Colonization of a reclaimed landscape by bighorn sheep *(Ovis canadensis)*

BETH MacCALLUM, Bighorn Wildlife Technologies Ltd., 176 Moberly Drive, Hinton, AB, Canada T7V 1Z1, ovis@bighornwildlife.com
ALICE PAQUET, Bighorn Wildlife Technologies Ltd., 176 Moberly Drive, Hinton, AB, Canada T7V 1Z1

ABSTRACT: Bighorn sheep (*Ovis canadensis*) have high fidelity to seasonal ranges and as such are thought to be poor colonizers. Under certain conditions bighorn sheep are quite capable of occupying new habitat. We documented a colonization event of newly available habitat on the Gregg River Mine (GRM) in west-central Alberta by bighorn sheep from adjacent alpine habitat with little to no spatial separation from the mine development. Wishart *et al.* (1998) described the rapid population increase of the nursery herd during this event. This paper is a companion article that documents and maps the pattern of mine reclamation and spatial occupation of bighorn sheep by sex/age class throughout the life of the mine. Initial colonization was accomplished by ram groups moving into recently reclaimed areas which provided basic habitat requirements for bighorn sheep (quality forage adjacent to pit walls retained as escape terrain). Colonization by nursery groups lagged by several years, occurring after larger areas of reclamation became available; once established however, nursery groups rapidly expanded into new habitat. Bighorn sheep did not abandon previously occupied habitat in favour of new habitat during the colonization event. Progressive reclamation as practiced by GRM provided the opportunity for bighorn sheep to discover and voluntarily colonize new habitat made available during the active phase of mining. Rewilding of the mine disturbance is an example of deliberate ecosystem rehabilitation in order to produce productive wildlife habitat. The reclamation of the Gregg River Mine demonstrates that given appropriate planning and design, reclaimed landscapes can provide habitat that fulfill the life requirements of bighorn sheep and other sympatric species.

Biennial Symposium of Northern Wild Sheep and Goat Council 22:114-130; 2020

KEY WORDS: bighorn sheep, colonization, ecosystem function, Gregg River Mine, *Ovis canadensis*, reclamation, restoration ecology, rewilding

INTRODUCTION

The distribution of bighorn sheep in North America was historically much larger than current day. Decimation of bighorn sheep populations occurred during settlement of the American west due to unregulated killing, diseases introduced by domestic livestock, competition with domestic, feral, or exotic hoofstock, and human encroachment (Brewer *et al.* 2014). This resulted in small and isolated populations that occupy a fraction of their historical range. Various wildlife agencies supported by public groups and organizations have developed management plans to actively restore lost or diminished populations, often by reintroduction of bighorn sheep to areas previously occupied. Understanding colonization of unoccupied habitat is necessary to manage fragmented populations. As habitat diminishes on the continent, creating new bighorn sheep habitat through restoration of disturbed landscapes may be a key factor in conservation of the species.

Bighorn sheep habitat is specialized; it is composed of grasslands adjacent to escape terrain; is generally associated with alpine environments; and is fragmented by mountainous terrain. During the course of one year, bighorn sheep may move between six seasonal ranges that may or may not be spatially connected (Geist 1971). Travel between

seasonal ranges is a learned behaviour and site fidelity is strong. Bighorn sheep are thought to be poor colonizers of habitat that is unknown to them (Geist 1971). Under certain conditions bighorn sheep are known to colonize new habitat made available by natural means (e.g., fire, avalanches) or through the use of management tools like prescribed burning, logging, and mechanical treatments (Arnett *et al.* 1990, Smith *et al.* 1999, Dibb and Quinn 2006).

Geist (1971:127,128) in his benchmark book *Mountain Sheep: A Study in Behaviour and Evolution* provided the theoretical conditions required for bighorn sheep to colonize new habitats: decreasing distance of unoccupied range to occupied range; large concentration of rams in spring; segregation of rams into age classes; younger rams roaming in groups, leading to the discovery of unoccupied range; and the discovery of new range by young two-year-old ewes, following rams on their spring excursions.

Jesmer *et al.* (2018) found that when reintroduced to previously occupied areas, bighorn sheep did not migrate as historical herds had; rather, new migratory patterns were formed over many generations, as culturally transmitted information was accumulated by individual experiences. Singer *et al.* (2000) indicated that high dispersal rates and rapid reoccupation of large areas could occur if bighorn sheep were placed in large patches of habitats with few barriers to movement to other patches. MacCallum and Geist (1992) documented colonization of the partially reclaimed Luscar Mine in Alberta by bighorn sheep from nearby occupied alpine range. A later study indicated there was no evidence of range abandonment of existing habitat in favour of newly created habitat (MacCallum 2008). Likewise, Smith *et al.* (1999) used radio collars and an experimental design to document bighorn sheep using nearby logged and burned areas while maintaining fidelity to original areas of occupation, indicating range expansion rather than abandonment.

The GRM is situated in west-central Alberta adjacent to the older Luscar Mine. It was predicted that bighorn sheep would colonize the GRM as they had the Luscar Mine, therefore reclamation was intentionally designed to provide habitat for bighorn sheep and other wildlife. Open pit mining creates benched highwalls and steep footwalls which provide escape terrain for bighorn sheep. Reclamation of GRM included not only replacing topsoil and establishing a vegetation cover but also the retention of walls in strategic areas to provide escape terrain, lambing sites, loafing sites, and secure travel for bighorn sheep. Mining and reclamation began on the east side of the GRM where the mine was closest to the alpine environment and progressed in an orderly fashion to the west. Since non-authorized human use is not permitted on mineral surface leases, the boundary creates a temporary refuge for wildlife where human activity is predictable. Bighorn sheep quickly learn that mining activity does not cause the energy expenditure required to respond to random human activity (i.e., hiking, photography, skiing, off-highway vehicle use, and other recreational activities). Hunting is not allowed on the GRM mineral surface lease.

Wishart *et al.* (1998) described the rapid population increase of the nursery herd during colonization of the newly available habitat on the GRM. This paper is a companion article that documents and maps the pattern of reclamation and spatial occupation by bighorn sheep through time by sex/age class since the beginning of the life of the mine. The purpose of this paper is to use spatial analyses to measure expansion of home range. The east-to-west progression of reclamation over 30 years provides a unique opportunity to document bighorn sheep response to the annual westward expansion of habitat.

STUDY AREA

The GRM is an open pit metallurgical coal mine that began construction in 1981 with coal production following in 1983 and ending in 2000. Mining occurred in subalpine habitat immediately adjacent to alpine habitat occupied by bighorn sheep. The primary end land use for the mine was identified as wildlife habitat and watershed protection as there was no potential for commercial timber prior to mining.

GRM is located on the east side of the Canadian Rocky Mountains about 40 km southwest of Hinton, Alberta in an area known as the Coal Branch (Alberta Forestry, Lands and Wildlife 1990). The mine occurs at the eastern limit of the subalpine ecoregion, elevations range from 1400 m to near tree line at 2000 m (4620 - 6600 feet) and is characterized by a Cordilleran Climatic Regime and Rocky Mountain vegetation. Lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanni*), and subalpine fir (*Abies lasiocarpa*) forests are dominant. Primary succession shrub communities of willow (*Salix* spp.) and dwarf birch (*Betula glandulosa*), and scattered grasslands also occur (Strong 1992). Soils are generally thin and rocky. Summers are cool (July daily mean temperature <13° C) and showery, with a short 165 to 170 day growing season (Chetner *et al.* 2003). The frost-free period is 85 to 95 consecutive days. Most precipitation falls in summer (>325 mm between May 1 to August 31). Winters are snowy (250 to 275 mm precipitation between September 1 and April 30), cold (January daily mean temperature -12 to -10°C) and characterized by frequent chinooks: warm dry winds that descend on the eastern side of the Rocky Mountains, periodically reducing snow cover.

METHODS

Mining and Reclamation

Mining at GRM progressed in two phases beginning in 1981 with the area referred to as the 15-Year Area and then proceeded northwest in 1998 to the Sphinx West area (Figure 1). Prior to mining, tree cover was logged and salvaged where possible. In anticipation of reclamation, all topsoil from disturbed areas was salvaged and stockpiled in accordance with legislation. Open pit mining was conducted using a truck and shovel method. As mining progressed the waste rock was used to backfill pits where mining had been completed, unless pit walls had been designated as escape terrain habitat for bighorn sheep. The slope angle on backfilled pits was reduced to less than 27 degrees using primarily D10N Caterpillars and backhoes. Sloping was done to create a smooth interface between the undisturbed and reclaimed landscapes, and to reduce erosion potential. Lines of sight were broken up to provide a diverse landscape designed to resemble natural landforms (Brand 2010). Following sloping, if the waste rock fell outside the specified regolith criteria, subsoil materials were added to re-establish overburden. Stockpiled topsoil was then placed on the recontoured slope. The final step in the process was revegetation, i.e., seeding and tree and shrub planting. The seed mix consisted of 14 species of native (25%), and agronomic (75%) grasses and legumes (Luscar 2003). Overall seeding application rates were reduced in later years to accommodate tree and shrub growth. In order to minimize erosion of precious topsoil, seeding occurred the same year of soil placement, or the following year if placement occurred in the fall. Seed mixes were designed to rapidly establish vegetation, accomplished largely through an initial fertilizer application and the inclusion of nitrogen fixing legumes. Tree and shrub planting was done the year after seeding when possible. As per regulation (Alberta Government 2016), native conifer seeds were collected on the GRM prior to disturbance, germinated in a greenhouse and planted in two-year-old stock containers. Similarly, native shrub seeds or cuttings were collected locally (i.e., green alder (*Alnus crispa*), dwarf birch, shrubby cinquefoil (*Potentilla fruiticosa*), and willow) and planted with tree stock. Areas designated for bighorn sheep were not planted with trees and shrubs to maintain field of view and quality forage.

In addition to providing forage for grazing ungulates, the rapid establishment of vegetation had the benefit of initiating soil development. Minerals accrue to the soil through rainfall, dust, microorganisms that fix materials from the atmosphere, and decomposition of plant material. Grazing ungulates present during vegetation establishment significantly affect mineral cycles in plant communities by returning 80-90% of ingested nutrients to the soil by excreta (Heady 1975:76). This pathway for nutrient cycling in soil occurs at an accelerated rate compared to cycling of detritus directly from plant material (Vanderwaal *et al.* 2011).

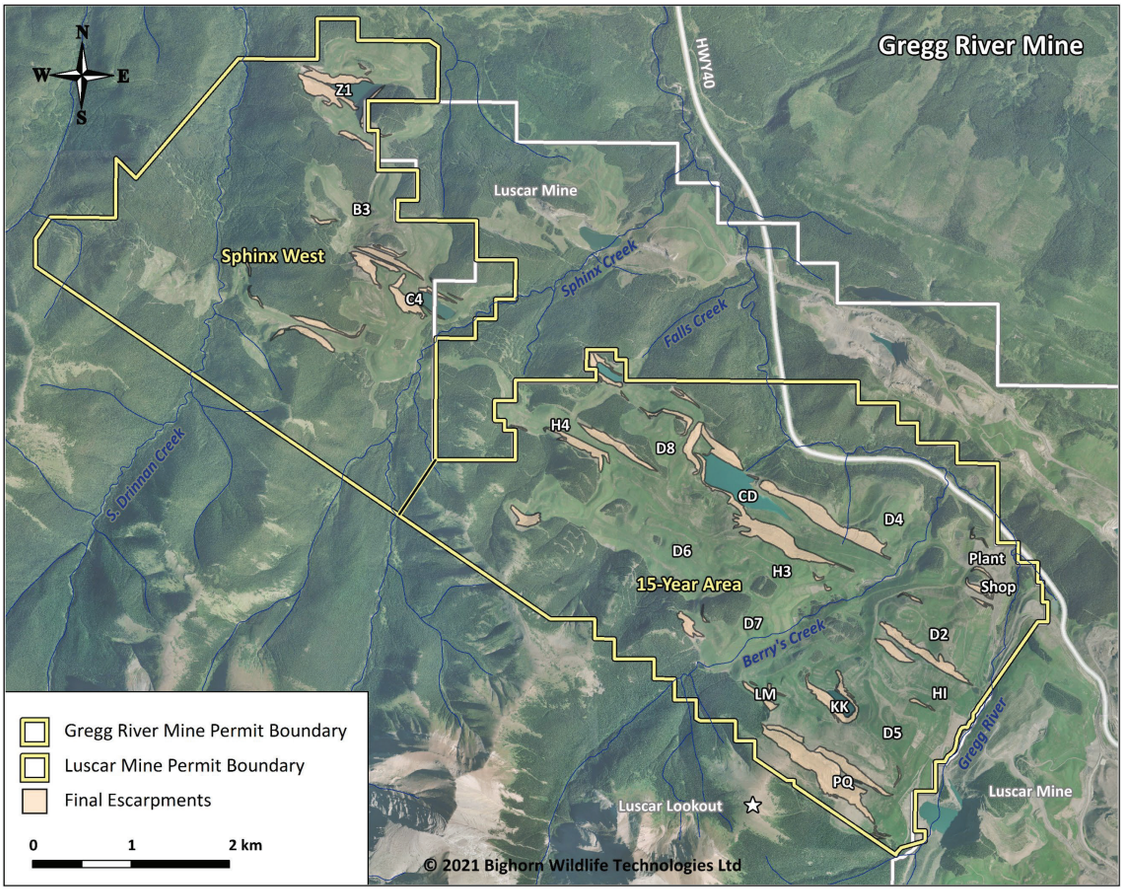

Figure 1. Gregg River Mine place names (Imagery 2011).

Coal seams at GRM were folded during mountain forming processes allowing for discontinuous pit development. This along with the intent of minimizing disturbance led to the preservation of areas of undisturbed vegetation cover within the disturbance boundary. Thirty tree islands were interspersed throughout the reclaimed landscape, averaging 3.3 hectares (range: 0.05-23.2 ha) and amounting to ~100 ha. The patches of undisturbed forest, meadow, and riparian vegetation were a vital feature in restoring a diversity of habitats during reclamation. The final reclaimed landscaped included patches of coniferous forest, grassland, escarpments, planted forest, riparian habitat, and end pit lakes (Figure 1).

Umbrella Species

The umbrella species concept provides a clear conceptual framework for reclamation planning for wildlife habitat. An umbrella species (or population) can be broadly defined as one whose conservation confers protection to a large number of naturally sympatric species (Branton and Richardson 2010). By creating habitat for umbrella species, other components of the wildlife community will benefit even though reclamation will not be aimed specifically at them (Green and Yonge 1985). Ungulates are suitable for use as umbrella species for reclamation to wildlife habitat because they have large home ranges, require a variety of landform features and vegetation types to fulfill their annual life requirements, and are important prey for carnivores. Bighorn sheep, mule deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*) are representative of the wildlife in the GRM area. These ungulates were chosen as the umbrella species for pre-planning of reclamation activities and for monitoring wildlife response to

reclamation. Design criteria for the 15-Year Area was informed primarily by habitat requirements by bighorn sheep, with reclaimed grassland placed adjacent to pit walls that serve as escape terrain. The Sphinx West area was designed primarily as mule deer and elk habitat and included grassland, open and closed forest, escarpments, end pit lakes and riparian areas (GRM 1998); bighorn sheep habitat was a secondary goal. While the umbrella species provided the framework for landscape design, smaller scale habitat features were incorporated based on the needs of species with specialized habitat requirements. Selective placement of brush and rock piles provided perching sites for raptors and various mammal uses (MacCallum 2003). Talus features created for travel and bedding of bighorn sheep using unsloped waste rock in turn provided habitat for small alpine mammals (i.e., hoary marmot (*Marmota caligata*), golden-mantled ground squirrel (*Callospermophilus lateralis*), and American pika (*Ochotona princeps*). Mineral licks were identified and preserved. Water features provided a source of insects for aerial insectivores, and habitat for shorebirds, waterfowl, and fish; water is not limiting to bighorn sheep in this area.

Wildlife Surveys

A population-based approach to monitoring the response of wildlife to reclamation on the GRM was initiated in 1989 (MacCallum and Kielpinski 1991) a few years after bighorn sheep began to use GRM systematically. The primary intent was to monitor the response of the umbrella species to the habitats designed for them; additionally, all wildlife species observed during monitoring were reported. From these surveys, bighorn sheep population characteristics, seasonal core use areas, annual home range, connectivity, movement, and lambing and rut areas were generated.

Ground-based wildlife surveys on GRM were conducted multiple times per year by driving, or walking, or observing from viewpoints from a fixed survey route as per Irby *et al.* (1988). Fixed surveys were designed to cover 100% of the mine lease; the length of the survey increased over time with expansion of mining. MacCallum (1991) used shifts in movement and behaviour to identify six biologically meaningful seasons for bighorn sheep on the Luscar Mine. These were combined into three generalized seasons for reporting: winter/early spring (mid-November to end of April), lambing/summer (May to mid-August) and pre-rut/rut (mid-August to mid-November). A minimum of one survey was conducted per season with the exception of the pre-rut/rut surveys when a minimum of 3 surveys were conducted. Mortality records (species, location, date, cause of death) were documented during surveys, and by the mine personnel and conservation officers throughout the year. Fall surveys were corrected with known mortality and the maximum count was used to generate demographic information.

Spotting scopes and binoculars were used to locate individuals or groups of large terrestrial mammals (bighorn sheep, elk, mule deer, white-tailed deer, carnivores), small and medium-sized mammals, and resident and migrating birds. The centroid of each group was recorded on 1:5,000 large scale maps. The age class and sex of each animal was recorded. For bighorn sheep, sex/age are identified using the classification by Geist (1971). Sign of carnivore activity was also recorded (e.g., bear digs, wolf tracks in fresh snow).

Reclamation mapping for bighorn sheep

Distribution of bighorn sheep was mapped every five years spanning the entire colonization event using scheduled survey observations for the calendar years: 1990, 1995, 2000, 2005, 2010 and 2015. Epanechnikov kernel home range and 65% core areas were generated using the *kernelUD* function in the *adehabitatHR* R package (Calenge 2006, R Core Team 2019). Harmonic mean centres were generated using the *Location Analysis* function in Range 9 v.14 (Kenward *et al.* 2014). Cumulative changes in the amount of revegetation, pit walls retained as escape terrain, and disturbance limits were included on maps to demonstrate quantity and distribution of newly available habitat over time. Distance to escape terrain was calculated

for each survey observation using the 'distance calculator' tool using MapInfo V.19.

In order to generate reclamation mapping, a combination of GIS methods was employed. Hardcopy maps from 1981 to 1998 GRM Annual Reports were borrowed from David Brand and scanned. These hand drawn maps showed the amount and location of seeding, reseeding, planting (tree and shrub), replanting, and proposed seeding and planting for each year; these were geo-registered (MapInfo V.8), digitized in GRM mine grid and reprojected to UTM Zone 11 (NAD83). AutoCAD mapping was available for 1997 to 2006 and was more comprehensive, including layers for seeding, planting, soil placement, waterbodies, escarpments, roads, ponds and other mine features. Both the digitized maps and the AutoCad layers were opened over orthorectified air photos from 2000 (1 m resolution), 2004 (1 m resolution) and 2011 (30 cm resolution). Any errors resulting from conversion from mine grid to UTM were corrected. Most reclamation was completed by 2006, with the exception of the former plant, shop, and silo areas near Hwy 40 which was completed in 2011.

Areas of revegetation were subject to different treatment in different years, including topsoil placement, seeding, reseeding, and planting. For the purposes of this study, an area was considered to be revegetated once the initial seeding was complete. A cumulative reclamation map was created for each year that included revegetated areas and retained pit walls. During the course of this study the reclaimed areas remained (and still remain) primarily open landscapes. Trees were planted in selected areas protected from the desiccating effect of chinook winds. Trees grow slowly in these alpine and subalpine environments, and during this study planted trees had not reached a height that would reduce the field of view or access to forage; tree growth did not influence the home range expansion of the bighorn sheep.

There may be discrepancies between areas generated from these GIS methods and those submitted in GRM annual reports. The areas generated for this study are intended to quantitatively track the spatial and temporal response of bighorn sheep to reclamation over time and may not be suitable for other purposes.

RESULTS

1981 to 1990

Mining and reclamation at GRM began on the eastern corner of the mine lease boundary near the Hwy 40 access (Figure 1). Small amounts of seeding (<50 ha) occurred in these areas from 1981 to 1984. By 1987 development had proceeded to the D6 area. Within the first ten years of development (1981 to 1990) ~132 hectares of the disturbed area had been seeded, mostly in the D4 area (near the Gregg River and shop/plant area) and the D5 area.

The progression of clearing, mining, and reclamation at the GRM was followed directly by colonizing bighorn sheep. It is suspected that bighorn sheep initially gained access to the mine in the southwest corner where the multi-benched PQ wall adjoins an alpine meadow below the former Luscar Lookout site (Figure 1). The PQ wall created new escape terrain adjacent to native grasslands. Winter aerial surveys (Stelfox 1964, Bibaud and Dielman 1980, Cook 1982) and results of a telemetry study (Lynch and Smith 1974) confirm that bighorn sheep used these alpine meadows prior to mining. By 1987, mine personnel consistently reported eight rams using the GRM (pers. comm. R. Zroback, March 27, 1987).

By 1990, patches of reclamation loosely connected the area between the PQ wall and D4 reclaimed area. These areas were within the annual 95% ram home range boundary (Figure 2a). Use by bighorn rams was concentrated on the D4 and D5 where a significant amount of reclamation had been completed. A small disjunct area on the west side of the ram home range in 1990 (Figure 2a) indicates a westward expansion of range. On 4 September 1989, seven young rams (six Class I and one Class II) were observed grazing in the Berry 's Creek undisturbed valley bottom. By the following spring three young rams (two Class I and one Class II) were observed west of Berry's Creek along the access road to the D6 area (22 April 1990). This westward expansion was enabled by the wide clearing adjacent to the D6 access road where

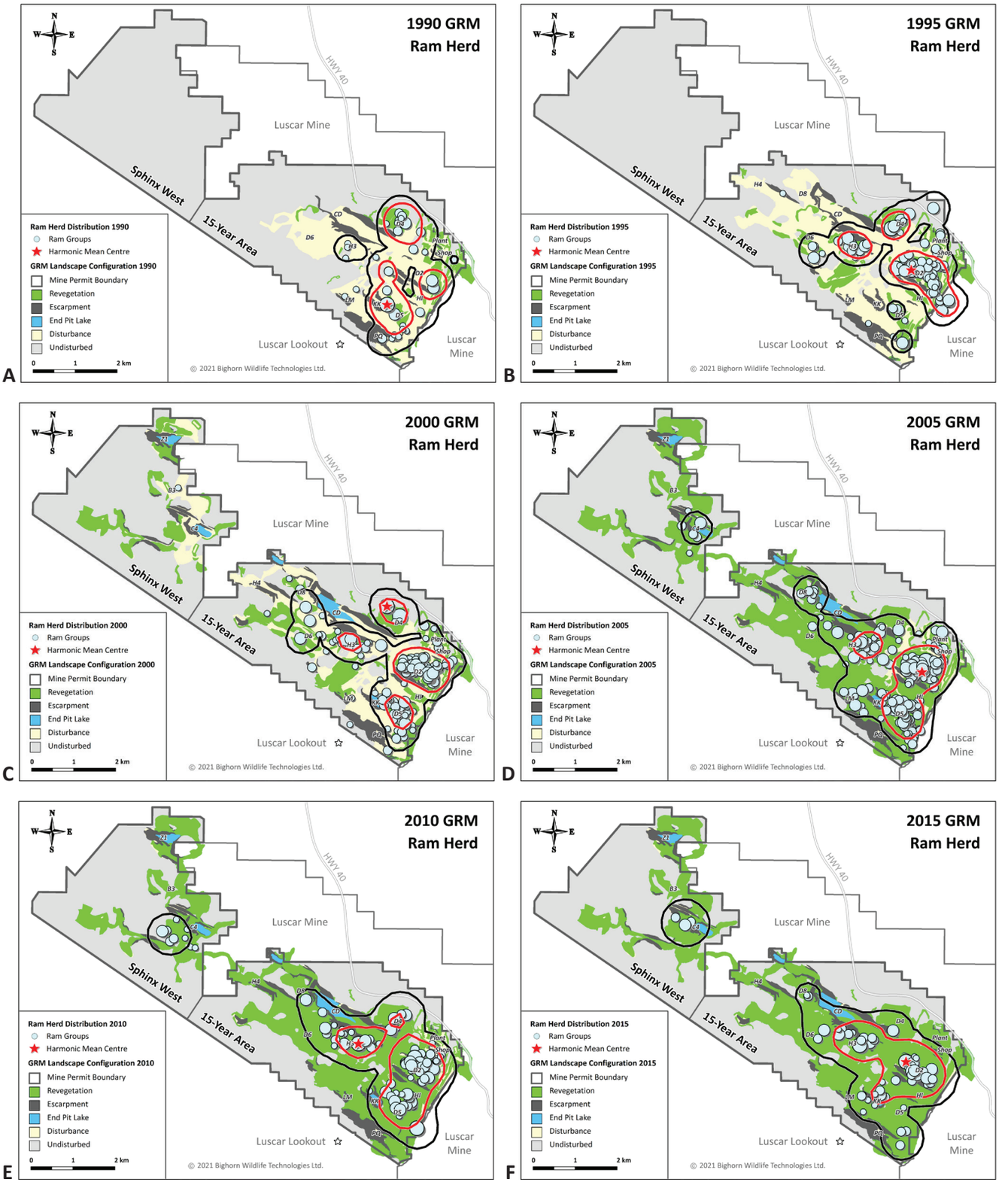

Figure 2. Annual ram herd distribution and reclamation progression on the GRM mapped at five year intervals during the 1989-2015 colonization period. Blue points are wildlife survey ram observations for the given year, scaled by group size; red isopleths are 65% core areas and black isopleths are 95% home range areas (Epanechnikov kernel use distribution).

Figure 3. Young rams grazing on a recently logged area, Gregg River Mine, 27 May 1990.

ground cover remained intact allowing for grazing and movement (Figure 3). Bighorn sheep use of areas recently cleared of trees was observed throughout the mine wherever these patches existed. Nine rams were observed on 31 May 1990 on the east side of the mine in the HI area which had been cleared of trees, but native ground cover and soil remained intact.

The first observation of members of the nursery herd on GRM occurred on 31 May 1990 when two ewes were sighted near new seeding close to PQ area in the southeastern part of the mine (Figure 4a). The two ewes spent a few days grazing then were seen in the alpine adjacent the top of the PQ multi-benched pit wall on 10 June 1990. They may have been seeking lambing sites or simply travelling to summer range in the alpine.

1991 to 1995

By 1995, a total of ~256 hectares of reclamation had been completed not only in the D4 and D5 areas but also in the H3, D6, D7, and D2 areas.

Between 1991 and 1995 rams continued to occupy newly reclaimed areas west of Berry's Creek. During these years more rams began to concentrate on D4, D2 and D5 areas causing the home range isopleths to tighten up when compared to the few, scattered bighorn sheep in the area in 1989-1990 (Figure 2b).

Ewes were not observed on the GRM in 1991. On 6 March 1992, five ewes, two lambs and one female yearling were observed at the base of the PQ multi-benched pit wall. Small numbers of ewes, lambs and yearlings continued to be observed during systematic surveys throughout 1992. Numbers and type of use by the nursery herd on the GRM began to increase after this initial occupation.

The nursery herd (six ewes, two lambs, two female yearlings, one male yearling) remained on GRM in the D5 area in fall of 1992, marking the first documented rut season on the reclaimed

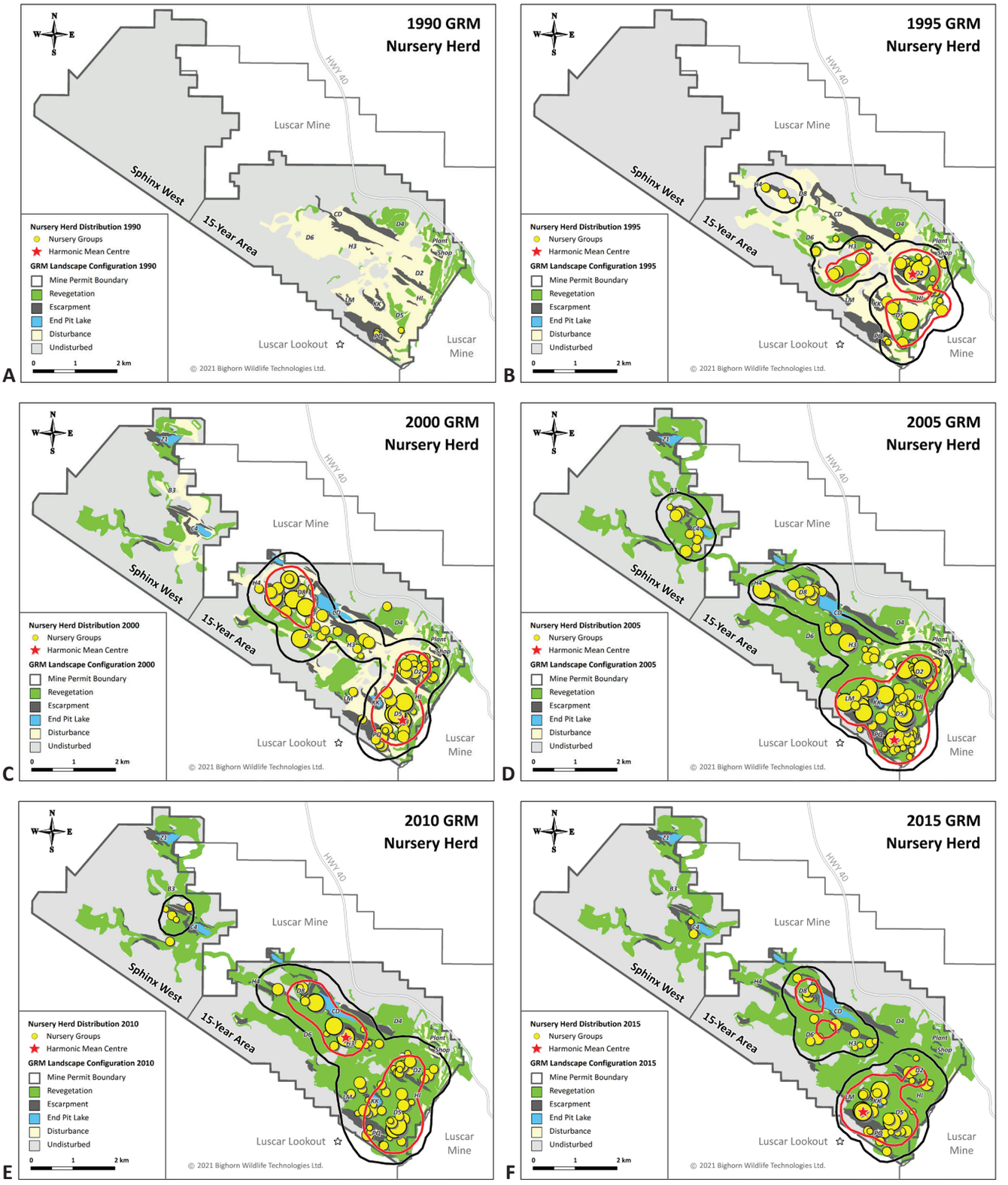

Figure 4. Annual nursery herd distribution and reclamation progression on the GRM mapped at five year intervals during the 1989-2015 colonization period. Yellow points are wildlife survey nursery observations for the given year, scaled by group size; red isopleths are 65% core areas and black isopleths are 95% home range areas (Epanechnikov kernel use distribution).

landscape. Rut behaviour continued in 1993 and 1994 and the D5 was established as a rut range. During the winter of 1993, members of the nursery herd were observed in small groups (2 to 5) on the eastern part of the mine. In 1994, the nursery herd made consistent use of the D5 area throughout the winter. The first record of lambing at GRM occurred on 10 May 1994 when one ewe with new lamb was observed on the LM highwall. By 1995 the nursery herd annual home range had extended west through the central part of the 15-Year Area and included a disjunct area known as the H4 pit (Figure 4b); annual (95%) home range more than doubled in size between 1992 and 1995.

1996 to 2000

Development in the Sphinx West area began in 1997. By 2000, cumulative reclamation on the GRM amounted to ~519 hectares and included seeding in both the 15-Year Area and in areas west of Sphinx Creek (Figure 2c).

The first records of bighorn sheep in the Sphinx West reclamation area were made 30 January 2000 when tracks of two young sheep were detected in fresh snow in the B3 area; later in the spring two Class I rams were observed in the B3 area 05 April 2000 (Figure 2c). The Sphinx West area is comprised of a series of rugged ridges and steep slopes. Bighorn sheep generally do not like to enter timber, but many records exist of bighorns making long, regular movements across forested valleys or through timbered areas (Geist 1971:119). Prior to mining development, the Sphinx West area was known as a traditional travel route for bighorn sheep linking Sphinx Mountain to the west with the reclaimed Luscar Mine to the east. Anecdotal records were confirmed in the fall of 1992 [16 November] when the tracks of two rams were followed through heavy timber from the western end of the Luscar Mine to the northern flank of Sphinx Mountain. Bighorn sheep will travel long distances in short periods during their seasonal migrations (Geist 1971:62).

By the year 2000, both the ram and nursery 95% home range extended throughout the 15-Year Area and were poised to follow the westward development into Sphinx West (Figure 2c and 4c).

2001 to 2005

Most of the revegetation of the 15-Year and Sphinx West areas was completed by 2005 amounting to ~1125 hectares (Figure 2d).

Bighorn ram groups began to use the Sphinx West area consistently beginning in 2002 when 2 male yearling, 4 Class I and 1 Class II were observed during the 3 November 2002 survey. Consistent use of this area by rams continued annually through to 2005 (Figure 2d). The ram 95% annual home range in 2005 was 1.4 times the size in 1990.

The first members of the nursery herd observed in Sphinx West occurred on 26 June 2003 when eight ewes, nine lambs, two female yearling, one male yearling, two Class I, and one Class II bighorn sheep were detected in the C4 area. By 2005, the nursery herd 95% annual home range encompassed most of the 15-Year Area as well as a disjunct area in Sphinx West (Figure 4d) and was four times the size in 1992.

2006 to 2010

Most of the disturbed area of the GRM was reclaimed by 2006 with only a few areas of roads and infrastructure remaining. The revegetated area in 2006 covered ~1182 ha.

From 2006 through to 2010 the ram and nursery 95% home range included all areas of suitable habitat previously occupied, stretching from the eastern side of the 15-Year Area to the west side, and also included a disjunct area in Sphinx West (Figure 2f and 4f).

The GRM population peaked in 2009 with 653 bighorn sheep recorded during the pre-rut (Figure 5a). During the 1989 to 2009 population expansion event, the GRM pre-rut surveys yielded a linear increase in both the ram herd (9.2 ± 0.86 SE sheep per year, $P < 0.001$, *CI:* 7.438 to 11.022) and the nursery herd (12.1 ± 1.9 SE sheep per year, $P < 0.001$, *CI:* 8.219 to 15.903).

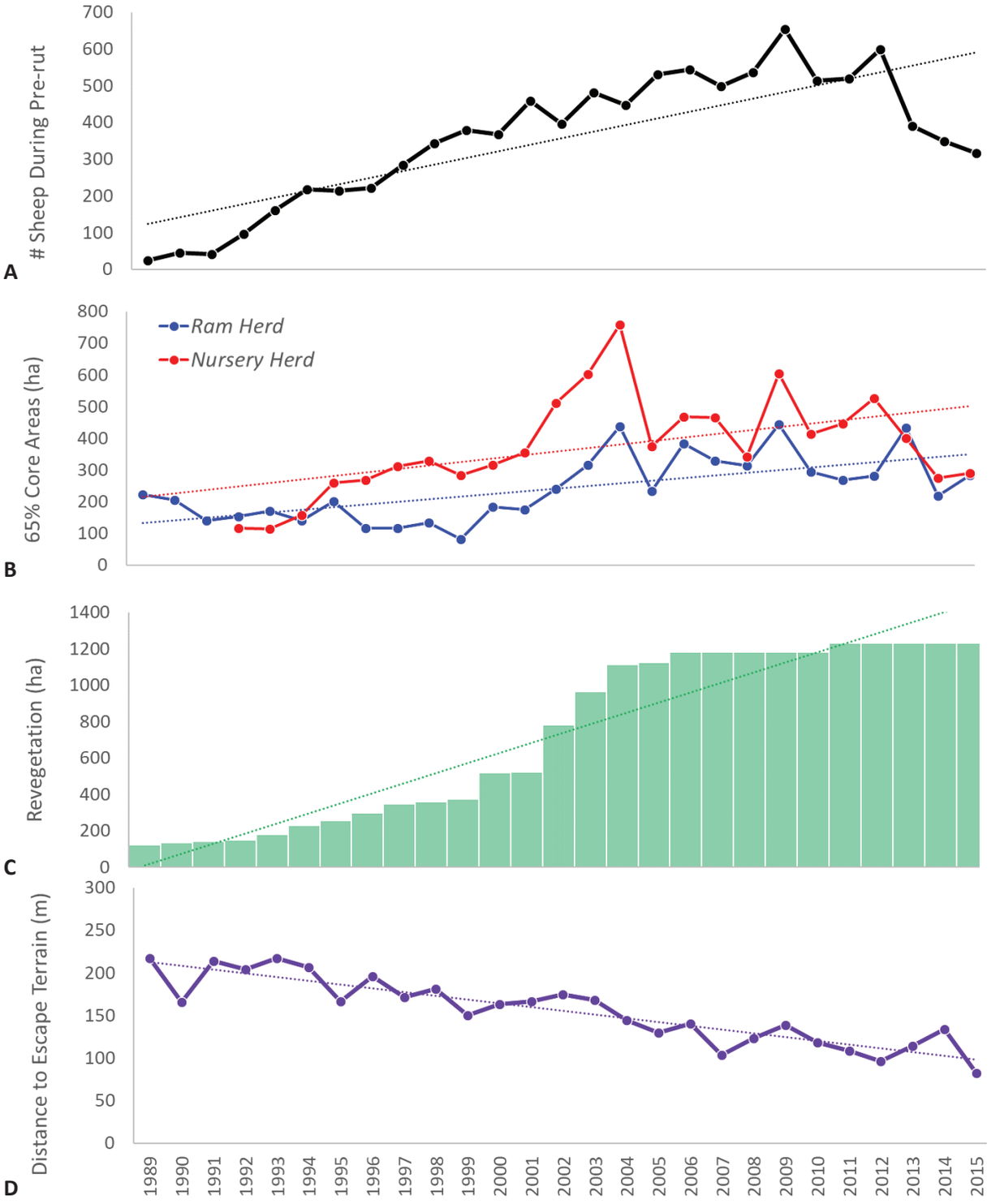

Figure 5. Gregg River Mine bighorn sheep colonization period 1989-2015. A) Maximum annual count from pre-rut ground surveys (mid-August to mid-November), adjusted for known mortality. B) 65% core areas for ram and nursery herd from Epanechnikov kernel use distribution analysis. C) Cumulative revegetation on the GRM lease. D) Average distance from observation location to nearest escape terrain feature.

During the design phase of the mine, it was predicted that the nursery herd would colonize once large areas of reclamation became available near the larger walls. The initial average annual group size of the nursery herd was relatively small in the early years (1.8 in 1990, 4.4 in 1992). By 1995, additional reclamation had become available and average group size was 9.8 and by 2009 the average group size was 14.3.

2011 to 2015

Reclamation was completed in 2011 with the removal of the shop, office and plant structures and seeding of those areas. While areas summarized in this section reflect revegetation (seeding and planting) the final composition of the reclaimed landscape included escarpments, end pit lakes, and tree islands which can be seen on the 2011 orthophoto in Figure 1. The total revegetated area in 2015 was ~1232 ha.

At this point in time, a combination of fixed habitat and pressure from poor winters, removals for translocation, predation, and increasing elk use brought bighorn sheep numbers down from their peak of 653 in 2009 to 317 in 2015. While the overall population came down from its peak in 2009, the spatial distribution in the 15-Year and Sphinx West areas remained constant; year-round occupation of the GRM reclaimed landscape by bighorn sheep was firmly established.

Overall

During the study period from 1989 to 2015 the ram 95% annual home range increased 36.5 ± 6.1 SE hectares per year ($P < 0.001$, *CI:* 23.979 to 49.011) while the 65% core area increased 8.3 ± 2.4 SE hectares per year ($P < 0.001$, *CI:* 4.186 to 12.359) (Figure 2 and 5b). From 1992, when the nursery herd first began to systematically use the reclamation, to 2015, the 95% annual home range increased 45.2 ± 12.6 SE hectares per year ($P = 0.0016$, *CI:* 19.194 to 71.267) while the 65% core area increased 16.0 ± 3.5 SE hectares per year ($P < 0.001$, *CI:* 8.672 to 23.269) (Figure 4 and 5b). The average distance to escape terrain (all seasons, all classes of bighorn sheep) decreased by 3.6 ± 0.5 SE m per year from 1989 to 2015 ($P < 0.001$, *CI:* -4.705 to -2.585) (Figure 5d). Since the early 1990s through to 2015, both the ram and nursery groups made consistent use of the GRM throughout all seasons (winter/spring, lambing/summer, and pre-rut/rut).

DISCUSSION

Geist (1971:127) described mountain sheep as a species that *"appear to be incapable of dispersal"* however, he discusses two possible mechanisms that allow bighorn sheep to perform range extensions. The first involves the presence of open terrain between occupied habitat and unoccupied habitat. Such a configuration would present no barrier to bighorn movement. The presence of occupied bighorn sheep habitat on the former Luscar Lookout site adjoining the reclaimed and unoccupied habitat on GRM fulfils this criterion. The second mechanism involves spring exploration movements by young rams in small groups. In the 15-Year Area, this type of movement was documented with the movement of young rams into the newly logged area on 27 May 1990 (Figure 3). In the Sphinx West area, the first observation of bighorn sheep was of two Class I rams 5 April 2000.

In the early years of colonization, rams were repeatedly observed using patches of vegetation which had been cleared of trees, but where the ground cover and soil remained undisturbed. These responses by bighorn sheep to newly cleared areas confirm the importance of a clear field of view. Opening habitat to provide an increased line of sight is a powerful tool for enhancing bighorn sheep habitat that has been encroached upon by shrub and tree cover. Indeed, bighorn sheep use of recently logged or mechanically cleared areas at timberline has been documented in south-central Wyoming (Arnett *et al.* 1990), Utah (Smith *et al.* 1999), and southeastern British Columbia (Dibb and Quinn 2006).

The nursery herd lagged behind the rams during initial colonization of the 15-Year Area in 1987 by six years. Once established the nursery herd home range expanded quickly, becoming

established in Sphinx West one year after ram colonization.

In general, the shape of home range polygons for both the bighorn rams and the nursery herd started out as a north/south occupation of the eastern edge of the mine, stretching progressively westwards as mining and reclamation proceeded to the northwest. Maximum expansion of home range was achieved by 2005. Throughout the entire period to 2015, the harmonic mean centres for the ram and nursery herds remained in the 15-Year Area which was designed as primary bighorn sheep habitat. While expansion into Sphinx West did occur, this area was designed primarily for mule deer and elk; bighorn sheep concentrations remained highest in the 15-Year Area. The Sphinx West area was historically important for connectivity but once reclamation was mostly completed in 2005, the area became part of the 95% home range for both the ram and nursery herds.

Once established, the bighorn sheep population responded directly to the increasing amount of reclamation. This study shows that bighorn sheep can be quick and effective colonizers under the right conditions. The home range expansion can be seen spatially for rams in Figure 2 and for the nursery herd in Figure 4. During the initial colonization event between 1989 and 2009, total numbers of bighorn sheep surveyed during the pre-rut increased with expanding area of available habitat. A linear population response of bighorn sheep to newly available habitat was predicted and verified as forage adjacent to escape terrain became increasingly available throughout development (Figure 5a and 5c). At the end of the life of the mine, new habitat stopped increasing and as expected the bighorn sheep population also stopped increasing. At this point, factors other than new habitat availability began to affect the population growth rate. Stabilization of habitat, colonization by cow elk beginning in 2003, presence of large predators (grizzly bear, gray wolf, cougar), poor winters, and removal of bighorn sheep (to enhance lost or diminished populations in the US and Alberta) all contributed to the population dynamics at the GRM.

The grizzly bear population in Bear Management Unit 3, which includes the GRM, grew at 7% per year between 2004 and 2014 (Stenhouse *et al.* 2015). This is higher than commonly seen in most grizzly bear populations in North America (Mace *et al.* 2011, Garshelis *et al.* 2004). Wolves were present in the early years of reclamation on GRM, but more consistent use by packs was recorded during wildlife surveys after 2000. Use of the reclaimed areas for denning and rendezvous sites between 2011 and 2018 (and possibly earlier) denoted a year-round presence of these predators.

In 2011, spring greenup was delayed three weeks by unusually deep and persistent snow on the GRM and Luscar mines and resulted in higher than usual ungulate mortality (MacCallum 2012). Records of known mortalities (27) between 01 January and 30 April of 2011 indicated cougars were responsible for 44% of all bighorn sheep mortalities, followed by natural causes (22%), unknown (15%), and wolves (11%).

Various authors have suggested that if harassment is great or predation high, bighorn sheep will select larger or steeper cliffs (Van Dyke *et al.* 1983, Stemp 1983). A review by Sawyer and Lindzey (2002) indicated that virtually all predators sympatric with bighorn sheep have been documented to prey upon bighorn sheep. They noted that in some cases, predation may have population-level impacts. Shroeder *et al.* (2010) noted that female bighorn sheep used more rugged terrain than males; they hypothesized that females used more rugged terrain to reduce the risk of predation and for protection of their vulnerable offspring, An indirect effect of predation is the restriction of range utilized by bighorn sheep to areas adjacent to escape terrain, changing how bighorn sheep are distributed over the area. MacCallum (1991) predicted that over time the presence of predators could potentially cause the bighorn sheep using the reclaimed mines to adjust their pattern of use by using areas closest to the highest and steepest pit walls. In accordance with this prediction the average distance to escape terrain at GRM decreased over the course of colonization (Figure 5d). The decrease in size of ram and nursery herd 65% core areas between 2010 and 2015 (Figure 5b) may in part be the result of predation

pressure. This emphasizes the importance of providing a large area of secure and open habitat for bighorn sheep. On GRM, the configuration of a series of large rock walls in parallel (PQ, KK, HI, D4, CD, H4, C4) provides secure habitat even during a period of high predation mortality. Conversely the decrease in distance from escape terrain may simply be a response to progressive reclamation of disturbed areas. Over time as sloping and revegetation were completed, more grasslands became established immediately adjacent the pit walls providing more opportunity for sheep to graze closer to escape terrain.

During the colonization of GRM, bighorn sheep did not abandon previously colonized habitat in favour of newly available habitat but maintained use of initially occupied areas while, at the same time, expanding to the northwest (Figure 2 and 4). Festa-Bianchet (1991) remarked that seasonal dispersion in the Sheep River Sanctuary may often be related to the gregarious nature of sheep: "*in certain seasons their movement within their ranges may be a function of the need to stay within a group and to follow the dominant animals"*. This plasticity of movement by bighorn sheep within their established range was described by Riggs and Peek (1980) who hypothesized that the "*lack of extreme rigidity in seasonal dispersion would be advantageous when new habitat is created through several changes following wildfires*".

A radio-collaring study of 19 bighorn sheep indicated that the bighorn sheep using the reclaimed GRM are part of a larger metapopulation that includes the adjacent partially reclaimed Luscar Mine, alpine ranges bordering the mines to the southwest and northwest, Whitehorse Wildland Provincial Park, and Jasper National Park (MacCallum 2008). There are no barriers preventing travel between these areas. Bighorn sheep that occupied adjacent historical alpine ranges initially shifted use patterns to include the reclaimed mines in their seasonal movements. With an increasing amount of available habitat, coupled with increasing numbers, bighorn sheep expanded into the newly available habitat, establishing new seasonal home ranges and traditions.

GRM is located within Wildlife Management Unit (WMU) 438. Bighorn sheep winter air surveys have been conducted by the Government of Alberta in the alpine ranges of WMU 438 adjacent the reclaimed mines beginning in 1963 (Alberta Wildlife Management 2015, Stelfox 1965). The surveys first recorded bighorn sheep on the mines in 1982; it is known anecdotally that bighorn sheep were present in small numbers in earlier years but were not detected by the surveys. Due to low survey frequency, these air survey counts should be used with caution when considering population demographics but are suitable for overall trend analysis (when incomplete surveys in 1999, 2012, and 2014 are excluded). In the undisturbed alpine portions of WMU 438 there was no evidence of a change in bighorn sheep between 1963 and 2015 ($P = 0.523$, *CI:* -1298 to 2.439, $n = 16$). In the whole of WMU 438 including the mines the overall trend showed evidence of increasing bighorn sheep numbers over the same period ($P < 0.0001$, $CI = 13.932$ to 23.264, $n = 16$). This increase can be attributed to the bighorn sheep response to newly available habitat.

In *101 Things To Do With a Hole in the Ground*, Pearman (2009) stresses that an enlightened approach to landscape regeneration can lead to better solutions to the problems of mining legacy and closure. The GRM's use of progressive reclamation throughout the life of the mine provides an example of working towards end land use goals in anticipation of closure, with the intent of leaving something of value into the future. In this case the goal was primarily wildlife habitat with a specific emphasis on bighorn sheep. Actively salvaging soil, storing soil, banking native seeds, and sloping are part of the reclamation cycle that precedes revegetation. Operators on the GRM had completed 41% of revegetation by the end of active mining in 2000. An additional 49% was quickly revegetated between 2001 and 2005, with the remaining 9% completed by 2011 (Figure 5c). Their expedience ensured that ecosystem function was restored as quickly as possible to these disturbed lands.

Revegetation in combination with retaining specific pit walls to provide escape terrain promoted early occupation by bighorn sheep of this

reclaimed habitat, thus adding to the regional bighorn sheep population and range. Given the decline of bighorn sheep in North America in the last century, the colonization of the GRM is a significant achievement. While bighorn populations elsewhere on the continent have declined due in large part to exposure to domestic diseases, the mine's remoteness has meant the GRM has never been exposed to domestic animals and diseases (MacCallum 2006); the reclaimed lands have thus contributed to the conservation of the species. Designing for and developing habitat on an on-going basis provides the opportunity for endemic wildlife populations to discover and voluntarily colonize newly available habitat during the active mining phase. On-going use of revegetated areas by grazing ungulates during the life of a mine promotes soil development and maintains grassland health. Rewilding, in this case deliberate rehabilitation of a highly disturbed area to produce a productive wildlife habitat, is part of David Attenborough's vision to restore biodiversity to mitigate the impacts of climate change (Attenborough and Hughes 2020). The reclamation of the GRM demonstrates that given appropriate planning and design, reclaimed landscapes can provide habitat that fulfill the life requirements of bighorn sheep and sympatric species. With appropriate management, these reclaimed lands can remain a valuable wildland into the future.

ACKNOWLEDGMENTS

Thanks to Westmoreland Coal Company for encouraging publication of this unique story of reclamation and colonization by bighorn sheep. Over the years, many dedicated professionals helped with various aspects of surveying, data entry, and report production. Thanks to Rick Zroback, Marlin Murphy, Trent Enzsol, and Howard Lutz who participated in the transformation of a highly disturbed area to valuable wildlife habitat. Byron Boyd produced annual reclamation maps by hand in the early years of GRM. David Brand oversaw the final reclamation and remediation efforts on GRM and provided insights on the reclamation history of the area. Special thanks to the equipment operators whose initiatives and creativity reshaped a highly disturbed area to a landscape with purpose and function. Without skilled cat and backhoe operators this result would not have been possible.

LITERATURE CITED

Alberta Forestry, Lands and Wildlife. 1990. Coal branch sub-regional integrated resource plan. Energy/Forestry, Lands and Wildlife, Pub. No. I/294. 91pp.

Alberta Government. 2016. Alberta Forest Genetic Resource Management and Conservation Standards Volume 1A – Stream 1. 65pp. https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/formain15749/$FILE/fgrms-stream1apr2018.pdf

Alberta Wildlife Management. 2015. Excel file: SheepSurveyInfo-1972-2015-A-Apr2015. http://esrd.alberta.ca/fish-wildlife/wildlife-management/bighorn-sheep-management.aspx [accessed September 29, 2015].

Arnett, E.B., L.L. Irwin, F.G. Lindzey, and T.J. Hershey. 1990. Use of clear-cuts by Rocky Mountain bighorn sheep in south-central Wyoming. Proceedings of the Biennial Symposium of the Northern Wild Sheep and Goat Council, Clarkston, Washington 7:194-205.

Attenborough, D., and J. Hughes. 2020. A life on our planet, my witness statement and a vision for the future. Hachette Book Group, Inc. 266pp.

Bibaud, A., and P. Dielman. 1980. Region 4 sheep survey. Alberta Energy and Natural Resources, Fish and Wildlife Division. 28pp.

Brand, D. 2010. Completion of reclamation of the Gregg River Mine, Alberta. Canadian Land Reclamation Association Conference, Courtenay, BC.

Branton, M., and J.S. Richardson. 2010. Assessing the value of the umbrella-species concept for conservation planning with meta-analysis. Conservation Biology Vol. 25(1):9-20.

Brewer, C.E., V.C. Bleich, J.A. Forster, T. Hosch-Hebdon, D.E. McWhirter, E.M. Rominger, M.W. Wagner, and B.P. Wiedmann. 2014. Bighorn sheep: conservation challenges and management strategies for the 21st Century. Wild Sheep Working Group, Western Association of Fish and Wildlife Agencies, Cheyenne, WY, USA.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197: 516-519.

Chetner, S., and the Agroclimatic Atlas Working Group. 2003. Agroclimatic Atlas of Alberta 1971 - 2000. Alberta Agriculture, Food and Rural Development, Agdex 071-1. Edmonton AB.

Cook, A.R. 1982. Aerial bighorn sheep census of designated winter ranges within the Edson District of the East Slope

Region. Alberta Energy and Natural Resources, Fish and Wildlife Division. 57pp.

Dibb, A.D., and M.S. Quinn. 2006. Response of bighorn sheep to restoration of winter range. Proceedings of the Biennial Symposium Northern Wild Sheep and Goat Council 15:59-68.

Festa-Bianchet, M. 1991. The social system of bighorn sheep: grouping patterns, kinship and female dominance rank. Animal Behaviour 42:71-82.

Geist, V. 1971. Mountain sheep, a study in behaviour and evolution. The University of Chicago Press. 383pp.

Garshelis, D.L., M.L. Gibeau, and S. Hererro. 2004. Grizzly bear demographics in and around Banff National Park and Kananaskis Country, Alberta. Journal of Wildlife Management 69:277-297.

Green, J.E., and K.S. Yonge. 1985. Wildlife end uses in reclamation: concepts and opportunities. Pages 384-410 *In* P.F. Ziemkiewicz (ed.) Workshop proceedings. Revegetation methods for Alberta's Mountains and Foothills. Alberta Land Conservation and Reclamation Council. RRTAC Rprt 85-1.

Gregg River Mine. 1998. Revised final reclamation (End Land Use) Plan December 1998. Prepared for Alberta Environmental Protection.

Irby, L. R., J.E. Swenson, and S.T. Stewart. 1988. How much difference do different techniques make in assessing bighorn population trends? Proceedings of the Biennial Symposium Northern Wild Sheep and Goat Council, Banff, Alberta 6:191-203.

Heady, H.F. 1975. Rangeland Management. McGraw-Hill Book Company. 460pp.

Jesmer, B.R., J.A. Merkle, J.R. Goheen, E.O. Aikens, J.L. Beck, A.B. Courtemanch, M.A. Hurley, D.E. McWhirter, H.M. Miyasaki, K.L. Monteith, and M.J. Kauffman. 2018. Is ungulate migration culturally transmitted? Evidence of social learning from translocated animals. Science 361 (6406):1023-1025.

Kenward, R.E., N.M. Casey, S.S. Walls and A.B. South. 2014. Ranges 9: For the analysis of tracking and location data. Online manual. Anatrack Ltd. Wareham, UK.

Lynch, G.M., and D.G. Smith. 1974. Red Cap sheep; their movements and migrations (1973 Progress). Alberta Fish and Wildlife Division. 24pp.

Luscar Ltd. 2003. Gregg River Mine 2002 Annual Report. Prepared for Alberta Environment and Alberta Energy and Utilities Board. 31pp.

MacCallum, N.B. 1991. Bighorn sheep use of an open pit coal mine in the foothills of Alberta. MSc thesis, University of Calgary, Calgary, AB. 202pp.

MacCallum, B. 2003. Reclamation to wildlife habitat in Alberta's Foothills. Technical Paper #14 *In* Price, W, W. Gardner, and C. Howell. Proceedings of the 27th annual British Columbia mine reclamation symposium, Kamloops BC, September 15-18, 2003. The British Columbia Technical and Research Committee on Reclamation. Bitech Publishers Ltd., Richmond, BC.

MacCallum, B. 2006. Summary of Disease Testing of Bighorn Sheep Translocated from the Luscar Mine, Alberta. Proceedings of the Biennial Symposium Northern Wild Sheep and Goat Council, Canmore, Alberta 15:69-88.

MacCallum, B. 2008. Bighorn Sheep Distribution and Movement in the Nikanassin Range of Alberta's Rocky Mountains. Proceedings of the Biennial Symposium Northern Wild Sheep and Goat Council, Midway, Utah 16:248 (Abstract Only).

MacCallum, B. 2012. Effects of Delayed Spring Greenup on Ungulates of the Luscar and Gregg River Mines, Alberta. Proceedings of the Biennial Symposium Northern Wild Sheep and Goat Council, Kamloops, BC 18:71-78.

MacCallum, B., and C. Kielpinski. 1991. Reclamation for wildlife habitat, Gregg River Resources Ltd. 86pp.

MacCallum, B., and V. Geist. 1992. Mountain Restoration: Soil and Surface Wildlife Habitat. GeoJournal 27.1:23-46.

Mace, R.D., D.W. Carney, T. Chilton-Radandt, S.A. Courville, M.A. Haroldson, R.B. Harris, J. Jonkel, B. McLellan, M. Madel, T.L. Manley, C.C. Schwartz, C. Servheen, G. Stenhouse, J.S. Walker, and E. Wenum. 2011. Grizzly bear population vital rates and trend in the Northern Continental Divide Ecosystem, Montana. The Journal of Wildlife Management 76:119-128.

Pearman, G. 2009. 101 things to do with a hole in the ground. Post-Mining Alliance and the Eden Project, St Austell, Cornwall PL24 2SG 138pp.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Riggs, R.A., and J.M. Peek. 1980. Mountain sheep habitat-use patterns related to post-fire succession. Journal of Wildlife Management. 44:933-938.

Sawyer, H., and Lindzey, F. 2002. A Review of Predation on Bighorn Sheep (*Ovis canadensis*). Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, WY.

Schroeder, C.A, R.T. Bowyer, V.C. Bleich, and T.R. Stephenson. 2010. Sexual Segregation in Sierra Nevada Bighorn Sheep, *Ovis canadensis sierrae*: Ramifications for Conservation, Arctic, Antarctic, and Alpine Research, 42(4):476-489.

Singer, F.J., M.E. Moses, S. Bellew, and W. Sloan. 2000. Correlates to colonizations of new patches by translocated populations of bighorn sheep. Restoration Ecology Vol. 8 (4S):66-74.

Smith, T.S., P.J. Hardin, and J.T. Flinders. 1999. Response of bighorn sheep to clear-cut logging and prescribed burning. Wildlife Society Bulletin 27:840-845.

Stelfox, J.G. 1964. Bighorn management problems in the Coalbranch region (S436 and S438). Alberta

Department of Lands and Forests, Fish and Wildlife Division. 20pp.

Stelfox, J.G. 1965. Bighorn and Rocky Mountain goat populations, reproductions, harvests and proposed 1966 seasons. Alberta Department of Lands and Forests, Fish and Wildlife Division. 17pp.

Stemp, R.E. 1983. Heart rate responses of bighorn sheep to environmental factors and harassment. MSc thesis, University of Calgary. 313pp.

Stenhouse, G.B., J. Boulanger, M. Effotd, S. Rovang, T. MaKay, A. Sorensen, and K. Graham. 2015. Estimates of grizzly bear population size and density for the 2014 Alberta Yellowhead Population Unit (BMA 3) and south Jasper National Park. Report prepared for Weyerhauser Ltd., West Fraser Mills Ltd., Alberta Environment and Parks, and Jasper National Park. Report prepared by fRI Research, Grizzly Bear Program, Hinton, AB, Integrated Ecological Research, Nelson, BC and Dept. of Mathematics and Statistics, University of Otago, Dunedin, New Zealand. 73pp.

Strong, W.L. 1992. Ecoregions and Ecodistricts of Alberta. 3 Volumes. Alberta Forestry, Lands and Wildlife, Land Information Services Division, Edmonton, AB.

VanderWaal, C. Kool, A., Meijer, S.S., Kohi, E., Heitkonig, I.M.A., DeBoer, W.F., VanLangevelde, F., Grant, R.C., Peel, M.J.S, Slotow, R., DeKnegt, H.J., Prins, H.H.T., and DeKroon, H. 2011. Large herbivores may alter vegetation structure of semi-arid savannas through soil nutrient mediation. Oecologia 165:1095-1107.

Van Dyke, W.A., A. Sands, J. Yoakum, A. Polenz and J. Blaisdell. 1983. Wildlife habitats in managed rangelands - the great basin of southeastern Oregon - bighorn sheep. Pacific Northwest Forest and Range Experiment Station, Forest Service, USDA, Gen. Tech. Rpt. PNW-159 1983. 37pp.

Wishart W., B. MacCallum, and J.T. Jorgenson. 1998. Lessons learned from rates of increase in bighorn herds. Proceedings of the Biennial Symposium, Northern Wild Sheep and Goat Council, Whitefish, Montana 11:126-132.