Main Stem	13	12	0.92	10	3	0.30	9	3	0.33
	All Groups	13	12	0.92	10	3	0.30	9	3	0.33
2012	Wind River	6	6	1.00	6	3	0.50	6	3	0.50
	Indian Creek	6	4	0.67	5	2	0.40	3	2	0.67
	Jersey Creek	6	5	0.83	6	3	0.50	5	3	0.60
	South Fork	2	1	0.50	2	0	0.00	1	0	0.00
	Main Stem	18	15	0.83	17	8	0.47	14	8	0.57
	All Groups	20	16	0.80	19	8	0.42	15	8	0.53
2013	Wind River	6	5	0.83	6	1	0.17	5	1	0.20
	Indian Creek	5	5	1.00	3	2	0.67	3	2	0.67
	Jersey Creek	5	5	1.00	2	1	0.50	2	1	0.50
	Manning Bridge	1	0	0.00	1	0	0.00	N/A	N/A	N/A
	South Fork	8	7	0.88	8	3	0.38	7	3	0.43
	Main Stem	17	15	0.88	12	4	0.33	10	4	0.40
	All Groups	25	22	0.88	20	7	0.35	17	7	0.41
2014	Wind River	4	3	0.75	4	1	0.25	3	1	0.33
	Indian Creek	6	6	1.00	2	1	0.50	2	1	0.50
	Jersey Creek	2	1	0.50	2	1	0.50	1	1	1.00
	Manning Bridge	1	0	0.00	1	0	0.00	N/A	N/A	N/A
	South Fork	5	4	0.80	4	3	0.75	3	3	1.00
	Main Stem	13	10	0.77	9	3	0.33	6	3	0.50
	All Groups	18	14	0.78	13	6	0.46	9	6	0.67
2015	Wind River	4	3	0.75	4	3	0.75	3	3	1.00
	Indian Creek	1	1	1.00	1	0	0.00	1	0	0.00
	Jersey Creek	2	1	0.50	2	0	0.00	1	0	0.00
	Manning Bridge	1	1	1.00	1	1	1.00	1	1	1.00
	South Fork	5	4	0.80	5	2	0.40	4	2	0.50
	Main Stem	8	6	0.75	8	4	0.50	6	4	0.67
	All Groups	13	10	0.77	13	6	0.46	10	6	0.60
	Reach									
	South Fork	25	21	0.84	23	10	0.43	19	10	0.53
	Main Stem	91	75	0.82	78	26	0.33	62	26	0.42
	All Groups	116	96	0.83	101	36	0.36	81	36	0.44

[a] Prod = Productions
[b] L:E = lamb:ewe ratio
[c] Surv = Survival

Appendix I (cont…)

Table 2. Estimates based on age ratios										
		Spring Age Ratios			Fall Age Ratios			Over Summer Lamb Survival		
Year	Female Group	No. Ewes	No. Lambs	L:E Ratio	No. Ewes	No. Lambs	L:E Ratio	Spring L:E Ratio	Fall L:E Ratio	Surv Rate
2008	Wind River	19	13	0.68	14	3	0.21	0.68	0.21	0.31
	Indian Creek	36	10	0.28	14	3	0.21	0.28	0.21	0.77
	Jersey Creek	11	2	0.18	4	2	0.50	0.18	0.50	2.75
	South Fork	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Main Stem	66	25	0.38	32	8	0.25	0.38	0.25	0.66
	All Groups	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2009	Wind River	27	14	0.52	21	8	0.38	0.52	0.38	0.73
	Indian Creek	43	27	0.63	46	11	0.24	0.63	0.24	0.38
	Jersey Creek	18	12	0.67	22	5	0.23	0.67	0.23	0.34
	South Fork	23	15	0.65	6	3	0.50	0.65	0.50	0.77
	Main Stem	88	53	0.60	89	24	0.27	0.60	0.27	0.45
	All Groups	111	68	0.61	95	27	0.28	0.61	0.28	0.46
2010	Wind River	23	12	0.52	26	2	0.08	0.52	0.08	0.15
	Indian Creek	26	16	0.62	41	4	0.10	0.62	0.10	0.16
	Jersey Creek	10	2	0.20	20	2	0.10	0.20	0.10	0.50
	South Fork	15	5	0.33	20	3	0.15	0.33	0.15	0.45
	Main Stem	59	30	0.51	87	8	0.09	0.51	0.09	0.18
	All Groups	74	35	0.47	107	11	0.10	0.47	0.10	0.22
2011	Wind River	37	22	0.59	17	6	0.35	0.59	0.35	0.59
	Indian Creek	36	21	0.58	33	7	0.21	0.58	0.21	0.36
	Jersey Creek	15	2	0.13	10	1	0.10	0.13	0.10	0.75
	South Fork	33	9	0.27	8	4	0.50	0.27	0.50	1.00[a]
	Main Stem	88	45	0.51	60	14	0.23	0.51	0.23	0.46
	All Groups	121	54	0.45	68	18	0.26	0.45	0.26	0.59
2012	Wind River	21	16	0.76	17	8	0.47	0.76	0.47	0.62
	Indian Creek	32	13	0.41	31	14	0.45	0.41	0.45	1.00[a]
	Jersey Creek	25	13	0.52	24	11	0.46	0.52	0.46	0.88
	South Fork	10	3	0.30	6	1	0.17	0.30	0.17	0.56
	Main Stem	78	42	0.54	72	33	0.46	0.54	0.46	0.85
	All Groups	88	45	0.51	78	34	0.44	0.51	0.44	0.85
2013	Manning Bridge	8	1	0.13	9	1	0.11	0.13	0.11	0.89
	Wind River.	23	17	0.74	23	3	0.13	0.74	0.13	0.18
	Indian Creek	32	19	0.59	34	6	0.18	0.59	0.18	0.30
	Jersey Creek	34	23	0.68	26	4	0.15	0.68	0.15	0.23
	South Fork	43	26	0.60	43	17	0.40	0.60	0.40	0.65
	Main Stem	97	60	0.61	92	14	0.15	0.61	0.15	0.25
	All Groups	140	86	0.61	135	31	0.23	0.61	0.23	0.37
2014	Manning Bridge	9	6	0.67	8	4	0.50	0.67	0.50	0.75
	Wind River	23	14	0.61	16	7	0.44	0.61	0.44	0.72
	Indian Creek	30	22	0.73	27	15	0.56	0.73	0.56	0.76
	Jersey Creek	14	8	0.57	14	8	0.57	0.57	0.57	1.00
	South Fork	61	20	0.33	50	16	0.32	0.33	0.32	0.98
	Main Stem	76	50	0.66	65	34	0.52	0.66	0.52	0.80
	All Groups	137	70	0.51	115	50	0.43	0.51	0.43	0.85
2015	Manning Bridge	7	4	0.57	8	4	0.50	0.57	0.50	0.88
	Wind River	16	8	0.50	14	8	0.57	0.50	0.57	1.00[a]
	Indian Creek	33	24	0.73	25	9	0.36	0.73	0.36	0.50
	Jersey Creek	10	4	0.40	16	3	0.19	0.40	0.19	0.47
	South Fork	53	20	0.38	55	19	0.35	0.38	0.35	0.92
	Main Stem	66	40	0.61	63	24	0.38	0.61	0.38	0.63
	All Groups	119	60	0.50	118	43	0.36	0.50	0.36	0.72
	Reach (not 2008)									
	South Fork	238	98	0.41	188	63	0.34	0.41	0.34	0.81
	Main Stem	552	320	0.58	528	151	0.29	0.58	0.29	0.49
	All Groups	790	418	0.53	716	214	0.30	0.53	0.30	0.56

[a] Fall age ratio higher than spring ratio; adjusted survival estimate to 1.00

APPENDIX J

SALMON RIVER BIGHORN SHEEP PROJECT

MORTALITY AND FIELD NECROPSY FORMS

SALMON RIVER BIGHORN SHEEP FIELD MORTALITY FORM

Animal I.D. ________ Radio Freq. __________ MORTALITY FORM No. _________

Investigator(s) __________________________________ Date ___________________________

Ear-tag color/numbers _______________ Sex ___ Age ___ Assigned Group _________________

Mortality Location

Social Group ___________________ Drainage ______________________________________

Lat (WGS 84; D.D) _________________ Lon _________________ Dist. to dsheep (km)__________

Description____

Monitoring Dates

Last observation _____________ Last live signal _____________ Mortality signal ______________

Recover radio/carcass ____________ Estimated date of death _____________________________

Mortality Site Habitat

Aspect __________ Slope (°) _____________ Distance to escape terrain(m) ___________________

Veg. type ____

I Carcass Decomposition Class (circle one)

1 Carcass Fresh: Soft tissue still hydrated; carcass not yet bloated; few to no maggots (not yet colonized); no to mild decomposition smell

2 Carcass lightly decomposed: Most soft tissue and organs intact; carcass bloated; heavy maggot load; strong decomposition smell; bluish-green tint to hide around groin area; sunken or missing eyes; muscle tissue with a brownish or "cooked" look..

3 Carcass moderately decomposed: Some muscle tissue remaining but dehydrated; organs completely desiccated; hide and hair present and may be intact but desiccated; some maggots present on underside of carcass, some decomposition smell when carcass disturbed

4 Carcass completely decomposed: No soft tissue (muscles/organs) remaining; little hide or hair; mostly bones remaining; little decomposition smell remaining; no to few maggots present; carcass may be disarticulated

5 Other (Describe ____)

SALMON RIVER BIGHORN SHEEP FIELD MORTALITY FORM

Animal I.D. ________ Radio Freq. __________ MORTALITY FORM No. _________

II Carcass Disposition (circle any applicable)

1 Carcass intact (Describe ____)

1a Natural disposition (Describe ____)

1b Unnatural disposition (Describe ____)

2 Carcass disarticulated (Describe ____)

2a All Skeletal parts present (Describe ____)

2b Skeletal parts missing (Describe ____)

2c Skeletal parts scattered (Describe ____)

2d Skeletal parts not scattered (Describe ______________________________________)

III Predation Assessment

A Carcass Consumption (predation or scavenging) (circle one):

1 Evidence of feeding by predators (predation or scavenging):

1a Carcass completely consumed: no to little soft tissue; little hide or hair; legs and vertebrae disarticulated

1b Carcass moderately consumed: some soft tissue remaining; hide or hair present on leg bones, skull; legs and vertebrae generally articulated;

1c Carcass lightly consumed: soft tissue remaining; all hide or hair left on leg bones; legs, vertebrae intact

1d Feeding pattern (Describe areas consumed ______________________________________)

2 No outward evidence of predation or feeding observed

B Feeding Pattern (predation or scavenging) (circle all applicable):

1 Bones crushed (Which bones/Describe____)

2 Bones consumed (Which bones/Describe_______________________________________)

3 Long Bone ends gnawed (Describe____)

4 Long Bone marrow consumed (Describe _______________________________________)

5 Hide peeled back (Describe____)

6 Hide torn/shredded (Describe____)

7 Hide consumed (Describe ____)

8 Canine punctures bone (lcn ______________________ span (cm) upper _______ span lower______)

9 Canine punctures skin (lcn _______________________ span (cm) upper _______ span lower _____)

10 Hair clipped (Describe ____)

11 Carcass covered up (Describe____)

12 Remains buried/cached (Describe____)

13 Scratching/scrapes (Describe ____)

14 Nasal Area Eaten (Describe____)

15 Other (Describe ____)

SALMON RIVER BIGHORN SHEEP FIELD MORTALITY FORM

Animal I.D. ________ Radio Freq. __________ MORTALITY FORM No. _________

C Evidence of Predation (within 100m) (circle any applicable):

1 Evidence of chase scene (Describe ____)

1a Tracks (Describe ____)

1b Disturbed ground (Describe ____)

1c Disturbed/broken vegetation/branches (Describe ______________________________________)

1d Blood trail (Describe ____)

1e Hair trail (Describe ____)

2 Evidence of attack site(s) (Ground; Describe ______________________________________)

2a Pooled blood (Describe ____)

2b Matted vegetation (Describe ____)

2c Tuffs of hair (Describe ____)

2d Disturbed ground (Describe ____)

2e Drag marks to carcass locn (Describe ______________________________________)

3 Evidence of attack site(s) (carcass; Describe ______________________________________)

3a Subcutaneous hemorrhaging (Describe/locn ______________________________________)

IV. Predator Sign (within 100m):

A Lion Sign (check all present)

Tracks fresh___ Tracks old___ Scat fresh___ Scat old___ Toilet___ Hair___ Tree scratching ___

Bedsites___ Scrape___ Plucked hair on carcass___ Rumen/remains buried/covered___

Throat attack site____ Carcass remains concealed near tree &/or low hanging veg.____

Skull attack site___ Carcass intact___ No crushed bones___ Evidence of feeding on soft tissue only___

Claw Marks___ Extensive Hemorrhaging in throat area ___

B Bear Sign

Tracks fresh___ Tracks old___ Scat fresh___ Scat old___ Hair___ Bedsite___ Claw marks___

Crushed skull___ Deep hemorrhaging on back and neck ___

C Coyote Sign

Tracks fresh___ Tracks old___ Scat fresh___ Scat old___ Hair___ Throat attack site___

No crushed bones___ Little hemorrhaging___

D Wolf Sign

Tracks fresh____ Tracks old____ Scat fresh____ Scat old____ Hair____ Bedsite(s) ____

Disarticulated/scattered carcass_____ Crushed bones_____ End of long bones eaten_____

Ribs eaten close to backbone____ Deep hemorrhaging in flank, groin, shoulder webbing____

SALMON RIVER BIGHORN SHEEP FIELD MORTALITY FORM

Animal I.D. ________ Radio Freq. __________ MORTALITY FORM No. _________

E Avian Sign

Tracks fresh_____ Tracks old_____ Feathers _____ Bird feces_____ Talon marks on carcass _____

Location of talon marks____

F Other Predator Sign

____

V. Photos Taken (check all appropriate)

Site___ Predator sign___ Carcass ___ Other ____

VI. Carcass Disposition

____

VII. Diagnosis and comments

____

____

____

____

SALMON RIVER BIGHORN SHEEP FIELD NECROPSY FORM

Radio Freq____________Animal I.D._____________Necropsy Form No.________________

Investigator(s)______________________________ Date_____________________________________

Ear-tag color/numbers_________________ Sex_____ Age_____ Assigned Group_________________

ANNULI INTERVAL LENGTH AND BASAL CIRCUMFERENCE MEASUREMENTS ON RAMS

Annuli	Length right	Length left	Annuli	Length right	Length left
Lamb			4		
1			5		
2			6		
3			7		
Basal circumference right			Basal circumference left		

SEE KISTNER INDEX Photos and description

Field form for rating physical condition.

Body Muscles (0-10)	Heart B. & Cor. Gr. (0-15)	Peri-card. (0-15)	Omentum (0-15)	Perirenal (Kidney) (0-15)	Tail B. & Rump (0-15)	Brisket (0-15)
( )	( )	( )	( )	( )	( )	( )

TOTAL SCORE __________ points

Arbitrary Scale of Relative Condition

0	10	20	30	40	50	60	70	80	90	100
Em		Poor		Fair		Good		Excellent		

Em = Emaciated

OVERALL BODY CONDITION (circle one) POOR FAIR GOOD EXCELLENT

I. SKIN/HIDE

Coat condition________________ Ectoparasites_______________

External scars or wounds YES NO Describe:_____________________________

Claw marks/rakes along shoulders YES NO Torn/shredded hide or mostly consumed YES NO

Subcutaneous hemorrhaging/haemotomas YES NO Location and description__________________________

Punctures associated with hemorrhaging YES NO Location and description__________________________

SALMON RIVER BIGHORN SHEEP FIELD NECROPSY FORM

Radio Freq__________Animal I.D.___________Necropsy Form No.______________

II. SKELETON

Arthritis

Location (vertebrae, pelvis, femur ball, etc) ____

Severity (Circle one): SLIGHT MODERATE SEVERE NOT POSSIBLE TO TELL

Jaw necrosis

Upper (Circle one): NONE SLIGHT MODERATE SEVERE

Lower (Circle one): NONE SLIGHT MODERATE SEVERE

Fractures

Old Fractures Bone(s)____________________________ Healed?________________________

Recent fractures Bone________________ Predation Related?___ Describe ____________________

Bone marrow

(femur or humerus best) 1. white/solid 2. pink/solid 3. red or yellow/solid 4. gelatinous

Teeth

missing teeth__________ tooth wear__________ gum infection_________ Other ________________

Hoof/Horn condition

Hoof wear____

Horn condition______________________________________

III. DIGESTIVE SYSTEM

Kidneys

separation of medulla and cortex present YES NO

Adrenal gland

Size____________ Color_______________

Stomach

Lesions/hemorrhages on serosal surface (outer lining) YES NO

Milk curds in stomach (lambs) YES NO Stomach full?______

SALMON RIVER BIGHORN SHEEP FIELD NECROPSY FORM

Radio Freq__________Animal I.D.___________Necropsy Form No.______________

Liver

Cysts YES NO Lesions YES NO Hemorrhages YES NO

Shiny with sharp edge? YES NO

Spleen

rough smooth swollen

IV. REPRODUCTIVE/URINARY SYSTEM

Lactating YES NO If possible express milk from mammaries.

Vaginal discharge YES NO take swab if large amount of discharge

Testicals infection inflamed redness

Penis discharge YES NO take swab sample if large amount of discharge.

Urine collect sample in syringe

V. CIRCULATORY SYSTEM

Heart

Petechia (small red spots) around coronary band YES NO Fluid in pericardium YES NO

Blood will be hard to remove from the animal with a needle and syringe if expired longer than 2 hours. Blood clots within vessels and heart are not good for disease screening. If fresh dead, take a blood sample in red top tubes only. Check major vessels for evidence of trauma.

VI. RESPIRATORY SYSTEM

Mouth Mucous in mouth or nose YES NO Describe:____________________

Evidence of blood spots or lesions on tongue YES NO

Fluid present YES NO Punctures YES NO Hemorrhages YES NO

Petechiae (small red spots) YES NO

Trachea/esophagus

Punctures YES NO

Hemorrhage YES NO Frothy fluid YES NO

Lungworm present YES NO

SALMON RIVER BIGHORN SHEEP FIELD NECROPSY FORM

Radio Freq___________Animal I.D.____________Necropsy Form No._______________

Lungs Fluid present in thoracic cavity (estimate volume)__________

blood in lungs YES NO

%______pink, spongy, soft, well-defined edges on lobes

%______dark, heavy, hard

%______nodules or abscesses filled with puss

%______mats of white fibrin

%______lung affected by disease

Adhesion of lung YES NO Lobes_______________________________

Lungworm observed YES NO ____________________________________

VII. Samples Collected:(Check if applicable)

Date Collected:______________Time Collected:______________ Ambient Temperature(F)________________

Entire Carcass______ Pswab______ Eswab________ Femur marrow__________ I1 Incisor__________

Feces_________ Skeletal muscle______ Vaginal Discharge Swab_____ Penis Discharge Swab_________

Blood: Red top____#____ Tiger top(red/grey)____#____ Purple top_____#____ Blue top______#_____

Green top_____#______

Diced size(1/4"X1/4"), formalin fixed samples (multiple samples in same jar ok):

Lung________ Liver__________ Kidney__________ Heart_____________ Spleen____________

Golf ball size, whirl pack samples (one sample per whirl pack; refrigerate 48 hours; freeze thereafter):

Lung________ Liver__________ Kidney__________ Heart_____________ Spleen____________

VIII. Sample Disposition

Sample	Laboratory	Date submitted	Date Received

APPENDIX K

SALMON RIVER BIGHORN SHEEP PROJECT

BIGHORN SHEEP MORTALITY BY CAUSE

Appendix K. Documented bighorn sheep mortalities on the Salmon River Bighorn Sheep Project, ID, USA , 2007–2015.

Year	Animal ID	Age	Sex	Estimated Mortality Date	Mortality Cause
2007	R9	Adult	Male	11/15/2007	Human; Other
2008	R16	Yearling	Male	5/12/2008	Human; Management
2008	E11	Adult	Female	9/5-22/2008	Natural; Predation
2008	R6	Adult	Male	10/7/2008	Human; Harvest
2008	Unmarked 08-1	Lamb	Male	10/26/2008	Natural; Other
2009	R14	Adult	Male	6/10/2009	Human; Management
2009	Unmarked 09-1	Adult	Female	9/2/2009	Unknown
2009	Unmarked 09-2	Lamb	Male	9/25/2009	Natural; Other
2009	Unmarked 09-3	Adult	Female	Spring 2009	Unknown
2010	R36	Adult	Male	12/22/2010	Unknown
2011	R34	Adult	Male	3/3/2011	Unknown
2011	R38	Adult	Male	4/12/2011	Unknown
2011	E43	Adult	Female	7/19/2011	Unknown
2011	E44	Adult	Female	7/20/2011	Unknown
2011	E5	Adult	Female	7/25/2011	Unknown
2011	R7	Adult	Male	9/27/2011	Human; Harvest
2011	R26	Adult	Male	10/29/2011	Natural; Other
2011	R22	Adult	Male	11/10/2011	Natural; Trauma
2011	E56	Adult	Female	11/14/2011	Human; Other
2012	E37	Adult	Female	2/25/2012	Natural; Predation
2012	E47	Adult	Female	3/16/2012	Unknown
2012	E17	Adult	Female	5/4/2012	Natural; Trauma
2013	E68	Adult	Female	4/5/2013	Natural; Predation
2013	Unmarked 13-1	Adult	Female	5/27/2013	Human; Other
2013	E54	Adult	Female	7/3/2013	Natural; Predation
2013	E49	Adult	Female	8/16/2013	Unknown
2013	E46	Adult	Female	8/24/2013	Unknown
2013	R55	Adult	Male	9/14/2013	Human; Harvest
2013	R19	Adult	Male	11/??/2013	Unknown
2014	E57	Adult	Female	2/16/2014	Unknown
2014	R4	Adult	Male	5/28/2014	Unknown
2014	E64	Adult	Female	5/29/2014	Unknown
2014	R66	Adult	Male	1/28/2014	Natural; Trauma
2014	R30	Adult	Male	9/26/2014	Human; Harvest
2015	R13	Adult	Male	2/13/2015	Natural; Other
2015	E69	Adult	Female	2/25/2015	Unknown
2015	Unmarked 15-1	Adult	Female	6/21/2015	Natural; Trauma
2015	R39	Adult	Male	8/16/2015	Unknown
2015	R23	Adult	Male	9/6/2015	Human; Harvest
2015	R15	Adult	Male	12/17/2015	Natural; Trauma

APPENDIX L

SALMON RIVER BIGHORN SHEEP PROJECT
BIGHORN SHEEP HELICOPTER SURVEYS
2010 - 2013

Appendix L. Bighorn sheep observed during helicopter surveys along the Salmon River, ID, USA, 2010-2013. Data courtesy of the Idaho Department of Fish and Game.

Bio Year	Flight Year	Flight Date	Reach	Adult Ewes	Yearling Ewes	Lambs	Total Rams	Total Sheep	Recruitment Lamb:Ewe	Ram:Ewe
2009	2010	3/11&13/2010	Main Stem	100	4	10	57	171	0.10	0.55
2009	2010	3/11&13/2010	South Fork (East)	24	0	1	8	33	0.04	0.33
2009	2010	3/11&13/2010	South Fork (West)	27	0	9	8	44	0.33	0.30
2009	2010	3/11&13/2010	South Fork (East & West)	51	0	10	16	77	0.20	0.31
2009	2010	3/11&13/2010	Main Stem & South Fork (West)	127	4	19	65	215	0.15	0.50
2009	2010	3/11&13/2010	Main Stem & South Fork (East & West)	151	4	20	73	248	0.13	0.47
2010	2011	3/2-4/2011	Main Stem	102	3	9	50	164	0.09	0.48
2010	2011	3/2-4/2011	South Fork (East)	36	6	23	9	74	0.64	0.21
2010	2011	3/2-4/2011	South Fork (West)	25	1	8	13	47	0.32	0.50
2010	2011	3/2-4/2011	South Fork (East & West)	61	7	31	22	121	0.51	0.32
2010	2011	3/2-4/2011	Main Stem & South Fork (West)	127	4	17	63	211	0.13	0.48
2010	2011	3/2-4/2011	Main Stem & South Fork (East & West)	163	10	40	72	285	0.25	0.42
2011	2012	3/5-7/2012	Main Stem	114	1	24	49	188	0.21	0.43
2011	2012	3/5-7/2012	South Fork (East)	30	7	13	16	66	0.43	0.43
2011	2012	3/5-7/2012	South Fork (West)	33	1	11	13	58	0.33	0.38
2011	2012	3/5-7/2012	South Fork (East & West)	63	8	24	29	124	0.38	0.41
2011	2012	3/5-7/2012	Main Stem & South Fork (West)	147	2	35	62	246	0.24	0.42
2011	2012	3/5-7/2012	Main Stem & South Fork (East & West)	177	9	48	78	312	0.27	0.42
2012	2013	3/4-7/2013	Main Stem	121	2	30	52	205	0.25	0.42
2012	2013	3/4-7/2013	South Fork (East)	40	3	13	11	67	0.33	0.26
2012	2013	3/4-7/2013	South Fork (West)	43	1	19	14	77	0.44	0.32
2012	2013	3/4-7/2013	South Fork (East & West)	83	4	32	25	144	0.39	0.29
2012	2013	3/4-7/2013	Main Stem & South Fork (West)	164	3	49	66	282	0.30	0.40
2012	2013	3/4-7/2013	Main Stem & South Fork (East & West)	204	6	62	77	349	0.30	0.37