Gallatin National Forest
Project Areas

Beattie Meadows

Cutler Meadows

Hayes Meadow

McPherson Meadow

OTO Horse Pasture

OTO Central Meadows

OTO West Upper Meadow

OTO Upper Meadow

OTO West Lower Meadow

Palmer Johnson Meadow

Gallatin National Forest
Historic Agricultural Lands Restoration Objectives
February 11, 2005

Attendees: Ken Britton, Lisa Stoeffler, Dan Tyers, Ron Gardner, Pat Hoppe, and Lynn Burton

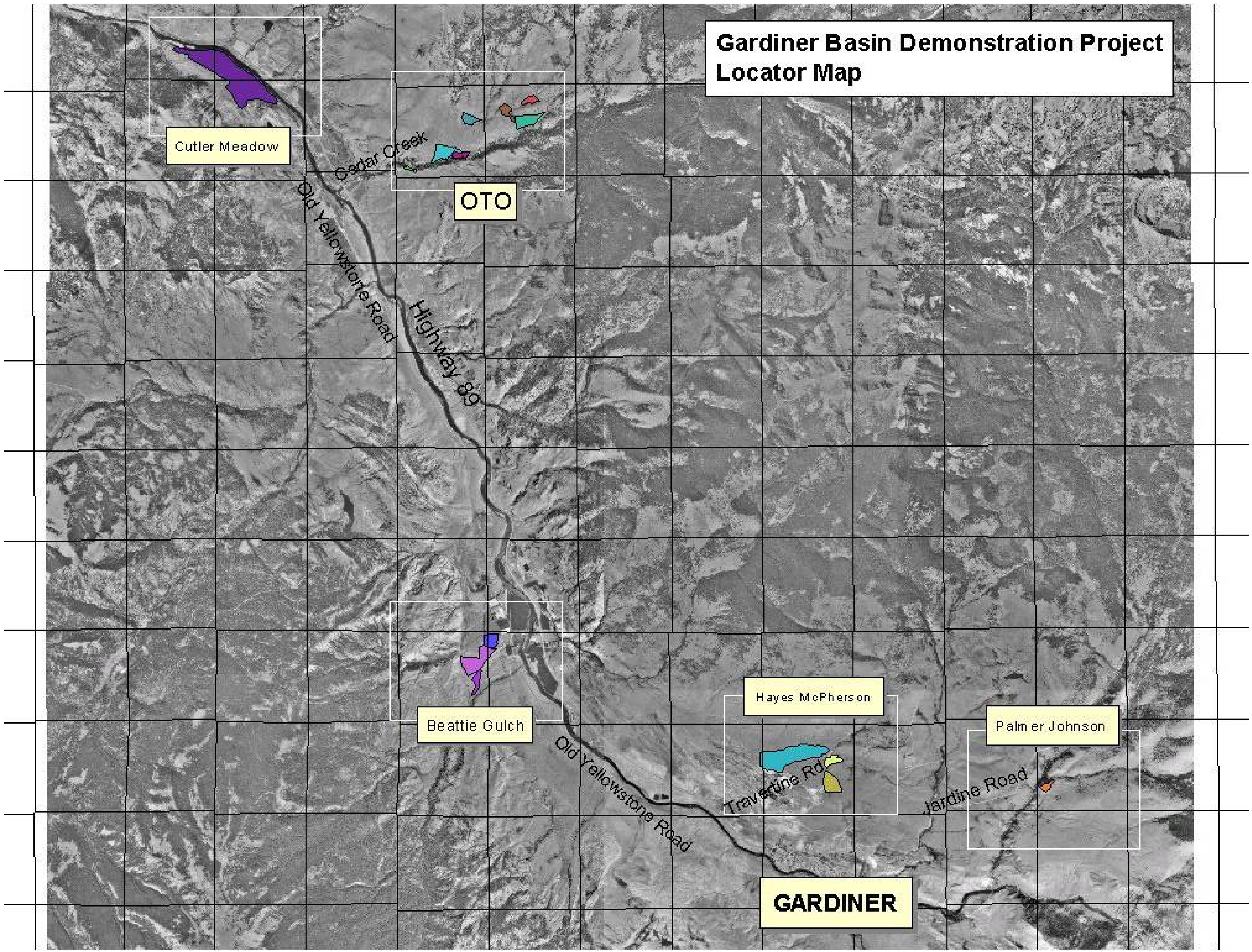
Common Restoration Themes:

1. Strive for sustainable plant communities that are ecologically stable over the long-term. Consider integrating perennial weed control into every treatment prescription.

2. Ensure future management is consistent with Devil's Slide Conservation Easement and other agreements associated with the acquire properties scheduled below.

3. Need to develop wildlife and bison management plans between the State of Montana, US Department of Interior, Forest Service and Royal Teton Ranch Inc. Consider providing treatment areas adequate rest from big game use until vegetative stand establishment occurs.

4. Initial seeding profiles have been developed for the predominant habitat types and attached to this document. These profiles will be the "boiler plate" from which the team of "Restoration Experts" will be asked to further develop for each of the Forest Service parcels.


Gardiner Basin Demonstration Project
Locator Map
Cutler Meadow
Cedar Creek
OTO
Old Yellowstone Road
Highway 89
Beattie Gulch
Old Yellowstone Road
Hayes McPherson
Travertine Rd
Palmer Johnson
Jardine Road
GARDINER

Cutler Meadows (155 Acres) - *Highest Priority*:

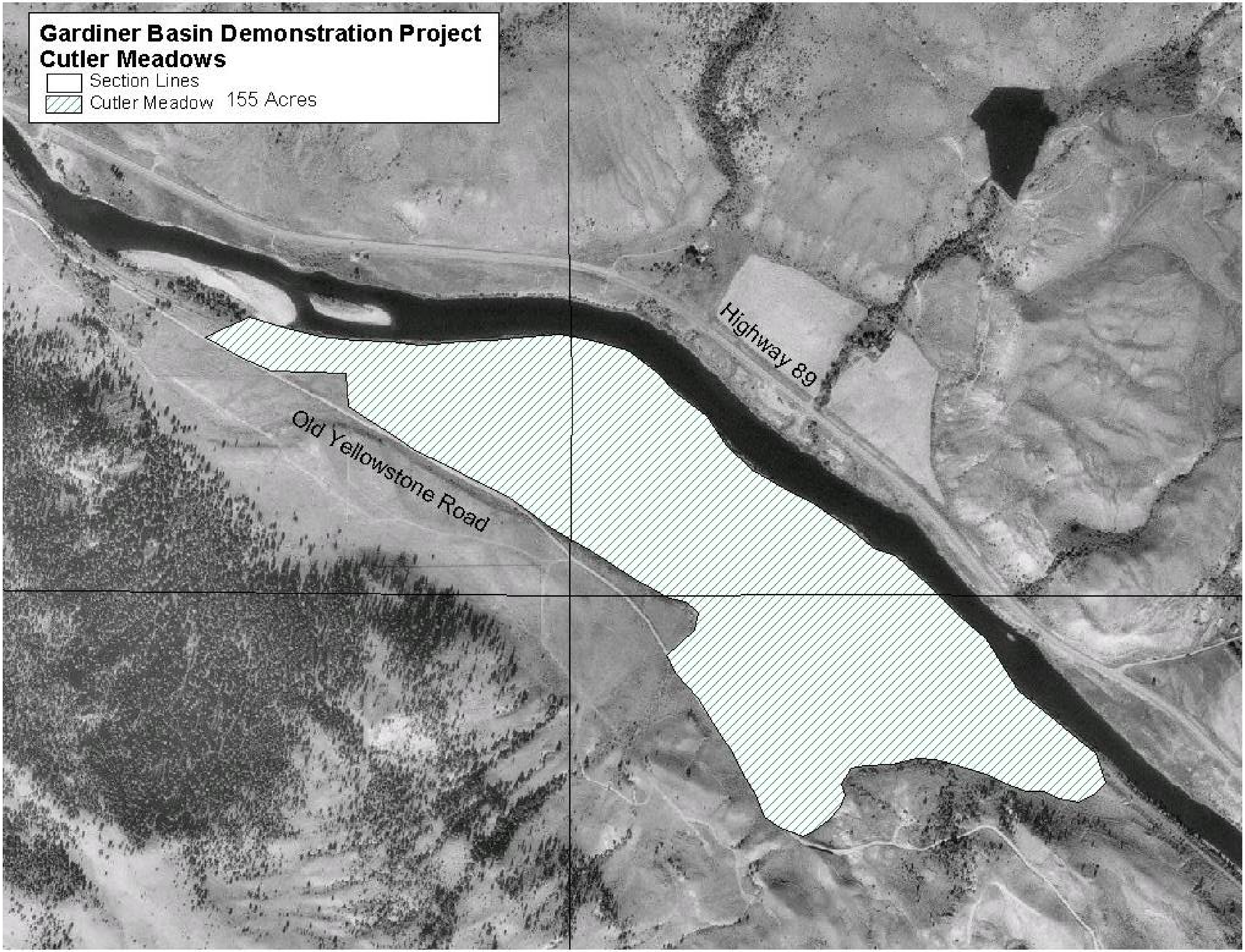
History: Tilled and irrigated hayfields since the turn of century. The Forest Service acquired these lands from Royal Teton Ranch through RMEF in 1999. This land has a water right for 10.66 cfs out of the Yellowstone River for a season of 4/15-11/19. The pump station and waterlines were removed since 1999 so temporary water for stand establishment would require additional investment. Remnant stands of alfalfa still exist. However, most of the area has converted to annual weeds.

Soils: Soils are mapped as: Map Unit 46-2A. (Shovic and Davis, Soils of the Gallatin National Forest, USDA, 1996, map sheets 49, 58, and 59.) These soils occur on terraces. They formed in glacial outwash and alluvial deposits. Dominant soils are loamy-skeletal, mixed Typic Argiborolls and Aridic Argiborolls. They have moderate clay levels with dark surface horizons. These soils have high natural fertility and high water-holding capacity. They are compactible if disturbed when wet.

Current and Potential Natural Vegetation (PNV): This site consists primarily of Great Basin Big Sagebrush/ Bluebunch Wheatgrass habitat type with inclusions of Wyoming Big Sagebrush/ Idaho Fescue on the more shallow soils, Rocky Mountain Juniper/ Idaho Fescue on the "fringe" areas protected from natural wildfire, and probably Black Cottonwood/ Bluejoint Reedgrass along the stream banks of the Yellowstone River. Current vegetation consists of: alfalfa, western wheatgrass, rubber rabbitbrush, smooth brome, kochia, and cheatgrass.

Restoration Objectives: Re-establish the potential natural vegetation. Native species would not need to be locally derived but preferably from sources originating in Montana. Water could be available for stand establishment, albeit expensive.

Challenges: The only stand of Russian knapweed occurring on the District occurs on this site. Big game currently uses these meadows year round, especially during the fall and spring migration and spring greenup. Bison will most likely use the area year round in the future, and perhaps under an enclosed quarantine setting so the plantings may need to withstand heavy fall through spring grazing use.



Gardiner Basin Demonstration Project
Cutler Meadows
Section Lines
Cutler Meadow 155 Acres
Highway 89
Old Yellowstone Road

Beattie Gulch (48 Acres Irrigated, 9 Acres Non-Irrigated) - *Second Priority*:

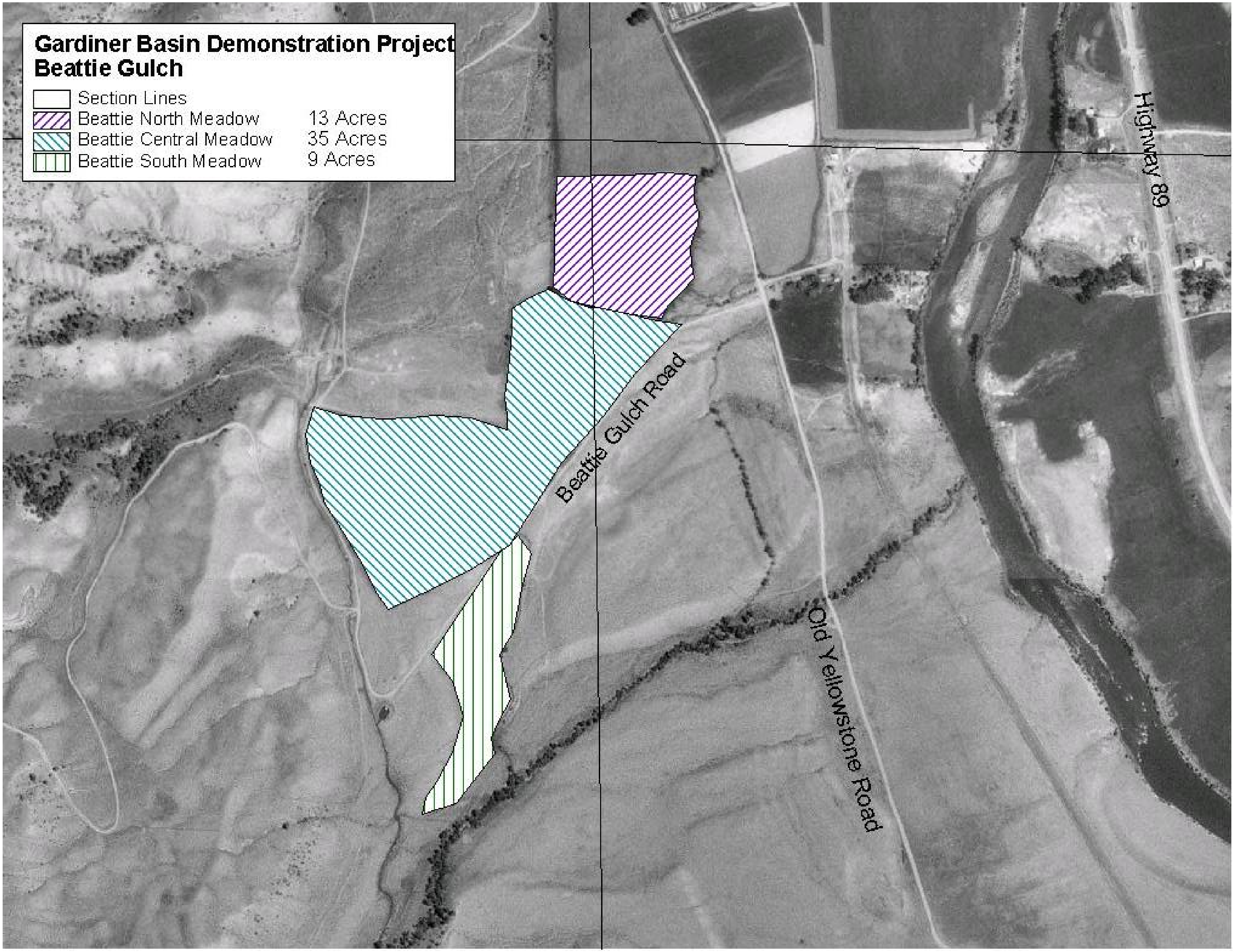
History: Tilled and irrigated hayfields since the turn of century. The Forest Service acquired these lands from Royal Teton Ranch through RMEF in 1999. This land has a water right for 4.53 cfs out of Beattie Gulch, Reese Creek, and the Yellowstone River for the primary use season of 4/15-11/19. However, adjacent land owners do have water rights and pipeline that cross these lands. The water rights are currently being finalized in the deeds, and we expect the US will receive the water rights. While much of this flow will probably remain in the stream and river for in-stream flows, some may be tapped during early season high flows for stand establishment purposes. Temporary irrigation facilities would require additional investment. Remnant stands of alfalfa still exist on the northern area. The southern portion has a stand of Crested Wheatgrass that was seeded after the Little Joe Fire camp was removed in 2002. The resident antelope herd is drawn to the remnant alfalfa stand and open area year round.

Soils: These fields are just north of Yellowstone National Park on Gallatin National Forest lands. The fields have slopes of 0 to 5% and are on slightly convex landforms. Soils are relatively fertile with low compaction levels. Soils are mapped as: Map Unit 46-2A. (Shovic and Davis, 1996) These soils occur on terraces. They formed in glacial outwash and alluvial deposits. Dominant soils are loamy-skeletal, mixed Typic Argiborolls and Aridic Argiborolls. They have moderate clay levels with dark surface horizons and many rock fragments. These soils have high natural fertility and high water-holding capacity. They are compactible if disturbed when wet.

Current and Potential Natural Vegetation (PNV): This site consists primarily of Great Basin Big Sagebrush/ Bluebunch wheatgrass habitat type on the north portion having the deeper soils and Wyoming Big Sagebrush/ Bluebunch Wheatgrass habitat types on the more southerly portion having the more shallow soils. Some of the latter area appears to have been reclaimed from a gravel source pit. Inclusions of Rocky Mountain Juniper/ Idaho Fescue occur on the "fringe" areas protected from natural wildfire. Current vegetation consists of: alfalfa, western wheatgrass, rubber rabbitbrush, smooth brome, kochia, and cheatgrass.

Restoration Objectives: Re-establish the potential natural vegetation. Water could be available for this restoration, albeit expensive. Support burying of the pipeline used by the adjacent landowners.

Challenges: This site borders Yellowstone National Park so the questions pertaining to the need for using locally derived native species needs to be worked out. Big game use this meadow year round especially in the fall through spring months. This area will receive heavy utilization by big game, especially elk and bison during the night that find refuge on the National Park Service lands during daylight hours.



Gardiner Basin Demonstration Project
Beattie Gulch
Section Lines
Beattie North Meadow 13 Acres
Beattie Central Meadow 35 Acres
Beattie South Meadow 9 Acres
Highway 89
Beattie Gulch Road
Old Yellowstone Road

Hayes (81.5 Acres) - *High Priority if Irrigation System Re-Established:*

History: These lands were cleared of sagebrush and the native sagebrush slopes irrigated since the turn of century. The Forest Service acquired these lands from Hayes through RMEF in 1991. The land has a water right for 6.3 cfs out of Phelps, Eagle, and Bear Creeks that has a transfer ditch. The ditch hasn't been used for a number of years. The Forest Service currently winters and supplemental feeds horses on this area from November through April each year.

Soils: Soils are mapped as: Map Unit 34-1B (Shovic and Davis, 1996). These soils occur on rolling glacial moraine formed primarily from hard-crystalline rocks and rhyolite. Dominant soils are loamy-skeletal, mixed Argic Cryoborolls. They have moderate clay levels with dark surface horizons and many rock fragments. These soils have moderate natural fertility and moderate water-holding capacity. They are resistant to compaction when wet.

Current and Potential Natural Vegetation (PNV): Consists primarily of Wyoming Big Sagebrush/ Idaho Fescue habitat type with inclusions of Great Basin Big Sagebrush/ Bluebunch Wheatgrass on the deeper soils, along with Black Sagebrush/ Bluebunch Wheatgrass and Rocky Mountain Juniper/ Idaho Fescue on the more shallow soil areas more protected from natural wildfire. Current vegetation consists of: alfalfa, western wheatgrass, rubber rabbitbrush, smooth brome, kochia, and cheatgrass.

Restoration Objectives: Restore a productive irrigated horse pasture. The use of already occurring exotic plant species would be acceptable if other native species are not thought to provide a sustainable setting. Kentucky bluegrass, orchard grass and smooth broom already occur on the site. Consider augmenting water from the adjacent streams with mine waste water from the Jardine Mine. Also pursue means that improves ditch efficiency and the quantity of water being delivered. The District plans to install a cross fence that will provide for a 10 acre holding area for winter feeding of horses. The remaining 70 acres will then be managed to sustain any seeding that occurs.

Challenges: Dalmation toadflax occurs throughout most of the adjoining lands. Plant species need to be adapted to heavy use by horses and big game. Horses are fed off the meadows during the fall and winter months. Big game use these meadows year round, especially during the summer months when other forage has dried out.

McPherson (9 acres of native irrigated slope and another 21.5 acres of tilled, seeded and irrigated lands) – ***Lower Priority*****:**

History: The upper more northerly 9 acres were cleared of sagebrush and irrigated since the turn of century. The lower more southerly 21.5 acre field was tilled, planted with alfalfa, and irrigated. The Forest Service acquired these lands from McPherson through RMEF in 1991. This area has a water right for 5.0 cfs out of Phelps, Eagle, and Bear Creeks that has a transfer ditch. The same ditch that services the Hayes area provides water for this area.

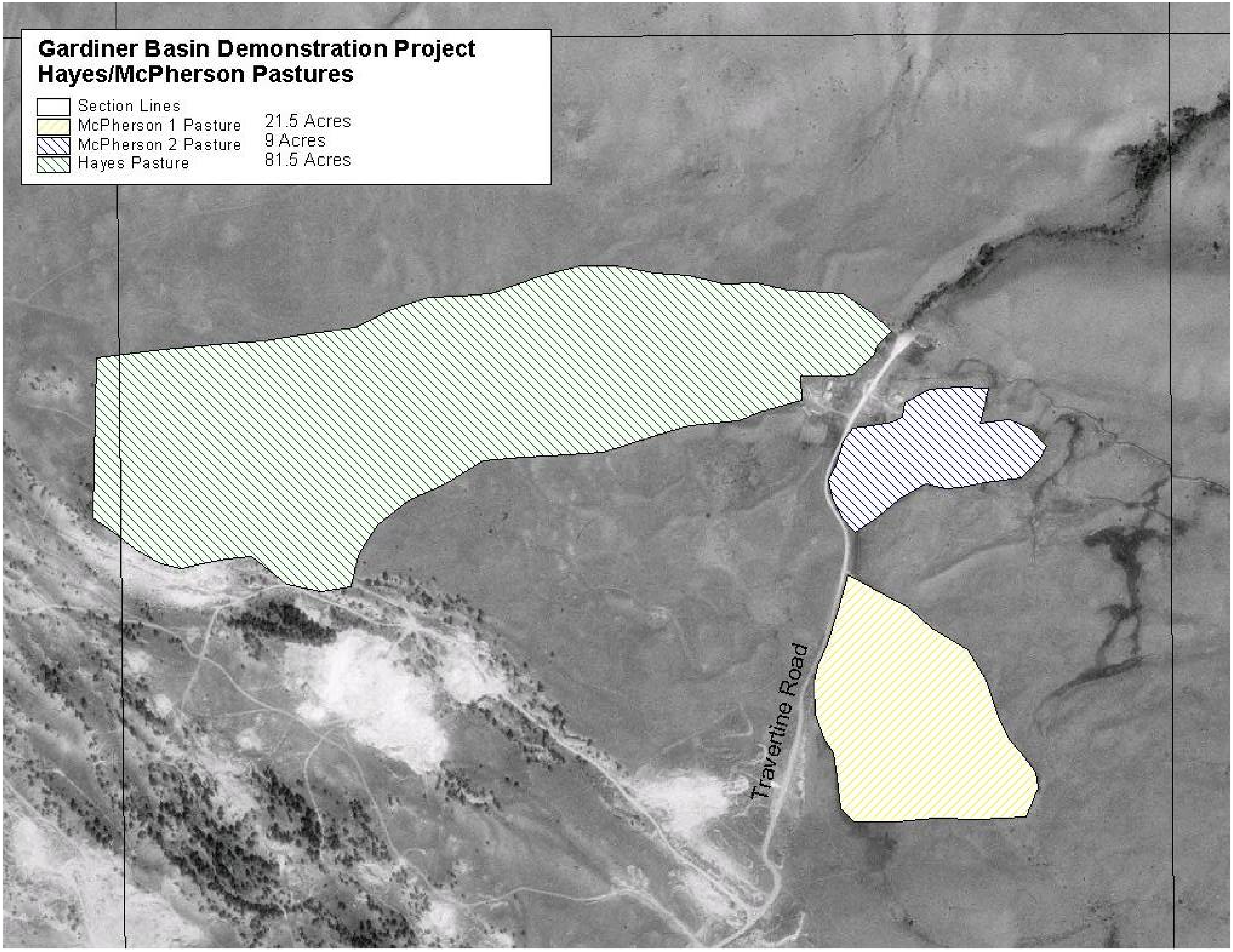
Soils: Soils are mapped as: Map Unit 34-1B (Shovic and Davis, 1996). These soils occur on rolling glacial moraine formed primarily from hard-crystalline rocks and rhyolite. The natural vegetation is mountain grassland and mountain shrubland (primarily low sagebrush near Gardiner.) Dominant soils are loamy-skeletal, mixed Argic Cryoborolls. They have moderate clay levels with dark surface horizons and many rock fragments. These soils have moderate natural fertility and moderate water-holding capacity. They are resistant to compaction when wet.

Current and Potential Natural Vegetation (PNV): Consists primarily of Wyoming Big Sagebrush/ Idaho Fescue habitat type with inclusions of Great Basin Big Sagebrush/ Bluebunch Wheatgrass on the deeper soils, along with Black Sagebrush/ Bluebunch Wheatgrass and Rocky Mountain Juniper/ Idaho Fescue on the more shallow soil areas more protected from natural wildfire. Current vegetation consists of: alfalfa, western wheatgrass, rubber rabbitbrush, smooth brome, kochia, and cheatgrass.

Restoration Objectives:

Re-establish the potential natural vegetation. Water could be used for stand establishment. Native species may need to be locally derived but preferably from sources originating in Montana.

Challenges: Dalmation toadflax occurs throughout most of the adjoining lands. Plant species need to be adapted to heavy use by wintering big game. Big game would use these meadows year round.


Gardiner Basin Demonstration Project
Hayes/McPherson Pastures
Section Lines
McPherson 1 Pasture 21.5 Acres
McPherson 2 Pasture 9 Acres
Hayes Pasture 81.5 Acres
Travertine Road

OTO (79.6 Acres among 8 fields) – *Lower Priority***:**

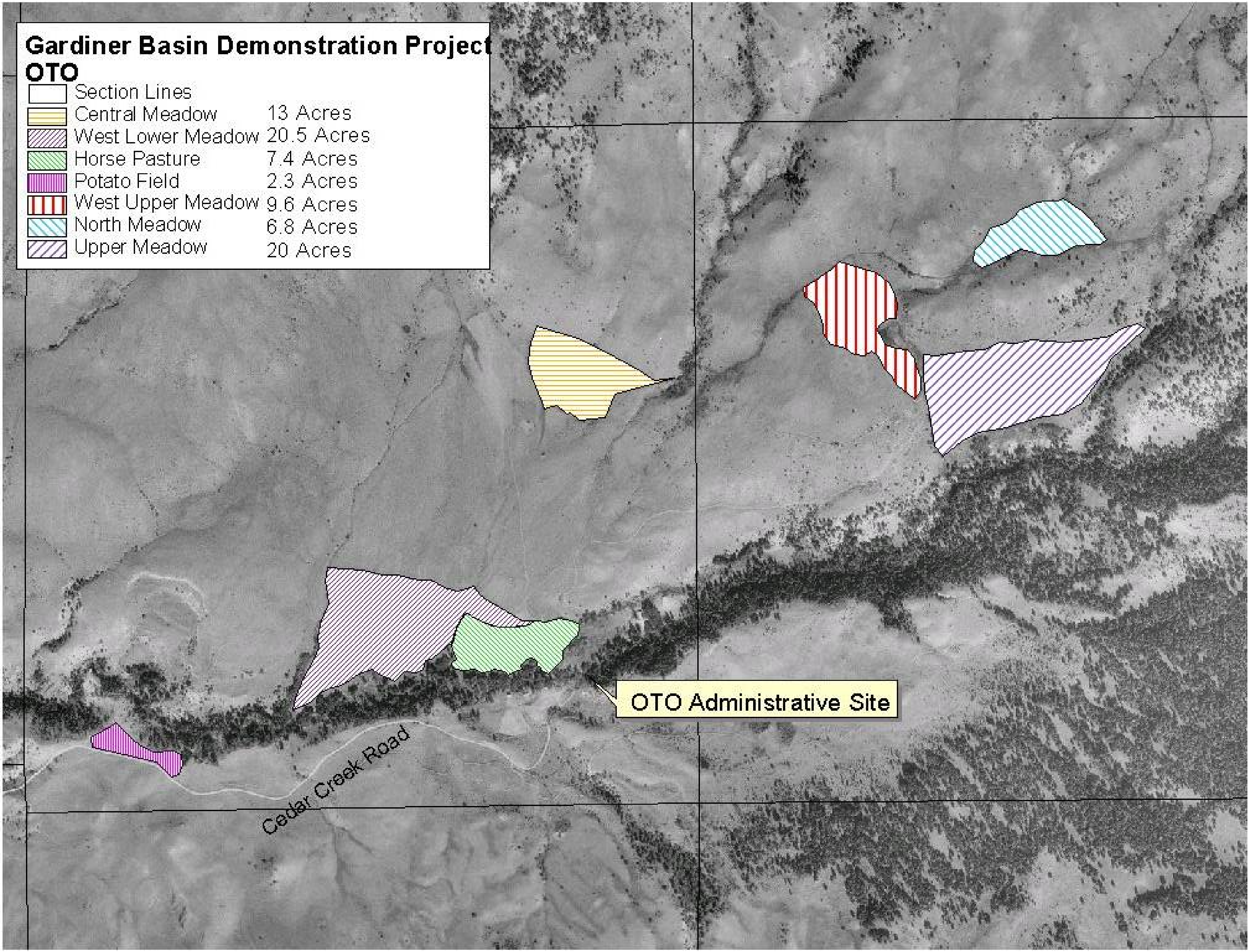
History: These lands were cleared of sagebrush and the native sagebrush slopes irrigated by lateral ditches from Cedar Creek since the turn of century. The Forest Service acquired these lands from Church Universal and Triumphant through RMEF in 1990. The land has a water right for 21.66 cfs out of Cedar Creek. The water right has since been kept in the stream for in-stream flow fishery purposes. The meadows are beginning to revert back to sagebrush types with some annual weeds.

Soils: Soils are mapped as: Map Unit 34-4C (Shovic and Davis, 1996). These soils occur on rolling glacial moraine formed primarily from mixed sandstone, shale, and volcanic rocks. Dominant soils are fine loamy, mixed Argic Cryoborolls and Argic-Pachic Cryoborolls. They have few rock fragments. They have moderate clay levels with thick, dark surface horizons. These soils have high natural fertility and high water-holding capacity. They are susceptible to compaction when wet.

Current and Potential Natural Vegetation (PNV): This site consists primarily of Great Basin Big Sagebrush/ Bluebunch Wheatgrass and Idaho Fescue habitat types with inclusions of Wyoming Big Sagebrush/ Idaho Fescue on the more shallow soils, and Rocky Mountain Juniper/ Idaho Fescue on the "fringe" areas protected from natural wildfire. Current vegetation consists of: western wheatgrass, meadow foxtail, rubber rabbitbrush, great basin big sagebrush, smooth brome, kochia, and cheatgrass. Each of the fields consists of a different mix of species some with all annuals to others having a large component of perennial vegetation.

Restoration Objectives: Manage the hayfields as part of the historic landscape similar to that of the 1920-30's. This would suggest irrigation practices remain active for at least portions of the growing season. Supplemental seeding may be necessary to replace undesirable weedy species and establish more drought tolerant type species that will persist over an extended period of time. In-stream flow needs will continue to occur so careful water management will be necessary. Irrigation practices may eventually be turned off.

Challenges: Control of perennial noxious weeds needs to be integrated into the prescription. Big game currently use these meadows year round, especially during the winter and spring months. Bison will most likely use the area year round in the future, and perhaps under an enclosed quarantine setting so the plantings may need to withstand heavy fall through spring grazing use.


Gardiner Basin Demonstration Project
OTO
Section Lines
Central Meadow 13 Acres
West Lower Meadow 20.5 Acres
Horse Pasture 7.4 Acres
Potato Field 2.3 Acres
West Upper Meadow 9.6 Acres
North Meadow 6.8 Acres
Upper Meadow 20 Acres
OTO Administrative Site
Cedar Creek Road

Other Sites Needing Prescriptions if Time Permits:

Palmer/Johnson Tract (5.5 Acres) – *Lowest Priority:*

Restoration Objectives: Re-establish native species for long-term stable system. Water may be available during the early growing season.

Soils: Soils are mapped as: Map Unit 46-2A (Shovic and Davis, 1996). These soils occur on terraces. The natural vegetation is mountain grassland and mountain shrubland. They formed in glacial outwash and alluvial deposits eroded from hard-crystalline rocks. Dominant soils are loamy-skeletal, mixed Typic Argiborolls and Aridic Argiborolls. They have low clay levels with dark surface horizons and many rock fragments. These soils have moderate natural fertility and moderate water-holding capacity. They are resistant to compaction if disturbed when wet.

Section 30 (__ Acres) – *Lowest Priority:*

Restoration Objectives: Currently a monoculture Crested Wheatgrass type that appears to be maintaining well. Probably should examine the long-term ecological goals. While we are not unhappy with this situation, there are probably some things we can do to enhance the current type without re-tilling.

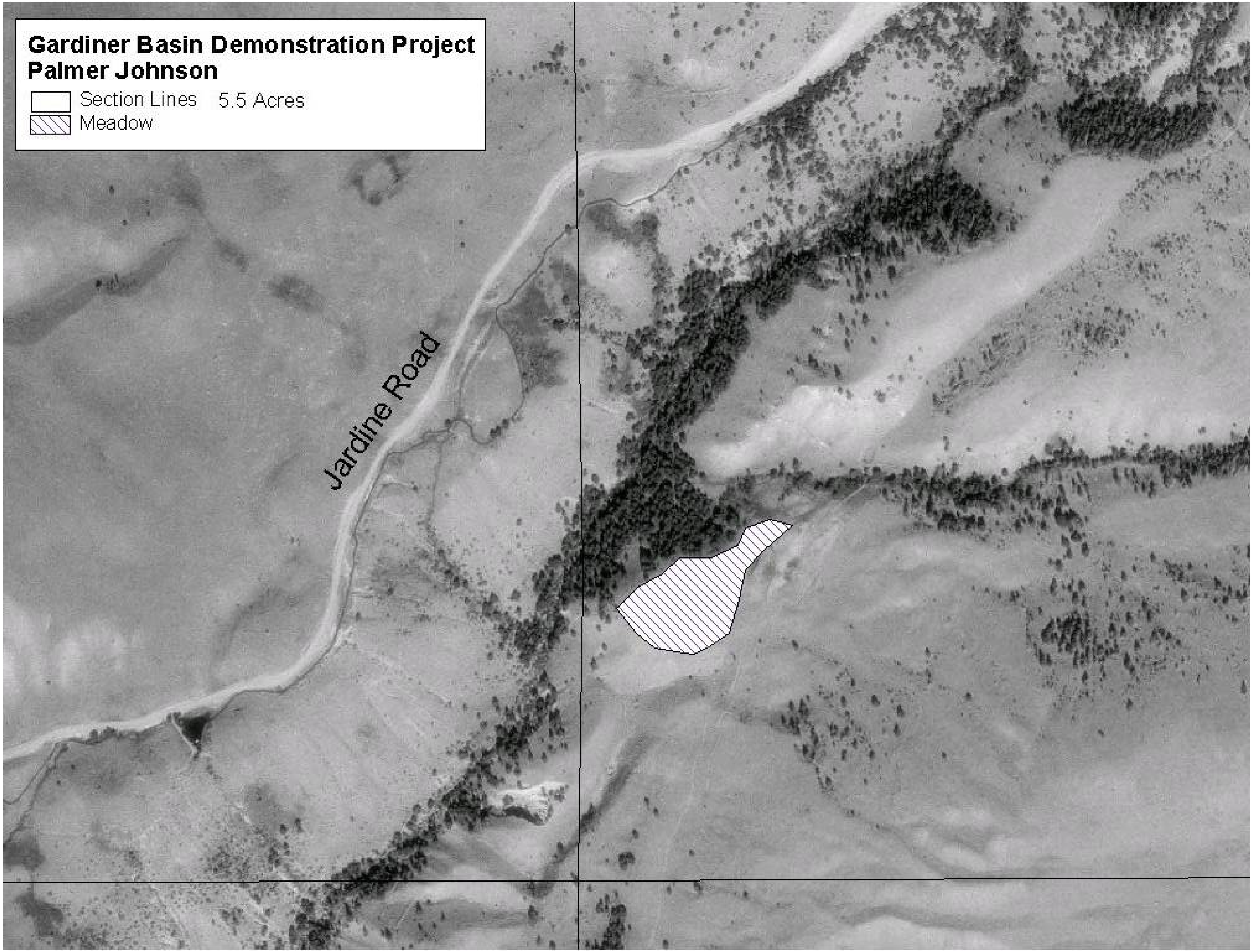
Railroad ROW (__ Acres) – *Low Priority:*

Restoration Objectives: This site bisects the above Section 30 lands and has also been seeded with Crested Wheatgrass. This site tends to be more weed infested and has very little soil or material to work with. Short of hauling it out and replacing it with soil, are there measures we could take? Irrigation is not an option.

Travertine Quarry Sites (__ Acres) – *Low Priority:*

Restoration Objectives: Not an Ag property, but needs restoration. Take any information from restoration of the other sites to use here. Mostly devoid of soil or nutrients.

These quarry sites are scheduled for closure on February 28, 2006. The Quarry Owner/Operators have quarry site restoration responsibilities per the terms of the purchase deeds which included reference to 36CFR 251.15 which states the owner of the reserved mineral rights will “restore the land to a condition safe and reasonably serviceable for authorized programs of the Forest Service”.



Gardiner Basin Demonstration Project
Palmer Johnson
Section Lines 5.5 Acres
Meadow
Jardine Road

Gallatin National Forest - Great Basin Big Sagebrush/Bluebunch Wheatgrass H.T.

Group Number	Priority	Common Name	"Variety"	Seeds Per Pound	Need Per Acre 1/		PLS/Sq. Foot	Project Needs 2/		PLS Cost Per Lb	Total Cost
					PLS Lbs	Bulk Lbs		Acres	PLS Lbs		
1	**1**	**Western Wheatgrass**	**Rosanna**	**110,000**	**2**		**5.0505**	**1**	**240**		
	1	Bluebunch Wheatgrass	"Local"	140,000							
	2	**Bluebunch Wheatgrass**	**Goldar**	**140,000**	**2**		**6.4279**	**1**	**240**	**15**	**3600**
	1	**Thickspike Wheatgrass**	**Critana**	**154,000**	**2**		**7.0707**	**1**	**2**	**2.75**	**6.4**
	1	**Idaho Fescue**	**"Local"**	**450,000**	**1**		**10.331**	**1**	**1**	**20**	**20**
	2	Idaho Fescue	Winchester	450,000							
	1	**Annual Ryegrass**		**227,000**	**1**		**5.2112**	**1**	**1**	**1.35**	**1.35**
2	1	Sandberg's Bluegrass	"Local"	925,000							
	2	**Big Bluegrass**	**Sherman**	**882,000**	**0.5**		**10.124**	**1**	**0.5**	**5.05**	**12.5**
	3	Canby Bluegrass	Canbar	926,000							
	4	Canada Bluegrass	Reubens	2,500,000							
	5	Switch Grass	Forestberg	389,000							
3	1	**Basin Wildrye**	**Trailhead**	**130,000**	**3**		**8.9532**	**1**	**3**	**3**	**36**
4	1	Yarrow	"Local"	2,770,000							
	2	**Yarrow**	**Great Northern**	**2,770,000**	**0.1**		**6.359**	**1**	**0.1**	**10**	**1**
5	1	Basin Big Sagebrush	"Local"	2,500,000							
	2	**Basin Big Sagebrush**		**2,500,000**	**0.1**		**5.7392**	**1**	**0.1**		**0**
		Rangeland Drill		**Order**	**11.6**		**65.266**	**1**	**487.6**		

Gallatin National Forest - Great Basin Wyoming Sagebrush/Idaho Fescue H.T.

Group Number	Priority	Common Name	"Variety"	Seeds Per Pound	Need Per Acre 1/			Project Needs 2/		PLS Cost Per Lb	Total Cost
					PLS Lbs	Bulk Lbs	PLS/Sq. Foot	Acres	PLS Lbs		
1	1	**Western Wheatgrass**	**Rosanna**	**110,000**	**2**		**5.050505**	**1**	**2**		
	1	Bluebunch Wheatgrass	"Local"	140,000							
	2	**Bluebunch Wheatgrass**	**Goldar**	**140,000**	**2**		**6.427916**	**1**	**2**	**15**	**30**
	1	**Thickspike Wheatgrass**	**Critana**	**154,000**	**2**		**7.070707**	**1**	**2**	**3.2**	**6.4**
	1	**Idaho Fescue**	**"Local"**	**450,000**	**1**		**10.33058**	**1**	**1**	**20**	**20**
	2	Idaho Fescue	Winchester	450,000							
	1	**Green Needlegrass**		**180,000**	**1**		**4.132231**	**1**	**1**		
	1	**Indian Rice Grass**		**160,000**	**1**		**3.673095**	**1**	**1**		
	1	**Annual Ryegrass**		**227,000**	**1**		**5.211203**	**1**	**1**	**1.35**	**1.35**
2	1	Sandberg's Bluegrass	"Local"	925,000							
	2	**Big Bluegrass**	**Sherman**	**882,000**	**0.5**		**10.12397**	**1**	**0.5**	**5.05**	**12.5**
	3	Canby Bluegrass	Canbar	926,000							
	4	Canada Bluegrass	Reubens	2,500,000							
	5	Switch Grass	Forestberg	389,000							
3	1	**Basin Wildrye**	**Trailhead**	**130,000**	**3**		**8.953168**	**1**	**3**	**3**	**36**
4	1	Yarrow	"Local"	2,770,000							
	2	**Yarrow**	**Great Northern**	**2,770,000**	**0.1**		**6.359045**	**1**	**0.1**	**10**	**1**
5	1	Wyoming Big Sagebrush	"Local"	2,500,000							
	2	**Wyoming Big Sagebrush**		**2,500,000**	**0.1**		**5.73921**	**1**	**0.1**		**0**
		Rangeland Drill		**Order**	**13.6**		**73.07163**	**1**	**13.6**		

Gallatin National Forest - Black Greasewood/Western Wheatgrass H.T.

Group Number	Priority	Common Name	"Variety"	Seeds Per Pound	Need Per Acre 1/ PLS Lbs	Need Per Acre 1/ Bulk Lbs	PLS/Sq. Foot	Project Needs 2/ Acres	Project Needs 2/ PLS Lbs	PLS Cost Per Lb	Total Cost
1	1	Western Wheatgrass	"Local"	110,000							
	2	**Western Wheatgrass**	**Rosanna**	**110,000**	**2**		**5.050505**	**1**	**2**		**0**
	1	Inland Saltgrass	"Local"	520,000							
	2	**Inland Saltgrass**		**520,000**	**1**		**11.93756**	**1**	**1**		
	1	Needle and Thread Grass	"Local"	115,000							**0**
	2	**Needle and Thread Grass**		**115,000**	**1**		**2.640037**	**1**	**1**		
	1	**Annual Ryegrass**		**227,000**	**1**		**5.211203**	**1**	**1**		
2	1	Alkali Bluegrass	"Local"	1,000,000							
	2	Sandberg's Bluegrass	"Local"	925,000							
	3	**Big Bluegrass**	**Sherman**	**882,000**	**0.5**		**10.12397**	**1**	**0.5**	**5.05**	**12.5**
3	1	**Basin Wildrye**	**Trailhead**	**130,000**	**3**		**8.953168**	**1**	**3**	**3**	**36**
4	1	Yarrow	"Local"	2,770,000							
	2	**Yarrow**	**Great Northern**	**2,770,000**	**0.1**		**6.359045**	**1**	**0.1**	**10**	**1**
5	1	Black Greasewood	"Local"	225,000							
	2	**Black Greasewood**		**225,000**	**0.5**		**2.582645**	**1**	**0.5**		**0**
	1	Nuttall saltbush	"Local"	112,000							
	2	**Nuttall saltbush**		**112,000**	**0.5**		**1.285583**	**1**	**0.5**		**0**
		Rangeland Drill		**Order**	**8.6**		**52.85813**	**1**	**8.6**		

Plant species common and scientific names.

Group Category:	Common Name:	Variety:	Scientific Name:
1. Bunch Grasses:	Western Wheatgrass	Rosanna	Pascopyrum (Agropyron) smithii
	Bluebunch Wheatgrass	Goldar	Pseudoroegneria (Agropyron) spicata
	Thickspike Wheatgrass	Critana	Elymus lanceolatus (Agropyron dasystachyum)
	Idaho Fescue	Winchester	Festuca idahoensis
	Green Needlegrass		Nassella (Stipa) viridula
	Indian Rice Grass		Achnatherum (Oryzopsis) hymenoides
	Inland Saltgrass		Distichlis spicata
	Needle and Thread Grass		Hesperostipa (Stipa) comata
	Slender Wheatgrass	Pryor	Elymus trachycaulus (Agroyron trachycaulum)
	Sand Dropseed		Sporobolus cryptandrus
	Red three-awn		Aristida purpurea (longiseta)
2. Filler Grasses:	Sandberg’s Bluegrass		Poa sandbergii
	Big Bluegrass	Sherman	Poa ampla
	Canby Bluegras	Canbar	Poa canbyi
	Canada Bluegrass	Reubens	Poa compressa
	Switch Grass	Forestberg	Panicum virgatum
	Alkali Bluegrass		
3. Deep Soil Grasses:	Basin Wildrye	Trailhead	Leymus (Elymus) cinereus
4. Forbs	Yarrow	Great Northern	Achillea millefolium (lanulosa)
5. Shrubs	Basin Big Sagebrush		Artemisia tridentate tridentata1
	Wyoming Big Sagebrush		Artemisia tridentate wyomingensis
	Black Greasewood		Sarcobatus vermiculatus
	Nuttall Saltbrush.		Atriplex
6. Other	Annual Ryegrass		Lolium perenne ssp. multiflorum

Appendices

Cheatgrass

For information on cheatgrass, please refer to this website link.
http://www.weedsbc.ca/weed_desc/cheatgrass.html

Eremopyrum triticeum

(*Agropyron triticeum* or *Agropyron prostratum)*
Annual wheatgrass (Poaceae)

Origin: Introduced.

General Botanical Characteristics:
Densely bunched, stems erect to somewhat spreading, 1.5-3.0 dm tall; blades flat to inrolled, 2-6 mm wide; inflorescence spike 1-2 cm long; the inflorescence rachis continuous; spikelets one per node, 8-12 mm long, very crowded and diverging at wide angles (40-80^o), the internodes 1/10 - 1/8 the length of the spikelets; glumes and lemmas becoming hardened or bony in texture at maturity, tapering to an awn-tip. Known in Montana from Garfield, Jefferson, Park, Power River, and Sanders Counties, but is expected to be locally common throughout the State especially in dry fields, or any dry site with sandy or gravelly soils where competition with other grasses is minimal.

This grass resembles a diminutive form of crested wheatgrass (*Agropyron cristatum*).

Reproduction: Annual wheatgrass reproduces by seed.

Note: Annual wheatgrass generally not considered a weed problem and no control/management literature was found for the species.

Agropyron cristatum

Crested wheatgrass (Poaceae)

Origin: Russia. Introduced grass from Europe and Asia.

General Botanical Characteristics:
Crested wheatgrass is a cool-season, medium-height, exotic perennial bunchgrass. The plant is drought- and cold-resistant and long-lived, enabling it to establish in recognizable monocultures. Crested wheatgrass culms are 10 to 40 inches (25-100 cm) tall and widely spaced. The deep, finely branched fibrous roots of crested wheatgrass penetrate to a maximum depth of 8 feet (2.4 m), with most roots extending to a depth of 3.3 feet (1 m). Crested wheatgrass is common in the Northern Great Plains and in Canada while desert wheatgrass is more common throughout the western United States. Desert wheatgrass is tall and coarse, while crested wheatgrass is smaller, leafier, and has broader seedheads. Crested wheatgrass is a diploid species, which differentiates it genetically from desert wheatgrass, a tetraploid.

Crested wheatgrass remains productive for more than 30 years. Stand mortality is virtually unknown, except in cases of extreme drought during critical phenological stages.

Reproduction: Crested wheatgrass is a perennial and reproduces by seed or vegetatively and is self-sterile. Crested wheatgrass seedlings are very hardy, vigorous, and easily established. The seeds of crested wheatgrass germinate well throughout a range of temperatures, allowing the plant to spread rapidly. Crested wheatgrass produces tillers, and its ability to spread vegetatively contributes to its presence at higher elevations, where the growing season may not be long enough each year to produce seed. However, in drier habitats, the ability of rhizomatous native grasses to propagate without setting seed allows them to compete well with crested wheatgrass. Crested wheatgrass is able to emerge from a relatively deep soil depth, which allows it to escape the more extreme environmental soil conditions closer to the surface. Crested wheatgrass shoots have long, numerous, and quick-growing roots, which may explain strong seedling establishment. Crested wheatgrass greens up 2 to 4 weeks earlier than native bunchgrass species. It goes dormant in the summer, but if soil moisture is available, it will grow again in the fall.

Seed longevity: Studies report seeds remain viable for at least 2 years, and up to 12 years in soils.

Seed production: A highly productive seed producer under a wide range of conditions.

Germination: Optimum germination occurs between 15-25 C.

Geographic Range: Crested wheatgrass has been planted throughout North America in a variety of ecosystems; the appearance of the species within a specific cover type does not necessarily indicate that crested wheatgrass is particularly well adapted to those climatic conditions.

Site Characteristics: Crested wheatgrass is tolerant of very cold and very dry conditions, typical of both its native habitat in Russia and some areas of the northern Great Plains. It grows best on medium-textured soils, from sandy loams to clay loams. Crested wheatgrass does not grow well in loose sandy soils, heavy clays, or saline soils. Crusted soils impede crested wheatgrass seedling emergence.

Crested wheatgrass thrives at around 12 to 16 inches (305-406 mm) of precipitation and competes poorly with other grasses on moister sites. In Utah, crested wheatgrass appears on sites with precipitation of at least 12 inches (300 mm).

Soils: Adapted to loamy, clay soils. Less adapted to heavy clays and sand. Most abundant on dry, medium textured soils.

Response to shading: Light is not a requirement for crested wheatgrass germination.

Competition: Fairly shade, drought, and cold tolerant. A very long lived plant.

Notes: Commonly planted for soil stabilization.

The above notes are from: Zlatnik, Elena. 1999 Agropyron cristatum. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/ [2005, March 14].

Other articles of interest include the following:

Bakker, J.D, S. D. Wilson, J. M. Christian, X.Li, L.G. Ambrose, and J. Waddington. 2003. Contingency of grassland restoration on year, site, and competition from introduced grasses. Ecological Applications: Vol. 13(1): 137–153.

Abstract. Semiarid ecosystems such as grasslands are characterized by high temporal variability in abiotic factors, which has led to suggestions that management actions may be more effective in some years than others. Here we examine this hypothesis in the context of grassland restoration, which faces two major obstacles: the contingency of native grass establishment on unpredictable precipitation, and competition from introduced species. We established replicated restoration experiments over three years at two sites in the northern Great Plains in order to examine the extent to which the success of several restoration strategies varied between sites and among years. We worked in 50-yr-old stands of crested wheatgrass (*Agropyron cristatum*), an introduced perennial grass that has been planted on $>10 \times 10^6$ ha in western North America.

Establishment of native grasses was highly contingent on local conditions, varying fourfold among years and threefold between sites. Survivorship also varied greatly and increased significantly with summer precipitation. No consistent differences were found between drilling and broadcasting in their effects on establishment, but survivorship was nearly threefold higher in broadcast plots. Plots without seed added, or with native hay added, had almost no seedlings of native grasses. In contrast, broadcasting the residue remaining after cleaning seeds from native hay produced the highest seedling densities of any treatment.

Competition from *A. cristatum* was significantly and consistently reduced through annual application of a generalist herbicide (glyphosate), which increased native grass establishment and survivorship and the richness and total cover of native species. Herbicide decreased standing crop and increased soil moisture and available nitrogen. *A. cristatum* was controlled without suppressing native vegetation, both by spraying in early spring, which selectively killed the cool-season *A. cristatum*, and by application with a wick, which selectively killed the taller *A. cristatum*. *A. cristatum* persisted over four years, however, in spite of annual herbicide application. *A. cristatum* cover in control plots increased significantly with summer precipitation.

In summary, broadcasting and drilling differed little in their effects on establishment, but broadcasting increased survivorship and will allow the emergence of plant-induced heterogeneity. Competition from introduced species can be reduced but not eliminated by continuing herbicide application. Lastly, the positive relationships between precipitation and both *A. cristatum* and native seedling survivorship suggest that management should focus on controlling *A. cristatum* during dry years and on introducing native species during wet years.

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Emergence of the Introduced Grass *Agropyron cristatum* and the Native Grass *Bouteloua gracilis* in a Mixed-grass Prairie Restoration

Laura G. Ambrose[1] and Scott D. Wilson[1,2]

Abstract

Prairie restoration at the northern edge of the Great Plains can be frustrated by previously established non-native perennial grasses. We compared the emergence of a widely introduced grass, *Agropyron cristatum*, and a common native grass, *Bouteloua gracilis*, in a 4-year-old field experiment in which the *Agropyron* -dominated vegetation had either been left intact or treated annually with herbicide. This was done at two levels of water supply, reflecting conditions expected in wet and dry years, to examine the effects of among-year variability in precipitation. Water addition significantly increased the emergence of both surface-sown and buried (1 cm deep) seeds. Herbicide treatment of neighbors did not increase the emergence of experimentally added seeds. Emergence was much greater for buried (80%) than surface-sown seeds (20%). Significantly more *Bouteloua* than *Agropyron* germinated from experimentally buried seeds. Whereas only a single seedling of *Bouteloua* emerged from the existing seed bank, the mean density of *Agropyron* seedlings emerging from the seed bank was 930/m^2 (range, 0 to 6,455/m^2). Surprisingly, the emergence of *Agropyron* from the seed bank was not decreased by 4 years of herbicide treatment, possibly because herbicide may release *Agropyron* from intraspecific competition and allow increased seed production to compensate for decreased plant abundance. In summary, we found few differences between *Agropyron* and *Bouteloua* in spring and summer emergence at high or low water availability. The persistence of *Agropyron* stands despite repeated herbicide application may be partly due to increased seed production.

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Extirpation or Coexistence? Management of a Persistent Introduced Grass in a Prairie Restoration

Scott D. Wilson[1] *and Meelis Pärtel*[2]

Abstract

Introduced perennial grasses are one of the greatest constraints to prairie restoration. Herbicides suppress but do not eliminate introduced grasses, so we explored the interaction of herbicide with two additional controls: heavy clipping (to simulate grazing) and competition from native species. A 50-year-old stand of the introduced perennial grass *Agropyron cristatum* (crested wheatgrass) in the northern Great Plains was seeded with native grasses and treated with herbicide annually for 7 years in a factorial experiment. Clipping was applied as a subplot treatment in the final 3 years. Both herbicide and clipping significantly reduced the cover of *A. cristatum* but clipping produced an immediate and consistent decrease, whereas herbicide control varied among years. The cover of *A. cristatum* decreased significantly with increasing cover of a seeded native grass, *Bouteloua gracilis* (blue grama), suggesting that both top-down (i.e., grazing) and bottom-up (i.e., resource competition) strategies can contribute to *A. cristatum* control. No treatment had any effect on the seed bank of *A. cristatum.* Even in the most effective control treatments, *A. cristatum* persisted at low amounts (approximately 5% cover) throughout the experiment. The cover of *B. gracilis* increased significantly with seed addition and herbicide, and, after 7 years, was similar to that in undisturbed prairie. The total cover of native species increased significantly with clipping and herbicide, and species richness was significantly higher in plots receiving herbicide. Clipping season had no effect on any variable. In summary, no method extirpated *A. cristatum* but clipping reduced its cover by 90% and doubled the cover of native species. Extirpation might not be a realistic goal, but relatively simple management allowed coexistence of native species.

Camelina microcarpa

(syn. *Camelina sativa*, subsp. *Microcarpa*)

smallseed falseflax

Identification: Smallseed falseflax is an annual from Europe found on dry or well-drained, sandy sites. It is a winter-hardy annual that grows as tall as 1 m and is erect with ascending branches. It has tiny forked or stellate hairs pressed flat to the stem, but hairless individuals are occasionally found. All the leaves are hairy, lanceolate, and without petioles, and the bases of the upper leaves clasp the stem. The petals are pale yellow, fading to white, and 4 to 5 mm long, borne on long racemes. The pods are shaped like teardrops with slightly winged margins, attached at the narrow end. They are 5 to 8 mm long with beaks 2 to 2.5 mm long on pedicels that are 5 to 10 mm long. The cotyledons are round, 4 to 6 mm long and 2 to 3 mm wide, with short petioles that have 2 to 3 short, marginal hairs. Seedling leaves are lanceolate, with entire margins, a prominent midvein, and slightly mustard-flavored. The seeds are yellow-brown, mucilaginous when wet, longer than broad, 1 to 1.5 mm long, with a finely reticulate surface texture.

Geographic distribution: Throughout all of U.S. except mid-Atlantic Coast states and states on the southern U.S. boundary.

Ecological distribution: Roadsides, foothills, gardens, and other disturbed moist to dry sites. Disturbed areas such as fields, waste places, and roadsides, mostly growing in flax areas.

Soils: A common weed of disturbed soils.

Reproduction: Annual (or winter annual), reproduces by seeds. Flowers April to September.

Germination: Majority of seeds germinate in early spring.

Control:

Mechanical: Mow close to surface to prevent seed production.

Chemical: 2,4-D has been used in pastures and small grain crops to control *C. microcarpa*. 2,4-D should be applied early in spring before seeds are formed. *Camelina microcarpa* is suspected to be resistant to sulfonylurea herbicides.

Amaranthus retroflexus

PIGWEED

OTHER NAMES: Redroot, green amaranth, rough pigweed, green pigweed.

ORIGIN: Native to Europe or tropical America

DESCRIPTION: Annual, reproducing by seed with a reddish to pink taproot. Redroot pigweed grows in cultivated fields, pastures, roadside ditches, and undeveloped areas. It is Most abundant on rich soils. It is a common annual weed, producing many seeds that remain viable for up to 5 years. It has a long, fleshy, reddish to pink taproot. The stems are erect, light green, stout, branched, 60-90 cm (1-3 ft.) high, rough, and angular. The leaves are alternate, stalked, dull green, ovate, rough, and 8-10 cm (3-4 in.) long. The flowers are numerous, small, green, crowded into dense finger-like spikes in axils of the leaves, and in a large terminal spike or panicle. Up to 100,000 seeds can be produced per plant and can survive 10 years in the soil.

Redroot pigweed requires high temperatures for germination (optimally, in the 20-30 degrees C or 70-85 degrees F range) and will continue to germinate throughout the summer if there is adequate soil moisture. It will grow almost anywhere and in any crop but is most abundant on rich soils, thriving at higher temperatures.

SEEDS: Jet black, glossy, somewhat flattened.

CONTROL PRACTICES:

Mechanical: Mow or hoe at early stages of growth, and pull seedlings. Cultivate regularly in row crops.

Cultural: Crops established before soils warm and hot weather sets in are very competitive with redroot pigweed. Do not allow the plant to flower. Infested stubble fields should be tilled shallowly in the fall or early spring to place the pigweed seed in a position for germination. This weed can be difficult to control in non-competitive crops like flax. It can also act as a host for tarnished plant bug which, in turn, can infest many field crops.

Chemical: Glyphosate (Roundup®) is effective as a spot spray. Use broadleaf herbicides if the crop is corn or other row crop. Preemergent such as trifluralin (Treflan®) may also be effective. Trifluralin must be incorporated into the soil by watering or disking to be effective.

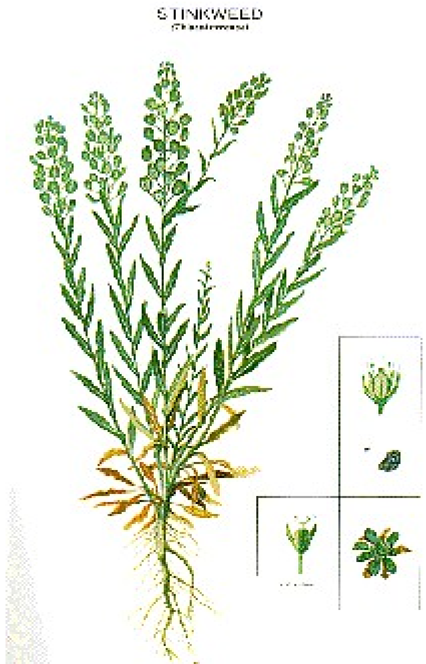
Herbicides are available in most crops for control of redroot pigweed. Watch growth stages carefully under hot conditions because the weed can quickly advance beyond the recommended stages for herbicide application.

Please refer to Saskatchewan Agriculture, Food and Rural Revitalization's *Guide to Crop Protection* for current herbicide rates and application recommendations. This annual publication is available at this site: http://www.agr.gov.sk.ca/docs/crops/cropguide00.asp. Relevant pages referring to herbicide weed control follow this page.

Thlaspi arvense

OTHER NAMES: Fanweed, pennycress, frenchweed, stinkweed

ORIGIN: Eurasia



HABITAT: Cultivated fields and waste places.

DESCRIPTION: Annual or winter annual reproducing by seed. Stinkweed can produce up to 15,000 seeds/plant.

STEMS: Smooth, erect, 5-61 cm high, often branched.

LEAVES: Alternate, without hairs, upper leaves clasping the stem.

FLOWERS: 3.2 mm across, petals white, stalked, pods green becoming yellow or orange at maturity, notched at the top.

SEEDS: 4 to 16 in each pod, reddish-brown to black, flattened, rows of curved ridges on each side.

Life Cycle
A summer and winter annual that reproduces by seed.

Emergence
Emergence of summer annuals occurs mainly in early spring. Seeds of winter annual germinate in late summer; seedlings overwinter and continue to grow in the spring.

Flowers
Winter annuals can flower in early spring. Flower and seed production of both forms take place throughout the summer.

Reproduction
Stinkweed seed can live for up to six years in the tillage zone. Seeds that are buried deeper than the tillage zone can live for up to 20 years and germinate when the come close to the surface. Dormancy of stinkweed seeds is encouraged by a thick seed coat.

Competition
Stinkweed can compete with crops for moisture and nutrients. However, a well-fertilized crop that has a head start over stinkweed will compete well.

Management Strategy
Control of fall rosettes of winter annuals is important so that seed is not formed early the following spring. During any tillage operations plants with developed pods should not be turned under because they can continue to ripen on the stalks in warm soil.

Control Mechanisms

- **Tillage**
  Summer fallow - Till early in the spring after stinkweed emerges. Make a shallow tillage in summer if needed. Fall tillage will control the winter annual rosettes.

  Pre-seeding tillage - To minimize competition with the crop, control weed seedlings in the spring with a shallow tillage operation before or during the seeding operation. If overwintered stinkweed is a problem, till early in the spring.

  Post-seeding tillage - Post-seeding tillage should not be required if pre-seeding tillage is done, or if seeding is after the main spring weed emergence.

  Fall tillage - Fall tillage controls rosettes that would otherwise overwinter and stimulates germination of annual weed seeds. Shallow tillage in early October with a field cultivator will conserve some crop residue and destroy weed seedlings.

- **Rotation**
  Crop rotation alone will not control stinkweed. A summer fallow year in the rotation will help to reduce seed levels in the soil. Seedlings will still germinate from existing seeds.

- **Seeding**
  Seed after the main weed seedling emergence. Waiting for stinkweed to emerge may delay seeding slightly.

- **Mowing**
  Mowing prevents seed production but short plants may escape cutting.

Russianthistle or **Common Russianthistle** [*Salsola tragus* L.]

Spineless Russianthistle [*Salsola collina* P.S. Pallas]

Barbwire Russianthistle [*Salsola paulsenii* Litv.]

SYNONYMS:

- **Russianthistle:** tumbleweed, Russian tumbleweed, tumbling weed, windwitch, witchweed, common saltwort, *Salsola australis* R.Br., *Salsola iberica* (Sennen & Pau) Botsch, *Salsola kali* L. var. *tenuifolia* Tausch., *Salsola kali* L. ssp. *tragus* (L.) Celakovsky, *Salsola kali* L. ssp. *ruthenica* (Iljin) Soo, *Salsola pestifer* Nelson. The synonymy of this taxon is complex, and correct use of some scientific names is currently uncertain. Only frequently used synonyms are listed.
- **spineless Russianthistle:** tumble thistle

GENERAL DESCRIPTION: Bushy summer annuals, with rigid branches and reduced, stiff, prickly upper stem leaves (bracts) at maturity. Introduced from Eurasia.

- **Russianthistle:** Plants are an alternate host for the beet leafhopper (*Circulifer tenellus*) that can carry the virus causing curly-top of sugarbeets, tomatoes, melons, and many other crop and native plants. Immature plants can provide extra forage for livestock on arid rangelands. However, under certain conditions, such as heavy nitrogen fertilizer application, nitrates or oxalates can accumulate to levels poisonous to sheep. Biocontrol has not been successful in California. Russianthistle consists of 2 variants or types in California. Currently designated type A and type B, the two types differ in chromosome number (A: 2n = 36; B: 2n = 18), spinyness, fruit size, calyx characteristics, seed weight, and pubescence. Both types hybridize with barbwire Russianthistle. Plants with intermediate characteristics can be found in regions where both species occur. Introduced into South Dakota around 1874 in flax seed from Russia.
- **spineless Russianthistle:** No infestations are currently known in California, but seed has been found as a contaminate of commercial birdseed. Widespread in the Midwest and appears to be expanding range. First reported in the Midwest in 1958.
- **barbwire Russianthistle:** Closely resembles, hybridizes with, and is often confused with Russianthistle. Plants rarely host the beet leafhopper. Thought to have been introduced to the Southwestern U.S. at the turn of the century, but unrecognized until 1967.

SEEDLINGS: Cotyledons and subsequent leaves needle-like. Leaves alternate, but often appear opposite because of short internodes.

- **Russianthistle:** Cotyledons 10-35 mm long. Subsequent leaves fleshy, soft, weakly spine-tipped. Stems slender, flexible, typically with reddish-purple longitudinal striations. **I**mmature plants taller than wide, with lateral branches ascending and shorter than the main stem.
- **spineless Russianthistle:** Subsequent leaves pliable, +/- fleshy, with a soft bristle at the apex.
- **barbwire Russianthistle:** Cotyledons similar to those of Russianthistle. Subsequent leaves resemble those of mature plants. Stems thick, +/- rigid, without purple striations. Main stem shorter than lateral branches. First 4 lateral branches often form a cross-shaped pattern and are nearly prostrate, with the tips curved upwards. Immature plants are wider than tall and appear mounded at an early stage.

MATURE PLANT: Leaves alternate, sessile, linear to needle-like, gradate into rigid, spine-tipped bracts in the inflorescences.

- **Russianthistle:** To 1 m tall, usually height +/- equal to width or taller than wide. Stems rigid, typically curved upwards. Foliage +/- blue-green, glabrous (mostly type B) or covered with short, stiff hairs (mostly type A). Leaves fleshy to leathery, 8-52 mm long, mostly 0.5-1 mm wide, sharp-pointed to spine-tipped. Bracts +/- awl-shaped, reflexed, not overlapping at maturity, with membranous, minutely barbed margins.
- **spineless Russianthistle:** To 1 m tall. Stems green and white striated, straight, erect to ascending. Foliage +/- glabrous, covered with minute papillae. Leaves to 5 cm long, pliable, +/- succulent to leathery, with a soft bristle at the apex and expanded bases that extend a short distance down the stems (slightly decurrent). Bracts lanceolate, appressed to stems and strongly overlap one another.
- **barbwire Russianthistle:** Typically to 0.5 m tall, wider than tall. Foliage +/- yellow-green, glabrous or covered with minute papillae. Leaves fleshy, thick, stiff, spine-tipped, 5-32 mm long, 1-1.5 mm wide, often curved away from the stem (recurved) near the tip, covered with short hairs or minute papillae. Bracts resemble those of Russianthistle.

ROOTS and UNDERGROUND STRUCTURES: Taprooted. Do not form mycorrhizal associations.

Russianthistle: To 1.5 m deep, with laterals spreading to 1.8 m. Plants can extract deep soil moisture that is not available to winter wheat.

FLOWERS:Bisexual, axillary, mostly solitary. Petals lacking. Sepals 4-5, persistent in fruit, typically with wing-like appendages that appear petal-like in Russian and barbwire Russianthistle. Calyx (sepals as a unit) mostly 2.5-3.5 mm long. Stamens 5, extended beyond sepals (exserted). Style branches 2, exserted. Wind-pollinated. Out-crossing and self-fertile.

- **Russianthistle:** July-October. Typically male flowers develop in early July. Bisexual flowers develop from about mid-July (type B) to early October (type A). Sepal tips acute, +/**- lax, not spine-like. Sepal wings fan-shaped, 0.5-2.5 mm long, usually minutely toothed to scalloped along the margins, translucent, often pinkish to d**eep red with conspicuous veins, folded (type A) or open (type B).
- **spineless Russianthistle:** Summer/fall. Sometimes with gall-like flowers in leaf axils of the lower portions of plants. Flowers +/- hidden by 2 large, fleshy, spine-tipped bracts. Sepal wings lacking or narrow, mostly less than 1 mm long, with minutely irregular-toothed margins.
- **barbwire Russianthistle:** June-September. Typically flowers 2-3 weeks earlier than Russianthistle. Sepal tips often stiff, erect, usually spine-like. Sepal wings similar to those of Russianthistle, but larger (2.5-4.5 mm long), typically flat, with entire to minutely irregular-toothed margins.

FRUITS and SEEDS: Utricles (fruiting structures) +/- spherical, 1-seeded, enclosed by persistent calyces. Seeds +/- round and slightly flattened to slightly conical, ~ 1.5-2 mm in diameter, with a thin, gray to brown translucent seed coat (pericarp) and visible dark greenish-brown coiled embryo.

- **Russianthistle:** Fruits 4-10 mm diameter, including sepal wings. Fruits of type A are generally smaller than type B fruits. Sepal wings flat (mostly type B) or folded (mostly type A). Type A seeds typically ~ 2-2.5 mg/seed, type B ~ 1.25-1.75 mg/seed.
- **spineless Russianthistle:** Fruits 3-5(7) mm diameter including sepal wings when present, hidden by 2 large, fleshy, spine-tipped bracts.
- **barbwire Russianthistle:** Fruits 7-12 mm diameter, including sepal wings.

POSTSENESCENCE CHARACTERISTICS: Plants become gray to brown. Main stems of Russianthistle break off at ground level under windy conditions allowing plants to disperse numerous seeds as they tumble. Skeletons persist for at least one year and are typically found along fences and other structures.

HABITAT: Typically infests sandy soils on disturbed sites, waste places, roadsides, cultivated and abandoned fields, disturbed natural and semi-natural plant communities.

PROPAGATION/PHENOLOGY: Reproduce by seed. Seed appears to require an after-ripening period. Cotyledons are photosynthetic upon emergence.

- **Russianthistle:** Most seed germinates the spring following maturation. Seed can germinate when night temperatures are below freezing and daytime temperatures reach 2º C. Optimal temperatures for germination are between 7 and 35º C (45 and 95º F). Germination requires little moisture (0.3 inches of rainfall) and occurs within in a few hours. Successful germination requires loose soils. Seedlings that germinate on firm soil seldom survive because radicles are unable to penetrate the soil. Seed in the field typically remains viable for only 1 year, some up to 2 years, rarely to 3. Plants about 0.5 m tall can produce about 1500-2000 seeds, and large plants can produce up to 100,000. Seed disperses when plants break off at ground level and tumble with the wind. Seedlings attain optimal emergence from litter or soil depths to 1 cm, but can emerge from soil depths to 6 cm.
- **spineless Russianthistle:** No information available.
- **barbwire Russianthistle:** Reproductive biology similar to that of Russianthistle, but seed appears to require less after-ripening time and germinates over a broader range of temperatures. Most seed disperses near the parent plant, and plants typically do not become "tumble weeds."

MANAGEMENT FAVORING/DISCOURAGING SURVIVAL: Seedlings cut just above the cotyledons seldom survive. Properly timed cultivation of seedlings prevents seed production and can control infestations, but cultivation must be repeated until the soil seed bank becomes depleted.

CONTROL METHODS:

Prevention: These thistles are part of a complex genus in the Chenopodiaceae family. They are strongly competitive in semiarid areas and are heavily favored by disturbance. They persist in dryland cropping systems, overgrazed rangeland, roadsides, and waste areas. The exact time of introduction into California for Salsola tragus and Salsola paulsenii is uncertain, but may have been near the turn of the century. Salsola collina is not currently present in California, but appears to be increasing its range across the Great Plains.

Tumbleweeds disperse seed over long distances as they are carried along the ground by the wind. Frequently, new infestations appear as a "trail" of tumbleweed seedlings across fields. Skeletons also often collect along fencerows , and subsequent populations can become very dense. One of the keys to preventing spread of Russian thistle is controlling seedlings along both sides of fence rows and along field borders, where tumbleweed skeletons accumulate. Additionally, areas "downwind" of infested areas are most likely to be invaded. In many cases, it is impossible to prevent tumbleweed movement and sensitive areas should be monitored each year for new plants.

Mechanical: Many mechanical strategies are effective in controlling these thistles. Mowing is effective on very young plants. However, older plants will recover by axial branching below the cutting level. Plants should never be mowed after seed set has occurred, as this will facilitate seed dispersal to new areas.
Tillage will control both seedling and larger plants. However, tillage increases disturbance, which favors additional germination of seeds. Seed viability appears to be 1-3 years for Russian thistle and is unknown for barbwire or spineless Russian thistle. Therefore, an intensive tillage program that completely prevents seed production for 2-3 years may eliminate these thistles. However, recurrent seed depositions from tumbleweeds blowing in from adjacent areas is highly probable.
Hand pulling of large plants is extremely difficult and may be injurious due to the spiny nature of Russian and barbwire thistle. Always wear gloves if attempting to hand pull these species.

Biological: There are two insects that have been approved and released for control of Russian thistle: a leaf mining moth (Coleophora klimeschiella) and a stem boring moth (Coloephora parthenica). Both are available for release in California. Beyond its known establishment in central California, there is little information on the effectiveness of Coleophora klimeschiella. Coloephora parthenica has not been effective in reducing Russian thistle populations. There are a number of possible factors for this, including predation by rodents, spiders, and parasitoids; poor host plant synchronization due to herbivore independent mortality; and a general lack of effectiveness in reducing seed production. Recent taxonomic reconsideration of Salsola tragus and its possible biotypes or subspecies may bring further clarity to the effectiveness of this biocontrol agent.

Chemical: These thistles primarily occur in dryland agricultural production systems, roadsides, rangelands, and waste areas. This presents the need for several different herbicide strategies. Generally, seedling Russian thistle is not difficult to control with the proper herbicides. However, as plants get older, moisture stress is often likely and herbicide efficacy is greatly reduced.
For roadsides, preemergent herbicides applied in the fall can provide season long control. Table 1 provides effective herbicides for roadside Russian thistle control. Post-emergent applications should be made in the seedling stage for effective control. Postemergent applications generally do not provide long term control due to repeated flushes of seed germination following herbicide application. Consult the label for application rates and restrictions.
Russian thistle has documented resistance to chlorsulfuron in Idaho, Oregon, and Washington. In California, a biotype with resistance to both chlorsulfuron and sulfometuron has been found. Avoid developing resistance by using a combination of management strategies and rotating between herbicide modes of action.

Table 1. Effective herbicides for roadside Russian thistle control.

Preemergent Herbicide	Post-emergent Herbicides
Bromacil	Bromoxynil
Chlorsulfuron	2,4-D amine and ester formulations
Diuron	Dicamba
Hexazinone	Glyphosate
Isoxaben	Triclopyr
Napropamide	
Oryzalin	
Oxyfluorfen	
Pendimethalin	
Sulfometuron	
Tebuthiuron	

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FLIXWEED

Descurainia sophia (L.) Webb ex Prantl

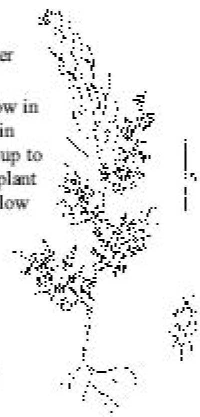
Family: *Brassicaceae* (Mustard).

Other Scientific Names: None.

Other Common Names: Flixweed tansymustard, herb-sophia, fine-leaved hedge mustard.

Legal Status: Not categorized.

Identification



Growth form: Winter annual forb.

Flower: Flowers grow in racemes, which lengthen when in fruit. These racemes may grow up to one-half the total height of the plant (FEIS 1996). The petals are yellow to greenish yellow and very small.

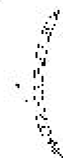
Seeds/Fruit: Seeds are borne in linear pods that are 11–33 mm long.

Leaves: Leaves are alternate, 2–3 times pinnately compound.

Stems: Mature plants are 0.3–1.0 m tall.

Roots: Flixweed has a slender taproot.

Seedling: Narrow, stalked seed leaves (cotyledons).



Similar Species

Exotics: None known.

Natives: Tansy mustard (*Descurainia pinnata*) is easily confused with flixweed but has leaves that are only 1–2 times compound.

Impacts

Agricultural: In cultivated areas, can crowd out crop plants and reduce yields (Mitich 1996).

Ecological: As an introduced species, flixweed has spread very rapidly across portions of the intermountain West (Morishita 1991).

Human: No information available.

Habitat and Ecology

General requirements: Flixweed is found growing in disturbed habitats, fields, roadsides, and logged-over forests. It grows on a wide variety of soil types, but it is most abundant on dry, disturbed sites. It is often found along roadsides and ditches where mineral soil has been exposed (FEIS 1996).

Distribution: Frequent throughout BC at low- to mid-elevations and present in all agricultural reporting regions except the Queen Charlotte Islands and adjacent coast (Douglas et al. 1998). It is common throughout North America.

Historical: Introduced from Europe.

Life cycle: Flixweed is an early-blooming winter annual or biennial and is one of the first weeds to appear in the spring. Flowering occurs from March through July, depending on geographic location. Flixweed spreads by seeds from early to late summer. Flixweed is an early seral species that quickly invades

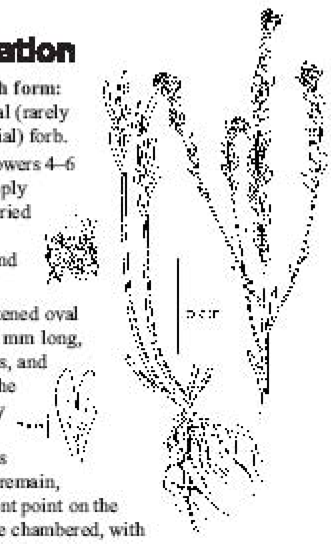
HOARY ALYSSUM

DISTRIBUTION

Berteroa incana (L.) DC.

Family: *Brassicaceae* (Mustard).
Other Scientific Names: None.
Other Common Names: None.
Legal Status: Regional Noxious: Kootenay-Boundary.

Identification



Growth form: Biennial (rarely perennial) forb.

Flower: White flowers 4–6 mm long with deeply notched petals carried on slender stalks. Sepals are hairy and soon drop off.

Seeds/Fruit: Flattened oval seed pods are 5–8 mm long, have star-like hairs, and are held close to the stem (BC Ministry of Agriculture, Food and Fisheries 1998). The styles remain, making a prominent point on the tips. Seed pods are chambered, with each chamber containing 3–7 seeds. Seeds, 2–3 mm long, are aligned in rows in the chambers (Douglas et al. 1998).

Leaves: All leaves are grey with star-shaped hairs. Basal leaves are 3–5 cm long with slender stalks. Stem leaves face upward, pressed close to the stem. Lower stem leaves have short stalks, but stalks are lacking higher on the stem.

Stems: Erect and branched, 0.3–1.1 m tall, and covered with star-shaped hairs.

Roots: Slender taproot.

Seedling: No information available.

Similar Species

Exotics: Pale alyssum (*Alyssum alyssoides*), desert alyssum (*Alyssum desertorum*), and wall alyssum (*Alyssum murale*) resemble hoary alyssum, but they are smaller plants with much smaller seed pods (at most 4 mm long) that carry only 1–2 seeds/chamber. Wall alyssum and desert alyssum have yellow flowers. Hoary alyssum is also similar to false flaxes (*Camelina* sp.) but differs in having pods on erect stems that touch, or nearly touch, the stem (Frankton and Mulligan 1970).

Natives: None similar.

Impacts

Agricultural: Tends to increase in forage crops following drought or winterkill. Horses consuming this plant may be troubled with fever, limb edema, and laminitis.

Ecological: Establishes in dry, disturbed habitats, such as roadsides and railway embankments.

Human: None known.

Habitat and Ecology

General requirements: Most common on dry sandy or gravelly soils. Grows on meadows, pastures, hayfields, dry fields, roadsides, embankments, and other disturbed habitats.

Distribution: Present in south-central and southeastern BC in the Okanagan, Thompson, and Kootenay agricultural regions. Present across southern Canada.

Historical: Introduced from Eurasia.

Life cycle: Can behave as an annual, biennial, or perennial. The plant emerges in early spring and

KOCHIA

Kochia scoparia (L.) Schrad.

Family: *Chenopodiaceae* (Goosefoot).
Other Scientific Names: None.
Other Common Names: Summer cypress, burning bush, fireweed.
Legal Status: Regional Noxious: Peace River.

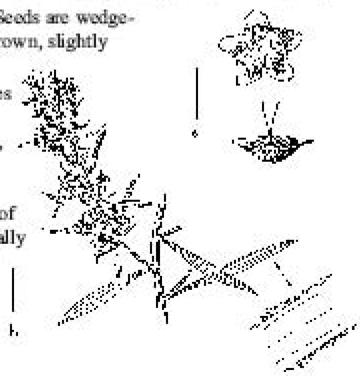
Identification

Growth form: Annual forb.

Flower: Flowers are inconspicuous, stalkless in the axils of upper leaves, and form short, dense, bracted spikes (Whitson et al. 1996).

Seeds/Fruit: Seeds are wedge-shaped, dull brown, slightly ribbed.

Leaves: Leaves are 2–6 cm long, alternate, and lance-shaped. The upper surface of the leaf is usually smooth, while the lower surface is covered with soft hairs.



Stems: Mature plants are 0.3–1.5 m tall with numerous branches. Stems are erect and simple to branched, and often form pyramidal or rounded tops. Stems are usually hairy but are occasionally smooth.

Roots: Taproots generally penetrate to depths of 2.0–2.4 m.

Seedling: No information available.

Similar Species

Exotics: Five-hook bassia (*Bassia hyssopifolia*) is easily distinguished from kochia by the 5 hooked structures on each seed. This plant is infrequent in south-central and southeast BC (Douglas et al. 1998).

Natives: None known.

Impacts

Agricultural: Although palatable to livestock, kochia sometimes contains high nitrate levels and sulphate toxicity (Whitson et al. 1996).

Ecological: Colonizes rapidly and may suppress other vegetation. An early successional plant on disturbed sites and can dominate vegetation for the first 2 years following disturbance (FEIS 1996). Kochia may spread into undisturbed sites when growing conditions are ideal.

Human: No information available.

Habitat and Ecology

General requirements: Locally common in dry areas of the Interior in roadsides, ditches, and disturbed habitats (Parish et al. 1996), kochia is generally found in open, unshaded areas on disturbed sites. It grows on a variety of soil types and is often found on saline/alkaline soils (FEIS 1996). Kochia can also be found in grasslands, mixed-grass prairie, shortgrass prairie, flood plains, riparian areas, sagebrush, and desert shrub communities.

Distribution: Frequent in south-central BC but rare in southwestern and northwestern regions (Douglas et al. 1998). It is present in the Kootenay, Okanagan, and Thompson agricultural reporting regions but is considered a major concern only to the Peace River. It

Selected Readings

National Park Service

Natural Resource Management Reference Manual #77

Source: http://www.nature.nps.gov/rm77

This Natural Resource Management Reference Manual #77 offers comprehensive guidance to National Park Service employees responsible for managing, conserving, and protecting the natural resources found in National Park System units. This Reference Manual serves as the primary Level 3 guidance on natural resource management in units of the National Park System, replacing NPS-77, The Natural Resource Management Guideline, issued in 1991 under the previous NPS guideline series.

NOTE: The transition of NPS-77 into Reference Manual #77 is in progress. Some sections are still being revised while others have undergone a field review with comments from the field incorporated as applicable. The later are considered in final form and are linked to from this page. However, it should be noted that the review of legal authorities has not yet been undertaken. In addition, as other level 3 guidance throughout the Service is finalized references to other National Park Service guidance may change.

Disturbed Land Restoration

Table of contents

Introduction

Several hundred thousand acres throughout the National Park System have been disturbed by recent human activities. Human disturbances of ecosystems and the physical landscape can affect all aspects of natural systems because of the direct and indirect interactions between physical and biological processes. Many of these disturbances conflict with the mission of the NPS and the mandates of National Park System units.

This section provides guidance for park staff and managers faced with the challenges of restoring disturbed systems. Although the physical aspects of restoration are emphasized in this section, restoration is fundamentally an interdisciplinary pursuit that involves the assessment and alteration of the biological and physical systems and the interactions between the two. The restoration of a sustainable ecological system often depends on the successful restoration of the physical conditions and processes with which the biological community evolved. Likewise, the ability of a system to sustain physical conditions and processes often depends on the condition and sustainability of the biological environment. Therefore, this section should be read in conjunction with the sections in this Reference Manual about aquatic systems, vegetation, soil, and nonnative plants and animals.

The term *natural system restoration* is often used as a conceptual rather than an absolute goal. Although a standard dictionary defines restoration as returning something to a former or unimpaired condition, the NPS's use of the term *natural system restoration* recognizes that reaching the former or unimpaired condition may take many years to decades. Therefore, natural system restoration by the National Park Service typically involves correcting resource interactions that function unnaturally and ensuring that the directions of the recovery processes are along the proper trajectory, rather than attempting to recreate the end state of an unimpaired natural system. For example, removal of materials of a roadbed may be sufficient to allow for recruitment of plant species (via seed bank or seed rain) into that reclaimed area. If plant community succession is facilitated in this way and requires no other active management or species introductions, then the area may be considered restored. Note that monitoring this process is essential to such a determination and that considerations of animal species (especially invertebrates) and other microbial organisms that control many functions of an ecosystem make the claim of complete and successful restoration difficult. This makes the selection of appropriate and realistic goals and objectives all the more important to a project.

First explained in this section are the steps that are generally used to restore NPS natural resources damaged by all types of disturbances such as abandoned structures or developments; abandoned mineral lands; abandoned or unauthorized roads; disrupted natural stream channels, floodplains, wetlands, or shoreline processes; agricultural areas; areas harvested for timber; campgrounds; and visitors' activities. The general steps are followed by information relevant for particular restoration projects, such as reducing hazards associated with mines, plugging abandoned wells, and restoring disturbed natural resources in a wilderness.

Definitions

Disturbed lands: Areas where the integrity of the natural setting and natural system processes has been directly or indirectly affected by human activities such as resource extraction, visitor use, development or maintenance, or invasion of nonnative species.

Natural system restoration: The long-term process of assisting the recovery of disturbed areas and reintegrating the site into the surrounding natural system so that the area reaches a planned condition and, ultimately, returns to its former unimpaired condition. Restoration involves active management (purposeful manipulations) of the disturbed habitat, such as biological (re-introduction of species), structural (removal of invasive woody or nonnative species), physical (restoration of natural topography), or chemical (mineral waste mitigation). Active management may also include removal of the anthropogenic disturbances that are causing resource degradation or that are preventing natural recovery of a site.

Reclamation: Actions that are oriented toward ecological upgrading of certain processes or functions, such as hydrologic functions or revegetation potential, but that stop short of restoring pre-disturbance natural conditions.

Recovery: The degree to which a disturbance has regained its pre-disturbance ecological form and function (physically and biologically) without human actions such as restoration, reclamation, revegetation, and so on.

Reference conditions/sites: Conditions and processes at naturally functioning sites in the ecological zone that represents the system to be restored. Used as models for restoration design or to measure the success of restoration or reclamation.

Resilience: The natural or internal capacity of components of an ecological system such as plant community or stream morphology to recover.

Restored: The point in the project where disturbed land areas no longer require active management (i.e., the site has reached a planned condition, but not necessarily the former or unimpaired condition). Restored conditions and processes should replicate those of the ecological zone in which the disturbance occurs, including the biological and physical components of the ecosystem, such as the geomorphology, hydrology, soils, biodiversity, and natural process linkages.

Policy and Program Objectives

NPS Management Policies

The following pertinent excerpts from NPS *Management Policies* provide specific direction for NPS natural system restoration:

> **Section 4.1.5 Restoration of Natural Systems**
>
> The Service will re-establish natural functions and processes in human-disturbed components of natural systems in parks unless otherwise directed by Congress. Landscapes disturbed by natural phenomena, such as landslides, earthquakes, floods, hurricanes, tornadoes, and fires, will be allowed to recover naturally unless manipulation is necessary to protect park developments or visitor safety. Impacts to natural systems resulting from human disturbances include the introduction of exotic species; the contamination of air, water, and soil; changes to hydrologic patterns and sediment transport; the acceleration of erosion and sedimentation; and the disruption of natural processes. The Service will seek to return human-disturbed areas to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated. The Service will use the best available technology, within available

resources, to restore the biological and physical components of these systems, accelerating both their recovery and the recovery of landscape and biological- community structure and function. Efforts may include, for example:

- Removal of exotic species;
- Removal of contaminants and non- historic structures or facilities;
- Restoration of abandoned mineral lands, abandoned or unauthorized roads, areas over- grazed by domestic animals, or disrupted natural waterways and/or shoreline processes;
- Restoration of areas disturbed by NPS administrative, management, or development activities (such as hazard tree removal, construction, or sand and gravel extraction) or by public use;
- Restoration of natural soundscapes; and
- Restoration of native plants and animals.

  When park development is damaged or destroyed and replacement is necessary, the development will be replaced or relocated so as to promote the restoration of natural resources and processes.

Additional statements in NPS *Management Policies* that further guide the NPS's restoration of natural systems include the following:

Section 4.1 General Management Concepts

.Just as all components of a natural system will be recognized as important, natural change will also be recognized as an integral part of the functioning of natural systems. By preserving these natural components and processes in their natural condition, the Service will prevent resource degradation, and therefore avoid any subsequent need for resource restoration.

The Service will not intervene in natural biological or physical processes, except:

- When directed by the Congress;
- In some emergencies in which human life and property are at stake;
- To restore native ecosystem functioning that has been disrupted by past or ongoing human activities; or
- When a park plan has identified the intervention as necessary to protect other park resources or facilities.

Any such intervention will be kept to the minimum necessary to achieve the stated management objectives.

Biological or physical processes altered in the past by human activities may need to be actively managed to restore them to a natural condition or to maintain the closest approximation of the natural condition in situations in which a truly natural system is no longer attainable. Prescribed burning and control of ungulates where predators have been extirpated are examples. The extent and degree of management actions taken to protect or restore park ecosystems or their components will be based on clearly articulated, well-supported management objectives and the best scientific information available.

4.4.1 General Principles for Managing Biological Resources

The National Park Service will maintain as parts of the natural ecosystems of parks all native plants and animals…. The Service will achieve this maintenance by:

- Preserving and restoring the natural abundances, diversities, dynamics, distributions, habitats, and behaviors of native plant and animal populations and the communities and ecosystems in which they occur; [and]
- Restoring native plant and animal populations in parks when they have been extirpated by past human-caused actions.

4.4.1.2 Genetic Resource Management Principles

The restoration of native plants and animals will be accomplished using organisms taken from populations as closely related genetically and ecologically as possible to park populations, preferably from similar habitats in adjacent or local areas. Deviations from this general policy may be made where the management goal is to increase the variability of the park gene pool to mitigate past, human-induced loss of genetic variability. Actions to transplant organisms for purposes of restoring genetic variability through gene flow between native breeding populations will be preceded by an assessment of the genetic compatibility of the populations.

4.4.2.2 Restoration of Native Plant and Animal Species

The Service will strive to restore extirpated native plant and animal species to parks whenever all of the following criteria are met:

- Adequate habitat to support the species either exists or can reasonably be restored in the park, and if necessary also on adjacent public lands and waters, and, once a natural population level is achieved, the population can be self-perpetuating;
- The species does not, based on an effective management plan, pose a serious threat to the safety of people in parks, park resources, or persons or property outside park boundaries;
- The genetic type used in restoration most nearly approximates the extirpated genetic type; and

- The species disappeared, or was substantially diminished, as a direct or indirect result of human-induced change to the species population or to the ecosystem.

4.4.2.4 Management of Natural Landscapes

Landscape and vegetation conditions altered by human activity may be manipulated where the park management plan provides for restoring the lands to a natural condition.

Landscape revegetation efforts will use seeds, cuttings, or transplants representing species and gene pools native to the ecological portion of the park in which the restoration project is occurring. Where a natural area has become so degraded that restoration with gene pools native to the park has proven unsuccessful, improved varieties or closely related native species may be used.

Landscape restoration efforts will use geological materials and soils obtained in accordance with geological and soil resource management policies. Landscape restoration efforts may use, on a temporary basis, appropriate soil fertilizers or other soil amendments so long as that use does not unacceptably alter the physical, chemical, or biological characteristics of the soil and biological community, and does not degrade surface or ground waters.

Program Objectives

The servicewide objectives for restoring disturbed areas are as follows:

- restoration of soil-geomorphic, chemical, and biologic characteristics and processes that were or are affected by modern human activities, so that the site will eventually reintegrate with the surrounding natural ecosystem functions and processes;
- elimination of threats to human safety and health that may be associated with disturbed areas;
- prevention of new and limitation of the effects of existing sources of disturbance.

Support and Tools for Restoration

The *NPS Organic Act* and the *Wilderness Act of 1964*

The responsibility of the NPS to restore disturbed lands in National Park System units arises from its mandates to conserve scenery and resources unimpaired; preserve wilderness character; and protect, manage, and administer units in light of their high public value and so as not to derogate the purposes for which they were established. See NPS Organic Act, 16 U.S.C. § 1 et seq. (1994); the General Authorities Act, 16 U.S.C. § 1a-1 (1994); the Redwood Act amendments, 16 U.S.C. § 1a-1 (1994); and the Wilderness Act of 1964, 16 U.S.C. §§ 1131-1136 (1994).

Park Enabling Statutes

Park enabling statutes may also provide direction for restoration. For example, the enabling legislation for Redwood National Park authorizes the NPS to develop and implement rehabilitation of areas inside and upstream from the park, which are contributing significant sediment because of past logging disturbances and road conditions. 16 U.S.C. § 79c(e) (1994).

Solid and Hazardous Waste Management Laws and Regulations

The restoration of lands and waters in National Park System units disturbed by non-NPS entities, such as the holders of private rights, should ideally be conducted or funded by the entities responsible for the disturbance rather than by NPS. If the responsible parties are identifiable and financially viable and if the disturbance releases or threatens to release hazardous substances into the environment, the NPS may be able to use the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. §§ 9601-9675. Under this authority, the NPS may remediate a disturbance and may then seek to recover costs from the responsible parties, or issue an order compelling the responsible parties to conduct the cleanup.

Another authority by which NPS may seek damages for injuries to natural resources, real or personal property, subsistence use, public services, and revenues is the Oil Pollution Act of 1990, 33 U.S.C. §§ 2701–2761 (1997). This act makes responsible parties liable for a vessel or facility from which oil was discharged or poses a substantial threat of discharge into waters of the United States and adjoining shorelines.

The NPS may also seek reimbursement from responsible parties to restore injured park resources under the authority of the Park System Resources Protection Act, 16 U.S.C. § 19jj (1997).

Some disturbed areas in National Park System units may be associated with unauthorized solid waste disposal sites. Solid waste disposal sites in National Park System units, even on private land, are subject to NPS regulations at 36 CFR Part 6. Under these regulations, solid waste disposal sites may only operate in parks pursuant to permits issued under 36 CFR § 6.4 (new sites) and § 6.5 (existing sites). The operators of solid waste disposal sites who have not obtained these permits must close their sites in a manner that protects the resources of the National Park System unit from degradation. [See § 6.4(a) and § 6.5(a).] Applying 36 CFR Part 6 regulations to unauthorized solid waste disposal sites may help prevent or reduce the effect of disturbances on park resources.

Executive Orders

Executive Order 13112 directs federal agencies, including the NPS, to provide for the restoration of native species and habitat conditions in ecosystems that have been invaded by invasive species (the Executive Order defines invasive species as species not native to that ecosystem and whose introduction does or is likely to cause economic or environmental harm or harm to human health). (See 35 Fed. Reg. 185-188 [Feb. 8, 1999].)

NPS Administrative Documents

The NPS *Strategic Plan* (2000) specifically identifies two critical components of broader restoration activities. These are found in Long-Term Goal Ia1: (1) Ia1A - 10% of targeted acres of parkland, disturbed by development or agriculture, are restored; and (2) Ia1B – 10% of the exotic vegetation on targeted acres of parkland are contained. On an annual basis, parks report all effort spent in restoring acreage or containing exotic vegetation. Specific guidance to parks on reporting to these goals is found in the *Technical Guidance and PMDS Users' Guides,* including detailed information requirements for dollars, FTE, performance indicators, unit measures, baselines, performance targets, and who to contact with questions.

Park planning documents may also contain direction for restoration. General management plans developed under DO 2 *Park Planning* define desired future conditions for park resources that should provide direction for restoration.

Potential Liability from Failure to Restore Disturbed Lands

In addition to the damage to park natural resources, failure to restore disturbed lands may result in NPS liability.

Abandoned mines on NPS lands that discharge pollutants into navigable waters may subject the NPS to National Pollutant Discharge Elimination System (NPDES) permit requirements (i.e., it is unlawful for any person to discharge any pollutant from a point source into navigable waters without a permit) pursuant to the Clean Water Act, 33 U.S.C. §§ 1251-1387. At least once to date, the NPS has been named by a regional water quality board as secondarily liable for a mine's illegal discharge. Adequate reclamation or restoration of these mines would help prevent NPS liability.

CERCLA § 120 provides that federal agencies are subject to the requirements of CERCLA to the same degree and same manner as private parties. Thus, the NPS can be held liable for the release of hazardous substances at sites presently or formerly owned or operated by the agency (such as unpatented mining claims) and compelled to engage in response activity or to reimburse other parties that engage in response activity. Federal agencies also are required to assess and respond to hazardous substance sites under their control and fulfill various reporting obligations to the United States Environmental Protection Agency.

Relationship to Other Guidance

DO/PM 77-1 address NPS wetland protection policies and procedures and mitigation measures for wetlands affected by development. They also set forth the policy that wetland impacts must be compensated for by restoration.

Other sections in this Reference Manual that provide guidance about specific components of disturbed lands restoration include Protection of Aesthetic Values, Hazardous Waste Management, Vegetation Management, Soil Resources Management, and Nonnative Species Management**.** Also, see DO/RM 28 *Cultural Resource Management*.

DO 12 *Conservation Planning and Environmental Impact Analysis, and Decision-making* and the companion Handbook 12 provide guidance about complying with the National Environmental Policy Act, the National Parks Management Omnibus Act of 1998, and the National Park Service Organic Act of 1916's non-impairment language, which NPS incorporated into Chapter 1 of NPS *Management Policies.*

General Restoration Step

Outlined below are the most common elements in restoration projects that include a physical component. Selection of appropriate methods and tools depends on the scale and nature of the disturbance.

Step 1: Inventory Sites and Select Reference Sites or Conditions

A disturbed lands restoration inventory includes the identification of the disturbed sites, assessments of the current condition of the sites, and selection of reference sites or conditions (naturally functioning areas or conditions used as models for restoration design). The purpose of the inventory is to gather enough information to create an understanding of the type, magnitude, and length of disturbances that affected, or continues to affect, the landscape and the degree to which the natural features and processes are affected. Inventory information allows managers to rank disturbed sites for restoration, develop preliminary alternatives for restoration, and estimate the costs to restore sites for budgetary purposes, including competing for project funds. Inventory information also can guide further sampling and monitoring.

Inventory and assessment of sites

Some or all of the following details should be included in the inventory:

- a site map, which should include all geomorphic features, hydrologic patterns, facilities, structures, existing uses, access routes, and other important details
- current and historic topographic, geologic, soil, and vegetation maps and aerial photographs to illustrate the degree and scope of the disturbance and the nature of the surrounding undisturbed topography
- descriptions of the historic uses of the site
- natural disturbance history (fires, floods, windstorms, etc)
- the legal history of the site
- species lists and community descriptions
- critical habitat for threatened and endangered species
- an evaluation of the potential recovery of damaged resources with and without restoration work; alternatively, an evaluation of potential recovery once the degrading agent is removed or discontinued
- a description of the existing and potential effects of the site on park resources as evidenced by groundwater or surface-water contamination, erosion, compaction, sedimentation, nonnative plant invasions, and other changes in habitat, such as species composition changes, altered vegetative structure, or decreased primary productivity
- samples of water and soil conditions, if appropriate

- photo points and photographs of the current condition of the site
- a current conceptual ecological model for the site.

The following factors should be considered when designing the inventory:

- The type of decisions that will be made with the collected data.
- Cumulative impacts: The inventory should record and evaluate past, ongoing, and future cumulative impacts on resources and site-specific impacts from disturbed sites
- Future utility: Consider that the inventory may be used with other inventories, that it may be used by others in the future, and that it should be compatible with existing inventory systems for comparison of the inventoried characteristics with numerous other landscape and ecosystem parameters.

Selection of reference sites and conditions

An identification of reference sites or conditions is important for several reasons. Reference site identification is essential for understanding the disturbances that have occurred to the system, and the reference site or conditions provide a model on which restoration is based. Reference sites and conditions must be carefully selected because they influence many stages of the restoration process.

Temporal aspects of succession and non-determinant trajectories of succession in ecological communities, must be recognized in selection of a reference site and, in fact, suitable reference sites for the physical aspects of a restoration project may be different from the reference sites for the biological aspects of that project. For example, reference sites or conditions for the physical aspects of restoration projects often represent pre-disturbance or undisturbed adjacent conditions (land areas that share similar physical characteristics with the disturbed area but have not been significantly disturbed). The pre-disturbance conditions may be determined from the historic journals and records of pioneers and early land surveyors who described the state of the land soon after European settlement, from historic photographs (from several periods, if available, and including aerial photography), and from visual inspections of the site and undisturbed areas.

Reference sites or conditions for vegetation and other biological aspects of a restoration project, on the other hand, may have been recently disturbed. In other words, these sites are not necessarily areas with climax or mature vegetation. For example, a site that was recently disturbed naturally by flood or fire and is recovering naturally may be an appropriate reference site, since such sites or conditions can serve as models for planting, revegetation, and re-introduction of other essential biota (e.g., arthropods) to restore ecosystem processes and functions. An understanding of native vegetation dynamics incorporated into an ecological model for the site will greatly enhance the decision on a reference site or condition for biological aspects of the project. The project manager may encounter a particular successional stage of plant community, and wish to restore it to a designated "climax" stage. Anthropogenic changes to natural systems may result in undesired vegetative patterns. Reintroduction of natural processes, such as fire or flooding, may not necessarily restore a desired vegetative plant community. In such cases, some other action must first be implemented before natural systems and processes can be restored.

Step 2. Rank Sites

Criteria for ranking may include historical, current, and potential impacts; the resources at risk and their value; the potential for restorative success; current and future visitor use; the relative effect of restoration on the integrity or recovery of the larger natural system; legal or ownership constraints; safety issues; and cost. NPS laws, management policies, and guidelines, and the park's enabling legislation should also guide the ranking process.

Step 3. Establish Goal and Objectives

In general, the NPS goal for disturbed lands is to restore natural systems and processes. However, the physical environment has often changed so much that restoration of pre-disturbance conditions is not possible. The NPS goal then becomes the design of new landforms that blend and function with the surrounding landscape and sustain desired habitats. Likewise, a pre-disturbance knowledge of the full suite of species and communities rarely exists. In this case, appropriate habitats should be designed to address species components compatible to surrounding natural areas, important structural characteristics within the habitat, and landscape patterns. This reflects issues of animal movement across habitat boundaries, and seed dispersal. In rare cases, a park may want to transform a disturbed site to something other than wildland, such as a parking lot, cultural resource preservation area, or critical habitat. If so, the park's goal should be to minimize the disturbed area, the disruption of natural processes, and the impacts to on-site or off-site resources.

The purpose of setting objectives is to define measures by which the success of the goal, which is the establishment of the planned condition, can be measured (see definition of "restored," above). If the objectives are not met, additional restoration work should be considered. The time frame of desired or acceptable recovery can be a key factor in defining objectives. Examples of objectives are: (1) in 5 years, plant diversity and density will be at 80% of target conditions, (2) in 10 years, the abundance of nonnative species will be less than 5%, and (3) in 10 years, average soil infiltration rates will exceed 10"/hour.

Step 4. Develop Preliminary Restoration Alternatives

Preliminary restoration alternatives should be developed at this stage. Each alternative should comply with NPS policies and support the restoration goal and objectives. Each alternative would expedite recovery of the site, but would achieve the goal and objectives in different time frames and by different types of active management/purposeful manipulation. Examples of various alternatives are:

- restoration of stable geomorphic configurations, improvement of soil characteristics, and revegetation with native species
- restoration of stable geomorphic configurations, improvement of soil characteristics, and natural recolonization of plants
- revegetation with native species without restoration of physical characteristics of landscape
- restoration of the site by completing work in smaller sub-areas as funding and staff become available

- natural recovery
- coordination with adjacent agencies, landowners, and other partners to resolve off-site problems that impair resources in a park

Often, an understanding of the degree of degradation drives these options. A subset of alternatives will include use of machinery v. hand-tools, source of plant materials (seeds v. seedlings), and mulching v. temporary cover crops.

Step 5. Undertake Compliance and Select an Alternative

The approval and conduct of restoration projects must be in compliance with statutes, regulations, executive orders, NPS *Management Policies*, and management documents. The number of compliance requirements that a given restoration project may trigger can be extensive. To help determine which requirements have been triggered and how to most efficiently and effectively comply with them, project managers are encouraged to contact NPS specialists in the park, regional offices, system support offices, and the Natural Resource Program Center. Below is a brief summary of the three key compliance requirements.

Foremost, proponents of restoration projects must comply with the requirements of the National Environmental Policy Act (NEPA) to evaluate whether the project is a major federal action, and, if so, whether it has significant effects on the human environment. For most NPS restoration projects, an environmental assessment (EA) fulfills this responsibility; thus, most parks do not have to prepare an environmental impact statement (EIS). The use of a categorical exclusion to comply with NEPA will be the exception not the rule for restoration work. Parks with numerous disturbed sites should consider writing a parkwide EA or EIS. DO 12 , Handbook 12, and the section entitled Environmental Compliance in this Reference Manual should be consulted for guidance on writing NEPA documents.

As part of the NEPA analysis, a park will need to make a written finding as to whether a restoration project might inadvertently result in impairment to park resources and values. If impairment may result, the project may not go forward. For further guidance on the need to make a finding regarding impairment, see Chapter 1 of NPS *Management Policies* and DO 12. e. Also, contact the NPS Office of Policy in Washington, D.C., and the Environmental Quality Division within the Natural Resource Program Center.

In addition to NEPA compliance, most restoration projects also will need to comply with the National Historic Preservation Act (NHPA) § 106 consultation process. Section 106 and its implementing regulations at 36 CFR Part 800 do not apply to all cultural and historic resources at or near a potential restoration site. Only the presence of historic properties *on or eligible for* the National Register of Historic Places triggers the 106 process. Furthermore, compliance with Section 106 and Part 800 does not require agencies to save historic properties. Instead, these provisions require parks to undergo the consultation process in order to evaluate fully the effects of proposed actions, such as proposed restoration work, on historic properties.

Once a park consults fully with the appropriate parties, including NPS cultural resource staff, state historic preservation officers, tribal historic preservation officers, other interested groups, and the public, the Section 106 process is completed and the park should proceed with the restoration project. As a result of information obtained during consultation, however, the park may decide to mitigate the damage to historic properties that will be caused by the restoration project. Mitigation to historic properties may include protection of certain historic features, documentation, curation, research, interpretation, education, recordation, or other courses of action.

Restoration projects may also be affected by other laws and guidance. For a list of these other laws and guidance, see Appendix A of this Reference Manual. In addition, for assistance in determining which requirements are applicable to a given project, contact your compliance specialists in the park, regional offices, system support offices, and the Natural Resource Program Center.

After complying with all the laws and policies triggered by the project, the park should select the alternative that best balances the competing considerations including effectiveness, the desired time of recovery, the environmental impacts, the available and potential staff, the available and potential funding, and relevant compliance efforts. The potential for restorative success, immediacy, and the degree of disturbance may also dictate the decision to restore, or only reclaim, revegetate, or stabilize a site.

The park may adopt a combination of alternatives for experimental management, for adaptive management, or for restoration conducted in phases over a long period. For example, a park could restore three comparable sites in different ways such as by natural recolonization, by treatment to accelerate natural recolonization (such as burning in a fire-adapted ecosystem), and by revegetation.

Step 6. Develop the Project Plan

The project plan is based on the selected alternative(s) and details the discrete tasks to achieve the restoration goal and objectives. The project plan ("work plan") is used to develop technical specifications, plan sheets, and material specifications for contracts; to otherwise provide clear direction for implementation of the restoration (in a non-contract situation); and to procure project funding. (See Steps 7 and 8 below concerning finalizing and implementing the plan).

First, the project plan should clearly articulate the goals of the project and how these goals will be assessed. Then, discrete project tasks must be identified. Usually, tasks are defined by type of activity and in chronological sequence. After the tasks are identified, planners should:

- define the materials, equipment, and personnel that are required to complete the task;
- describe each task in detail sufficient for the method of implementation (e.g., contract, park staff, or volunteers), including specifications such as grade, volume, area, density, material, depth, etc.;
- determine the time required to complete the task; and
- identify the point in the project sequence when work on a specific task can begin and when work must be completed to avoid delay in initiating subsequent tasks.

In addition to written task descriptions, the plan should contain well-designed maps and technical drawings that show site-specific requirements and details that are difficult to describe. Mapping is commonly done planimetrically using standard survey techniques, enlarged aerial photographs, and topographic maps. GIS methods often augment modern mapping techniques. If needed, technical drawings (e.g., cross-sections) should be prepared to detail design specifications for work localities, including grades, depths, material handling, amendments, and other site-specific tasks or treatments.

Typical project tasks

Restoration that includes physical treatment generally involves some or all of the following regardless of whether the restoration is done by heavy equipment or by hand: (1) site preparation, (2) earthmoving, (3) soil treatment, (4) control of surface erosion, (5) reestablishment of native vegetation, (6) final closure, and (7) monitoring and maintenance. These tasks are explained below to describe the typical considerations in the plan and design of physical restoration. A design may require the collection of additional data beyond what is gathered during the assessment and alternative development process. Strategies for additional data collection should be well thought out, so that the data collection contributes to restoration design and implementation.

Detailed information on design criteria for a full range of restoration types is beyond the scope of this document. If warranted by site-specific conditions, specialists should be consulted.

1. Site preparation

Site preparation consists of all activities before the primary restoration work, including stream corridor protection, habitat protection, historic feature protection, and removal of debris, structures, and toxic substances. To plan for site preparation, it may be necessary to:

- develop a stormwater protection plan;
- develop a mitigation plan for sensitive, threatened, or endangered species;
- develop a mitigation plan for historic features that were identified during the NHPA § 106 process (this may require photographing the features before they are removed, moving the features, or working around the features); and
- plan to remove debris, structures, and toxic substances or mitigate on-site in accordance with the requirements of relevant statutes including CERCLA. Removed substances must be disposed in an appropriate landfill. On-site mitigation includes treatment (neutralization), burial, and capping in a location away from groundwater and topsoils.
- Collection of seed, propagation, and planning for transport and planting

2. Earthmoving

The scale and type of a disturbance and its effects influence the selection of appropriate tools (e.g., motorized versus non-motorized) for earthmoving. (See discussion about appropriate tools in the wilderness section, below.) The goals of earthmoving in restoration are to replicate natural landscape characteristics on a macro- and micro-scale; uncover buried landforms such as stream channels, floodplains, and soil profiles; and create land surfaces and features that blend into and function with the surrounding undisturbed landscape if replicating the natural landscape is not possible.

The following issues may need to be considered while planning the earthmoving phase.

- protecting waterways from stormwater with appropriate erosion control, such as silt fencing and temporary settling ponds
- protecting existing vegetation (especially root zones) if necessary
- stockpiling vegetation that is to be salvaged, large organic debris, and topsoil out of the way of heavy equipment operation; protection of topsoil from erosion and loss of biologic activity (particularly soil microorganisms)
- decompacting land surfaces as needed
- balancing cuts and fills or importing or exporting materials to achieve the desired landforms and functions
- facilitating plant growth by uncovering buried topsoil and ensuring it remains on the surface
- providing natural water-flow courses by uncovering buried streambed armor and side bank soils and restoring natural stream channels and gradients
- importing materials that are appropriate to the site, i.e., found locally in similar settings
- heterogeneity of the desired condition (not a smooth surface which might normally be required of a machine operator)

Additional data needs for planning earthmoving activities may include the following.

- The following information should be collected:
    - geomorphic data, including flood recurrences, floodplain locations (before and after disturbance), drainage patterns, erosion and sedimentation sources and rates, landform analysis, and slope stability analysis
    - surface and groundwater quantity and quality data, including information on low flows, peak flows, timing of flows, water table fluctuations, groundwater flow patterns, alkalinity, pH, nutrients, contaminant concentrations (e.g., metals), turbidity, conductivity, and temperature
    - bedrock geology data, which influences the chemistry of soils and waters, ground and surface water flow styles, climate, and topography
    - climatic data,including precipitation, expected temperature range, snowpack, and microclimate data (e.g., slope aspect, roughness)
- Volumetric surveys should be conducted for all areas within the project site that will be excavated, transported, filled, and shaped. Surveys should be extended beyond the boundary of the disturbed area to ensure that the restored grades blend with surrounding undisturbed areas. Critical survey locations should be documented so that they can be revisited after excavation

to quantify the actual material that was excavated and moved for contract payment purposes.

- All areas should be identified where plant materials, soils, large debris, or other habitat elements may be salvaged, including the location of temporary storage and handling areas.

3. Soil treatment

If soil data indicate that soil amendment or replacement is necessary, the earthmoving design should incorporate the delivery and mixing of necessary materials into the major earthmoving work. Some potential amendments include fertilizer, mulch, sand, clay, or lime. Unless constrained by the need to protect roots of existing vegetation, soil depths should be determined based on the root depths of the plants slated for revegetation, particularly where soil will be placed over toxic materials (e.g., mine spoils), bedrock, or clay. A soil scientist familiar with NPS restoration policies should be consulted at this point. (Also see the Soil Resources Management in this Reference Manual).

Additional data needs for soil treatment planning are:

- soil data, including profile descriptions, particle-size analysis, bulk density, pH, organic matter, plant-available macronutrients (nitrogen, phosphorus, and potassium), micronutrients, cation exchange capacity, conductivity of soil solutions, and metal concentrations, patchiness, buried horizons, moisture characteristics, etc.; and
- geomorphic data (see additional data needs for earthmoving, above).

4. Control of surface erosion

Freshly restored sites may initially be vulnerable to accelerated surface erosion by water or wind. On some sites, potential surface erosion may need to be controlled until the soils settle and native vegetation reestablishes. On other sites, the need for temporary, artificial, surface erosion controls can be minimized by recreating the surface details that exist at the reference sites. Some surface details that minimize erosion naturally include surface roughness and irregularity, rocks and boulders, logs, branches, twigs, leaves, needles, and duff. Reestablishing these factors at freshly restored sites typically provides temporary control of surface erosion and restores the fine structural elements necessary to ecosystem recovery.

Various options of temporary erosion control include seeding to establish temporary vegetation, seeding with irrigation, seeding and mulch, mulch alone, erosion-control blankets, netting, and silt fences. The plan should reflect consideration of:

- the most valued resource on the site that could be lost to erosion
- what on or near the site could be harmed by sedimentation
- the natural processes that could accelerate erosion
- the duration between application of a treatment and control of erosion
- the extent to which a treatment inhibits reestablishment of native vegetation
- applicable regulatory requirements

- costs and benefits of various erosion control options

Depending on objectives, an erosion control expert and a plant ecologist should be consulted to determine appropriate treatments or combinations of treatments and their advantages and disadvantages.

Additional data needs for planning erosion control are:

- geomorphic data (additional data needs for earthmoving, above)
- soils data (see additional data needs for soil treatments, above)
- list of plants prescribed for use and installation scheme

5. Reestablishment of native vegetation

Physical site preparation is a prerequisite to successful reestablishment of native vegetation. Timely reestablishment commonly depends also on specific biological factors. Depending on the environment, native plants may reestablish themselves on their own, may require only propagule reintroduction, or may require additional manipulation. The estimated time to recovery, the likelihood of natural colonization, symbiont inoculation, succession, competition from nonnative plants, stress from herbivory and other animal activities, and potential soil erosion all help determine the appropriate revegetation prescription.

Several revegetation methods may be employed simultaneously in one restoration plan. The methods may be passive or active. Passive methods achieve results within the plan's timetable without intervention (e.g., nearby native plants dispersing seeds that germinate and establish in a project site). Passive methods are preferable, if effective, because they leave natural processes (dispersal and selection) intact. Proximity to a seed source, including the soil seed bank, should be evaluated. Likewise, proximity to sources of nonnative and invasive plants should be evaluated. However, a physically restored site may not revegetate (become biologically restored) without intervention. Active methods should replace any ineffective passive methods. Typical active methods include seeding, biological inoculation, planting, and control of competing nonnative species. A plant ecologist can provide advice on ecological requirements and selection of methods appropriate for particular plant species and vegetation types.

In active revegetation, the collected native seed and planting stock must be genetically appropriate and compatible with native plants in adjacent and nearby areas. All plant material should be collected from reference sites or areas with reference conditions that are located as near to the project site as practicable. In addition, the collection should cover an area at least as large as the area to be restored, in order to capture sufficient genetic variability. Collecting should never biologically degrade a source site. If material is insufficient, it can be augmented by a propagator or the collection area can be expanded.

In wetland and riparian areas, the relationships between the desired vegetation communities and hydrologic characteristics (flood regime and water table fluctuations) must be determined to reproduce the desired habitats. The assumption that the faunal communities will colonize a site after the vegetative communities are restored does not always hold true because (1) the plants and animals often have symbiotic relations and cannot survive unless both species are present and (2) extirpated faunal populations may not be able to recover naturally.

Site-specific language in contracts can be used to ensure that revegetative goals are met. Some examples are (1) a designated distance from the restored area where native plants or seeds can be collected; (2) certified weed-free plant material (3) destruction of existing invasive plant material where the plant material contains nonnative or native invasive plant stock or materials; (4) certified weed-free fill or mulch; and (5) cleaning soil and plant material from equipment before entrance into the park. Because potential problems and biological distances vary among National Park System units, the specifics of the contract language must be developed locally.

Many sources of technical assistance such as the Natural Resources Conservation Service, native plant nurseries, native plant societies, university extensions, and The Nature Conservancy are available. The Plant Conservation Alliance (www.nps.gov/plants) maintains a white paper on native plant projects that should be used in conjunction with this section, and also provides other useful resources.

Additional data needs for planning vegetation reestablishment are:

- vegetative and faunal communities**,** including species composition, density, frequency, and structure
- quality of soil for the establishment of plant material (see Soil Treatment, below)
- threatened and endangered species, including species that are currently using the disturbed area and that may use the disturbed area after restoration
- invasive species, including species that currently inhabit the site and those that may invade the site after restoration
- indicator and keystone species and critical interspecific interactions that are vital to the long-term sustainability of the plant community, including mycorrhizal and nitrogen-fixing symbionts, pollinators, seed dispersers, decomposers, earthworms, and predators that control plant herbivores, etc.
- facilitators, such as non-mycorrhizal nurse plants for mycorrhizal-obligate plants, and shade plants for shade tolerant species, that should be installed in appropriate sequence

6. Final closure

Restoration plans should address closing, decompacting, or removing equipment access roads; removing stormwater detention devices; distributing large organics over the disturbed areas; installing signs (interpretive or safety); and removing waterway diversions.

7. Monitoring and maintenance

Restoration plans should include monitoring to determine whether goals were reached and objectives met and to assist future restoration efforts. Monitoring may also indicate that site maintenance or further restoration work is required, such as erosion control, planting, soil amending, or in extreme cases the additional restoration of landforms or processes.

Monitoring plans should be based on the information needed in the years following the restoration work. Information/data needs within five years of the restoration work may differ from those ten and twenty years following restoration. In addition, restoration successes and failures may not be apparent for many years after the restoration, especially after chemical mitigation (e.g., in abandoned mine restorations). Lastly, monitoring should be designed to distinguish natural systems variability from change attributable to restoration. Therefore, reference areas should be monitored along with the restoration project area.

Photographs of the project site should be taken before, during, and after, restoration from established locations to track restoration progress over many years. Photographs are also useful for monitoring, interpretation, public relations, and fundraising. Photo points must be chosen with care because they may no longer exist after restoration. For example, the area may have been cut, filled, or otherwise completely regraded. Permanent markers can be used in conjunction with global positioning system (GPS) units for locating photo-point locations within the altered project area.

Data management should follow formats and guidelines established by the NPS Servicewide Inventory and Monitoring program.

Step 7. Finalize the Project Plan and Funding Requests

Based on the specific restoration tasks developed in Step 6, the project plan is finalized and project costs developed. A complete project plan consists of the statement of the problem; descriptions of the technical approach, methods, and tasks; identification of key park personnel and qualifications; a list of equipment and personnel needs, costs, and schedule; and expected results or outcomes.

When details are finalized, additional compliance or consultations may be necessary (e.g., Clean Water Act § 404 review, and National Historic Preservation Act § 106 and Endangered Species Act § 7 consultations).

Cost development. Cost estimates for each task are needed for soliciting project funding and contracting. Cost estimates are based on the list of discrete tasks developed in Step 6, above. As necessary for each task, material purchase costs, transportation costs, and the time required/cost per hour for labor and equipment should be accounted for. For bookkeeping purposes, it may be useful to tally all tasks and estimated costs using a spreadsheet. The maintenance divisions of some parks are able to estimate costs for heavy-equipment work. Otherwise, a restoration specialist, geologist, hydrologist, revegetation specialist, or the Geologic and Water Resources divisions may be consulted. In addition, certain funding sources may require specific cost-estimating protocols and formats. For example, NPS line-item construction funds (>$500,000 projects) require a standard A, B, or C level cost-estimate format.

If possible, the cost structures of recently-issued heavy equipment contracts or restoration contracts in or around the park should be analyzed to determine the average local cost for different types of tasks (e.g., cost of excavation and fill per cubic yard, revegetation per acre, and road removal per acre). This information can be used to roughly estimate the cost of a restoration project.

Funding application. Sources of funding in and outside NPS are numerous. The Associate Directorate for Natural Resource Stewardship and Science coordinates funding calls for certain fund sources and can refer parks to outside sources of funding. Projects costing more than $500,000 are eligible for construction funding. Such projects must be submitted in response to calls for construction projects and are selected through the Choosing by Advantages process, using regional and national panels. For all fund sources, restoration projects should be reflected in the Project Management Information System. In most cases, the project-funding proposal should include a summary of the restoration tasks described in Step 6. As appropriate, specific plans for research, data management, analysis, quality control or assurance, and interpretation to the public may be included in the funding proposal.

Step 8. Implement and Oversee the Project

Although the park is responsible for a restoration project, the restoration may be overseen by contractors; central office staff, such as those at the Natural Resources Program Center, the region, or the Denver Service Center; restoration nonprofit organizations; or a combination of the above.

Project supervisor. The work plan for any restoration project should identify a project supervisor, who is the primary person responsible for planning, designing, and implementing the work. The project supervisor ensures that materials are available, outside experts are consulted as necessary, and appropriate equipment is used; schedules crews; leases equipment; coordinates fueling, servicing, and mobilization; coordinates equipment operations; and ensures the availability of administrative support.

Regardless of how the project is implemented (e.g., contract, volunteers, etc.), the project supervisor should constantly monitor the on-the-ground restoration, particularly all earthmoving. The information gained by observing the excavations is also invaluable in later stages of the project, including reporting and monitoring.

Contracting. Contracting should allow for flexibility during the project. In most projects, the restoration plan will change as original surfaces or stream channel components are uncovered or other conditions change. Contracts should include:

- a clear and concise description of the site and the intent for the project;
- a description of each task (typically, the bid item), including quantities and technical specifications; and
- technical drawings of the site and specific bid items such as plan maps and cross-sectional views of existing and proposed grades.

Method of payment for each bid item can vary. Payments based on excavated and placed volumes provide incentive to the contractor to do the work efficiently. Payments based on actual hours worked are most appropriate if the quantification of volumes is difficult or extremely time consuming or design work must be done as the restoration progresses. Such payment is particularly appropriate if the contractor and operators can be trusted not to take advantage of hourly pay. Lump sum payments are discouraged because they may result in short-changing the specifications or restoration needs and in problems when changes in design require additional work.

Selecting contractors. Contracts may base selection criteria on bid price, demonstrable experience in restoration, unique capabilities by a few contractors, or a combination of all three. Experienced restoration contractors and equipment operators can provide invaluable feedback on approaches to earthwork.

Step 9. Reporting Activities and Results

Details about the restoration and recovery should be recorded and archived to provide information about the techniques, costs, successes, and failures, and to assist in designing future restoration projects. The details to be reported are the reason, time, and location of tasks; materials and equipment and the associated costs; the labor and equipment time for each task; conditions during completion of each task; monitoring results; additional maintenance (if needed); and the rate of recovery.

Special restoration situations

In addition to following the general steps described above, restoration activities in the special situations described below often require additional expertise and considerations.

1. Restoration in wilderness

Disturbed lands in NPS wilderness areas detract from the wilderness experience and can cause severe impairment of resources. Abandoned or rarely used roads in wilderness seldom receive adequate maintenance, due in part to a general reluctance to use motorized equipment in wilderness. The lack of appropriate maintenance or restoration often leads to severe erosion and overall degradation of natural systems.

Before planning and implementing restoration in an NPS wilderness, the park's wilderness management plan should be reviewed. The minimum requirement decision tree, described in DO 41 Wilderness Preservation and Management, should be used to decide whether a proposed wilderness restoration is necessary. If it is, the restoration must be done with the appropriate methods. Areas that were originally disturbed by pick and shovel may be restored with a pick and shovel. Likewise, areas that were originally disturbed by heavy equipment may need to be restored with heavy equipment to achieve natural system forms and functions. An inadequate procedure or tool often causes incomplete or delayed restoration and continued damage to the resources.

Section 1133(c) of the Wilderness Act provides as follows:

> ***[E]xcept as necessary to meet minimum requirements for the administration of the area for the purpose of this chapter*** **(including measures required in emergencies involving the health and safety of persons within the area), there shall be no temporary road, no use of motor vehicles, motorized equipment or motorboats, no landing of aircraft, no other form of**

> mechanical transport, and no structure or installation within any such area. (Italics added for emphasis.)

This means that the Wilderness Act expressly allows the NPS to use motorized equipment when necessary, including for restoration of disturbed lands in a wilderness area.

2. Plugging abandoned oil, gas, geothermal, and water wells

When restoring properties that include oil, gas, geothermal, or domestic and agricultural water supply wells, the first step is to plug the well. The wellbore (the drilled hole) of a well allows fluids to move from zone to zone underground or to be transported to the surface. Plugging the well protects the zones of usable water from pollution and prevents the escape of oil, gas, or other fluids to the surface or to other subsurface zones.

Plugging and abandonment of water wells should be coordinated with the Water Resources Division. Before plugging water wells, the division should be contacted to determine whether the well should be maintained for monitoring water levels or water quality. In most cases, a state agency has regulations and guidelines for the abandonment and plugging of water wells.

The Geologic Resources Division recommends that plugging of oil and gas and geothermal wells meet the minimum standards of the Department of Interior's Onshore Oil and Gas Order Number 2, Section III. G., Drilling Abandonment.

Well plugging tasks. Cement plugs are set to:

- isolate all formations containing oil, gas, and geothermal resources and other prospectively valuable minerals,
- isolate all formations bearing usable-quality water,
- isolate the surface casing from open holes below the casing shoe, and
- seal the well at the surface.

Well plugging design and cost estimation. For any well that becomes part of a restoration plan, the assistance of a petroleum engineer should be obtained for well evaluations, plugging designs, and the preparation of cost estimates. Well plugging should be coordinated with the Geologic Resources Division and the Water Resources Division.

Hazardous wastes. Most historical petroleum or geothermal operations have associated earthen pits that serve as dumping grounds for contaminated wastes from operations. The Geologic Resources Division can be consulted to identify the presence of pits, design a sampling program for the pits, and recommend appropriate mitigation.

3. Reducing Abandoned Mine Hazards

The National Park Service Abandoned Mine Land (AML) Program has identified more than 3,000 mine sites in the National Park System, which include 11,000 underground openings or hazardous features and which cover approximately 30,000 acres in 140 parks. Planning and implementing mine closures generally follow the steps outlined in the General Restoration Steps described in this section. However, the consultation process required by Section 106 of the National Historic Preservation Act and its regulations at 36 CFR Part 800 is particularly important for abandoned mine closures, because certain abandoned mines may be "historic properties."

The Section 106 consultation process is discussed above in Step 5 of General Restoration. After completing the consultation, parks should generally proceed with the mine closure in order to reduce safety hazards or with completely restoring a mine area to a pristine condition. Where appropriate and consistent with natural resource protection and safety concerns, the park should also mitigate the damages to historic properties caused by the mine closure or restoration. Mitigation may include protection of certain historic features, documentation, curation, research, interpretation, education, recordation, or other courses of action.

Definitions specific to mines

Adit: **A horizontal or nearly horizontal passage mined from the surface for developing an underground mine.**

Collar: **The opening at the top of a shaft, often reinforced with concrete or timber.**

Glory hole**: The area where a stope breaks through to the surface. Typically, the edges of a glory hole are undermined and susceptible to collapse.**

Headframe**: A wooden or steel structure constructed over a mineshaft to facilitate hoisting in and out of an underground mine.**

Highwall**: The cliff-like feature in a surface mine left when material has been removed from a hillside.**

Incline: **A steeply inclined passage mined upward or downward from the surface for developing an underground mine. Typically one refers to an incline as steeper than an adit, which can easily be walked, but less steep than a shaft, which would require ropes or some sort of hoisting mechanism to access.**

Ore, orebody: **A mineral deposit that can be mined at a profit under existing market conditions.**

Portal: **The entry to an adit or a tunnel.**

Shaft: **A vertical or near vertical passage mined from the surface for developing an underground mine.**

Stope: A broad, open, underground mine feature where a large mass of ore has been removed from the area. With so much rock removed from these areas, stopes are typically some of the more hazardous areas underground due to inadequate support, leading to potential rock fall and collapse.

Tailings: Waste material from a mill; the remnant ground rock material left after the desired commodity has been removed from an ore. Typically, this material is homogenous and fine-grained.

Tunnel: A horizontal or nearly horizontal passage mined from the surface through a hill or mountain to the surface on the other side.

Waste rock, spoils, dump: Barren or sub-grade rock that was mined to gain access to the orebody. In an open pit, waste material that must be stripped to access a buried orebody is called overburden. Because this material is not sent to the mill, it is typically discarded near the mine entrance and varies from coarse to fine-grained.

Hazards related to surface mining

Mine workings at the surface may have dangerous highwalls, cuts, or fills that present safety hazards to visitors and park staff. Such hazards may involve persons falling off these steep slopes, or debris falling from the slope endangering people downhill. Other surface hazards at mines include unstable structures, such as buildings, and loading facilities.

The preferred method of minimizing hazards from highwalls, cuts, or fills is reducing the slope to a gradient where falls would not be injurious or where slope materials are stable. Determination of the gradient's stability may require the assistance of an engineering geologist, geomorphologist, or engineer with experience in rock mechanics or slope stability analysis.

The slope gradients may be reduced by (1) backfilling (placing material at the base of the slope); (2) cutting (pushing material from the top to the bottom of the slope); or (3) benching (creating a series of steps across the slope). Combinations of these techniques may be appropriate if warranted by site conditions or availability of materials. Blasting or heavy equipment are often appropriate for reducing highwalls and slopes. A reclamation geologist or specialist may be consulted to select suitable equipment and to estimate costs.

When planning slope reduction work, the effects of other surface processes, such as fluvial processes, on the reconfigured slopes and on surrounding undisturbed areas must be considered. For example, appropriately designed channels or diversions may be required to ensure that surface erosion does not hinder the post-work recovery of the site. Determination of potential erosion and design of stable channels may require the assistance of a geomorphologist or hydrologist with experience in channel sizing and design.

Other measures to reduce surface hazards include fencing and signing. However, these are temporary stopgaps. They may be initially less expensive but require relatively frequent maintenance, are prone to vandalism, and do not reduce the hazard.

Unless they are significant and unique historic properties, buildings and other structures should be removed. Safety evaluations and procedures for stabilization or demolition are best conducted with the assistance of structural or civil engineers, and may also require a historical architect.

Hazards related to underground mining

Hazards at underground mines may involve persons falling into shafts; cave-ins from unstable rock or rotten timbers; deadly gases, oxygen deficiency, or radioactive emissions; explosives; and unstable aboveground (e.g., headframes and buildings) and underground structures (e.g., ladders). Collapse and subsidence are significant hazards of underground mine features such as rooms (found in coal mines), stopes, and glory holes. Such hazards especially exist in relatively shallow workings.

Park staff may complete the initial site inventories but should not enter underground mines unless qualified by appropriate training. Detailed site inspections, underground inspections, and recommended closures require the assistance of geologists or mining engineers with experience in underground mine safety, mine closure, and mitigation techniques. Underground inspection and closure work are usually coordinated with specialists from the Geologic Resources Division.

Selection of the most appropriate closure option for underground mines depends on two important considerations. First, the consultation process required by Section 106 of the NHPA and its regulations at 36 CFR Part 800 needs to be completed. Many underground closures have no effects or have a non-adverse effect on historic properties. Second, the importance of habitat that the mine offers to wildlife in the area must be determined, particularly to federally listed or state-listed threatened and endangered wildlife species such as bats and desert tortoises.

Guidance for closing specific underground features is presented below.

***Shafts and inclines*: Shafts and inclines can be closed in several different ways. In the absence of significant historic properties or critical habitat, permanent closures that return the land to a relatively pristine condition are preferred. If access for heavy equipment is good and adequate mine waste is available onsite, shafts should be backfilled to the approximate original contour or slightly above to allow future settling.**

In sensitive or wilderness areas where heavy equipment may not be acceptable (see wilderness subsection above for discussion of appropriate restoration tools in wilderness), a variety of methods can be used for closing shafts. Prison laborers have been used to backfill shallow shafts by hand. For deeper shafts where hand-backfill would be impractical, polyurethane foam (PUF) plugs are formed near the collar of the shaft and

the remainder of the shaft is backfilled with waste rock from the site. PUF plugs are formed from two liquid components that react when they are combined, expanding to 30 times their original volume and turning into a rigid plug within minutes. The materials can be packed into a site or dropped by helicopter without adverse effects on the site or its access. When properly designed and installed, PUF closures can support great loads such as vehicles and heavy equipment driving over the reclaimed surfaces.

Steel grates and nets of braided steel cable have also been made onsite. Such closures are susceptible to vandalism but may be appropriate in some sites. Where shafts provide significant habitat for bats, steel grates are designed to keep people out but allow bats access and egress. With careful planning, most of these closures are compatible with cultural values in historic mine sites.

***Adits and tunnels*: Adits and tunnels are closed by a variety of techniques depending on site conditions and available material. Backfills, bulkheads, steel gates, cable nets, and bat gates are used to close adits. As much of the portal as possible should be backfilled when equipment access, material availability, and habitat are not constraints. Bulkheads can be constructed of PUF, native stone, and mortar or of dry-stacked native stone, preferably in conjunction with backfilling to the portal.**

Steel gates and cable nets are less resistant to vandalism than bulkheads. Bat gates, although not impervious to vandalism, are designed of very heavy or vandal-resistant steel and effectively deter access while protecting critical habitat for bats and other species such as desert tortoises.

***Stopes:* Where large stopes have been mined near the surface or where they have breached the surface to form a glory hole, some type of support should be provided. Good options are PUF and various types of grout.**

Roles and Responsibilities

The *Director* of the NPS establishes and approves servicewide restoration policies and standards. The Director is ultimately responsible for establishing restoration that conserves natural resources unimpaired for the enjoyment of future generations and for ensuring that such programs are in compliance with directives, policies, and laws.

The *Associate Director of Natural Resource Stewardship and Science (ADNRSS)* has functional authority through the *Natural Resources Program Center* for:

- developing policies and standards for the director’s approval;
- providing policy oversight of NPS restoration, including evaluating the results of field performance in compliance with directives, policies, and laws;
- providing direct assistance to parks in specific program areas; and
- administering restoration programs for which the ADNRSS has direct authority.

The *Natural Resources Program Center* exercises the associate director's responsibility by:

- administering disturbed land and aquatic system restoration programs, including those that provide direct assistance to parks in designing and carrying out restoration;
- formulating and interpreting servicewide restoration policies, regulations, guidance, and standards that help parks conduct restoration programs;
- carrying out functional oversight in assigned program areas;
- seeking funding;
- providing technical assistance;
- maintaining the servicewide database of AML sites;
- partnering with other government agencies and private organizations; and
- maintaining a list of servicewide contacts involved in restoration and keeping such contacts informed of developments in restoration issues in NPS.

This work is coordinated by the Natural Resources Program Center's Restoration Technical Advisory Group, comprised of professional staff assigned to the Geologic Resources Division, the Water Resources Division, the Biological Resources Management Division, and the Natural Resource Information Division.

The *Denver Service Center* assists parks in carrying out restoration projects.

The *regional director* is responsible for:

- ensuring that restoration projects in the region are uniformly implemented in compliance with directives, policies, and law; and
- identifying regional and central office coordinators and contacts for NPS restoration programs, when appropriate, who can provide information and data about the program to the Natural Resources Program Center.

The *support office natural resource staff and regional or cluster level restoration leads* advise parks in:

- the details of restoration-need assessments;
- data collection and analysis;
- project planning and implementation;
- proposal and funding requests; and
- related technical assistance and advice.

Superintendents are responsible for:

- understanding natural resources and their condition including disturbances in their parks;
- facilitating the restoration of a park's disturbed lands and aquatic systems; and

- establishing and managing park restoration programs and ensuring that they comply with directives, policies, and laws.

Park natural resource managers on behalf of the superintendents conduct need assessments and planning operational restoration in compliance with directives, policies, and laws.

Other sources of help include:

- Redwood National Park, which has an extensive restoration program and can provide technical assistance and advice on many aspects of disturbed lands and aquatic system restoration.
- the states of Arkansas, California, Colorado, Montana, Nevada, Texas, Utah, Virginia, and Wyoming, which have AML reclamation programs and can work cooperatively with NPS to mitigate abandoned mine hazards and environmental problems in national parks within each state.
- The Society for Ecological Restoration (www.ser.org/) provides guidelines for projects, and publishes two journals on restoration research and projects.

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United States Department of Agriculture	**Forest Service**	**R-1**

Reply To: 2200/2470 **Date:** June 8, 1993

Subject: Use of Vegetative Materials on National Forests

To: Forest Supervisors

The implementation of ecosystems management in R1 necessitates the formulation of a new policy regarding the source and type of plant materials used in seeding and planting projects. Policies and procedures for reforestation of conifer trees are well documented, but policies and procedures for handling other plant material do not exist. Several Forests have asked for guidance in the handling of plant material other than trees. The new policy and guides are stated below, followed by explanatory notes and guides for project implementation.

Policy

1. To the extent practicable, seeds and plants used in erosion control, fire rehabilitation, riparian restoration, forage enhancement, and other revegetation projects shall originate from genetically local sources of native species. When project objectives justify the use of non-native plant materials, documentation explaining why non-natives are preferred will be part of the project planning process.

2. All Forest projects that involve collection or purchase of vegetative materials must be also carefully evaluated to ensure that proper procedures are established to ensure that all vegetative material is in excellent physiological condition when planted or seeded. Not only must high quality stock be purchased or collected, but care must be taken to ensure that the material is properly stored and handled and that it is conditioned for the season of the planting.

3. Prescriptions for use of vegetative materials should be reviewed prior to implementation to ensure the project is feasible and appropriate vegetative material is used. Objectives must be clear and steps taken to meet objectives must be clearly defined.

Explanation

This policy was designed to emphasize the importance of biodiversity, and to recognize the intrinsic value of native plant vegetation as a component of natural forest and rangeland ecosystems. Non-native species, although useful at times, have great potential for disrupting natural communities. For example, non-native species may become aggressive competitors and cause the displacement of native plant species. Alternatively, exotics or non-locally adapted populations may be poorly adapted to local environments, exhibiting poor survival and growth patterns and a high susceptibility to environmental extremes and endemic pests and pathogens. New insects or diseases may also be introduced into our forest ecosystems by the use of non-native plant species.

The reliance on non-native species can be reduced only gradually over time. In the short-term, barriers to utilizing native plant materials include cost considerations, plant material availability, and the lack of knowledge regarding plant culture and propagation. These limitations may lead to a decision to use non-native species.

If a genetically local stock of native tree, shrub, or grass species is not available, consider not doing, or delaying, the project, or using exotic species that will not persist and become a permanent part of the ecosystem. Sterile varieties or short-lived annuals make a good choice for grass species, for example. In the case of native seed that is not genetically local to an area, consider using species that are self-pollinating and, therefore, unlikely to pollute the gene pool of local plant populations through intermating.

Consult local Forest specialists for recommendations on appropriate plant species for your geographic area. Enclosed please find some genetic guidelines for planting of adapted populations of native species and guidelines for implementing successful projects.

/s/ JACK A. BLACKWELL
for

DAVID F. JOLLY
Regional Forester

Enclosure

GENETIC GUIDELINES FOR NATIVE PLANT COLLECTIONS

1) HIGH QUALITY
- a) Use healthy, vigorous parent stock.
- b) Collect at appropriate time.
- c) Use optimal collection, processing, and storage procedures.

2) GENETICALLY DIVERSE
- a) Collect from a large number of unrelated donor plants (-30-50).
- b) Separate collections by -100'.
- c) Collect an approximately equal number of seeds/cuttings from each donor plant.

3) LOCALLY ADAPTED
- a) Use seed zones to guide the transfer of seeds/cuttings from upland plant species.
  - i. Exhibit #5 from Seed Handbook FSH 2409.26f R-1, original seed zone map for conifers. This map was originally used as a guide for all conifers and was based on ecological vegetative zones. It no longer applies to conifers but still has merit as a guide for moving vegetative material.

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  - ii. Local County---Within these seed zones local counties can be used as a further refinement to transfer guides, and many seed dealers identify their seed collections by county.
  - iii Watershed delineations (FSM 2513.2, R-1 Supp-5th field of exhibit) can be used to move riparian seeds and cuttings.
- c) Limit transfers to -1000- upward or downward in elevation from the point of collection.

4) ORIGIN IS KNOWN
- a) Document location of parent plants.
- b) Identify and track collections from nursery to field.
- c) Monitor survival and growth performance over time.

QUALITY MATERIAL GUIDELINES

1. Contracts for purchase of quality plant material must be carefully prepared to ensure that quality stock is produced and delivered in proper condition for outplanting. Care must be taken to ensure that the physiological state of the delivered stock is correct for the time of year the
stock is to be outplanted. Regional reforestation specialist and the Coeur d'Alene Nursery can provide advice on sources and preparation of contracts for purchase of vegetative materials.

2. Plans must consider steps necessary to maintain stock once it is received. Vegetative material will often require cooler storage at prescribed temperatures and humidities to maintain vigorous stock.

3. Proper care during planting or seeding operation must be planned and implemented to ensure plants are properly and carefully established to ensure success.

4. All projects should have a monitoring plan for 1 to 3 years to evaluate the project's success.

COORDINATION OF PROJECTS

1. All projects should receive careful review prior to implementation.

   A. Reforestation and nursery personnel should be consulted for advice on how to obtain and care for native plant materials.

   B. District reforestation personnel can be utilized to help prepare and administer contracts for planting of native plants.

2. Projects should be reviewed to ensure objectives are sound and that they can feasibly be met. Protection from browsing of established material is often necessary to meet objectives. A common error is the planting of native shrubs without protection in riparian areas on winter range when heavy animal use can be expected. Care must be taken to ensure that projects are properly scheduled to minimize damage from cold, frosts, drought.

3. Projects should be monitored to determine if resource objectives have been met. Results should be documented and distributed so that people planning future projects can benefit from the experience

The Center for Invasive Plant Management (CIPM) promotes the ecological management of invasive plants in the West through education, by increasing collaboration among researchers, educators, and land managers, and by funding research projects and weed management areas. Our objectives are to advance ecologically-based management of invasive plants by serving as an information clearinghouse, providing examples of ecologically-based management, and delivering implementation tools and products to land managers.

CIPM's Restoration Program was established to:

- Further the scientific knowledge of ecologically-based restoration
- Produce resources and serve as an information center for the restoration of invasive-plant-dominated lands
- Increase communication among land managers and researchers

We are glad to be participants in the *Gardiner Basin Native Vegetation/Ungulate Winter Range Restoration Workshop* as a means to bring together land mangers and researchers to provide ecologically-based restoration recommendations for the Gardiner Basin.

CIPM follows the Society for Ecological Restoration's definition of Ecological Restoration: "Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed." We have expanded this definition to relate explicitly to invasive plants and their management. Below is our working definition of ecologically-based invasive plant management.

Ecologically-based invasive plant management incorporates our understanding of ecosystem processes and patterns with appropriate tools to develop sustainable management programs.

Ecologically-based invasive plant management requires:

- understanding and manipulating the mechanisms and processes that direct community dynamics
- understanding and manipulating the biology and ecology of the invasive plant and the desired habitat
- understanding that ecosystems have feedbacks; manipulations will have foreseen and unforeseen consequences
- understanding that management tools have limitations and are not benign
- performance indicators to measure management success
- augmenting desired components of the habitat during management

Ecologically-based invasive plant management principles include:

- Recognizing that ecosystems are always changing.

- Incorporating an understanding of the three general causes of plant community change — **disturbance**, **colonization**, and **species performance** (the ability of plants to compete, persist, and/or disperse in the habitat) — and uses weed management technologies (herbicides, biological control, revegetation, grazing, prescribed fire, etc.) to control disturbance colonization, and species performance, resulting in a desirable habitat.
- Using weed management technologies to manipulate the biology/ecology of both the invasive plants and the desirable species to create a desired state.
- Recognizing that the best ecologically-based management strategy is prevention.

These principles are consistent with the "adaptive management" approach because they build on learning, are a participatory approach to research and land management, recognize that effective management is based on sound science, assume a variety of pathways can meet a given objective, and recognize that partnerships are essential to achieving sustainable ecosystems.

Examples of ecologically-based invasive plant management

- ***Designed disturbance, colonization, and species performance***

  To direct an ecosystem to a desired state, a site or niche must be available for desirable species and unavailable for undesirable ones. Designing a disturbance, such as controlled grazing, burning, or herbicide applications can open sites for desired species.

  Once sites are available, desired species must be available and managed to fill the sites through controlled colonization. During this phase, introductions of desirable species must be augmented or enhanced, while introductions of the weeds must be limited. This could be achieved through revegetation of desired species and/or grazing weedy species. These techniques will decrease competition from the weed, decrease weed seed production, and encourage the development of desired plants.

  When sites are created and desirable species become established, species performance must be altered to favor desirable species over weeds. This includes using methods to alter growth and reproduction of specific plant species, thus contributing to a desirable shift in the habitat.

  Methods that directly alter species performance may include repeated grazing or use of biological control with natural enemies. Grazing can exert short-term stress on the target weed population, temporarily releasing the desired species from competition. In biological control, once natural enemies are established, they exert constant stress on the weed population, reducing the competitive advantage of the weed population, and increasing the likelihood of impact by other strategies, such as revegetation.

Figure 1 shows how these various decisions might contribute to an ecological management strategy.

- ***Biology and ecology***

  Ecologically-based invasive plant management also incorporates a thorough understanding of the biology and ecology of the invasive plant and the desired plant community. This includes understanding the reproductive biology (e.g., seeds, adventitious buds on rhizomes) and conditions favoring growth (e.g., soil conditions, competitive interactions) for both the invasive plant and the desired plant species in the community.

  For example, the reproductive biology of an invasive annual can be addressed during weed management by burning or spraying prior to seed set. This will negatively impact seed production and persistence and may subsequently free resources for desired species.

- ***Managing for functional diversity***

  Another example of an ecologically-based management plan is designing management to negatively impact the growth of invasive species while favoring growth of desired species. This may require establishing (revegetation) or maintaining (careful timing of management technologies) a functionally diverse plant community that uses resources more completely and leaves fewer resources available for invasive species.

Conclusion

Sustainable ecologically-based invasive plant management requires land managers to think beyond simply controlling weeds.

Instead, we need to focus on maintaining and establishing desired plant communities that will increase competition with weed species and meet our land use objectives.

Working definition developed by

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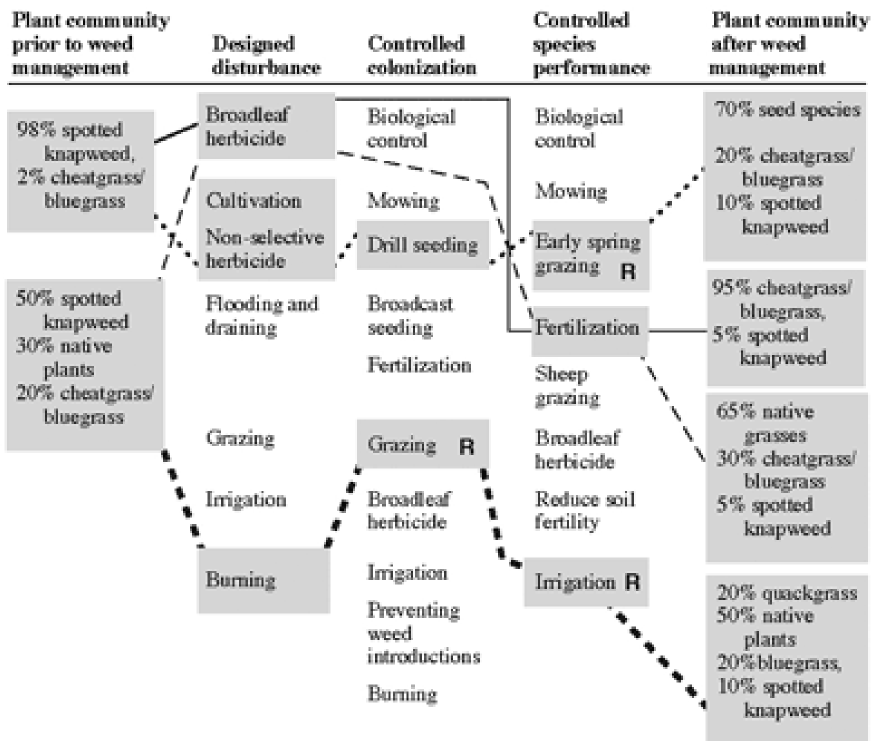
Reviewed and edited by current and past members of the CIPM Steering Committee and *Science Advisory Council*.



This chart lists the various choices that could be made in devising a strategy to manage spotted knapweed infestations. Follow the track from hypothetical situations in the left hand column through treatment options that design disturbance, control colonization and control species performance to find the expected results in the right hand column. "R" refers to repeated aplications.

Figure 1. An example of ecologically-based invasive plant management

Reprinted from: Healthy Plant Communities: MontGuide fact sheet 199909/Agriculture, with permission from the authors and the Montana State University Extension Service. Issued July 1999.

Yellowstone National Park
Heritage and Cultural Center Revegetation Project
Report – April 18, 2005
Dale Reinhart & Sam Reid

Yellowstone National Park staff has implemented revegetation of the Heritage and Cultural Center of the Park's northern boundary in Gardiner Montana. These efforts were a response from a severe windstorm on January 25, 2002. This is a severely impacted site that was a gravel pit, crushing site, batch plant site and disposal of soil and rock from the interior of the park and Gardiner Montana. The revegetation of the Heritage and Cultural Center is funded by grants from the Cooperative Conservation Initiative and the Yellowstone Foundation.

A Yellowstone team of plant, soil landscape architect specialist implemented a revegetation plan for the Heritage and Cultural Center. The team, with concurrence from Yellowstone National Park's Resource Council, attempted to establish native vegetation by first land contouring, then incorporating boulders, sowing native seed, planting containerized native plants, spreading shredded fir/cedar bark mulch, watering the area and controlling weeds.

During the implementing of re-establishing native vegetation to the triangle, Yellowstone Park staff and the A&E firm, CTA drew concept drawing and grading plans for the site. The concept was to create glacial wash and deposition like the surrounding area. The earth material came from excavation from the building and soil and rock stored on the site. The contractor did the initial earth moving and the park equipment operators who specialize in natural lands restoration completed the final contouring and boulder placement. Another purpose of creating rolling boulder fields was to stabilize the soil from wind and water erosion and to help establish native vegetation.

Yellowstone Park staff sowed native and foundation seed on November 3, 2003, May 27, 2004 and November 3, 2004. Different portions of the reclamation areas were ready at different times. The seed came from the park's seed increase and banking program in cooperation with the Natural Resource Conservation Service (NRCS) Bridger Plant Material Center (BPMC). With limited native seed available, the team decided sow additional 'foundation seed'. This is seed grown by BPMC that is native to other areas of Montana and distributed through the Foundation Seed Stock programs at Montana State University (MSU) & University of Wyoming (UWYO) for commercial production. Park staff chose species that grow in the area of the Heritage and Cultural Center.

Through an Indefinite Quantities Contract with the National Park Service, Denver Service Center, Yellowstone National Park contracted with Bitterroot Restoration to grow containerized plant materials for the revegetation efforts of the Heritage and Cultural Center. The orders are for Bitterroot Restoration to grow plants using Yellowstone National Park native seed and sent to the projects in various size containers. The orders are scheduled for delivery in 2004, 2005, 2006 and 2007. In 2004, approximately 4,000 plants were delivered and planted.

After seeding, Park staff, Montana Conservation Corps (MCC), and volunteers spread 280 cubic yards of mulch. The mulch consisted of dry shredded bark of 2/3 fir and 1/3 cedar. This rate of mulch was less than ½ inch thick.

Park staff and MCC distributed 6 inch and 4 inch aluminum irrigation hand-lines and sprinklers over the site and connected it to metered municipal water from the town of Gardiner Montana. An adjacent fire hydrant was used. The plan was to water the area two nights per week at the precipitation rate of .10 inch per week.

Weed control was difficult to implement on the revegetation efforts of the Heritage and Cultural Center. A flush of kochia dominated the vegetation cover during the 2002 growing season. Spraying was not an option because of the emergence of new native seed. Yellowstone National Park orchestrated extensive efforts for weed control. MCC, Yellowstone Conservation Corp (YCC) and visiting boy scouts were enlisted in the weed control efforts on this 4 acre site. Mostly hand pulling was the method of weed control. Park staff hand pulled weeds as well as mowed them. Besides kochia, Russian thistle, white top and mustard were controlled.

One year since revegetation efforts were underway on the Heritage and Cultural Center, wind and water erosion has not been observed. A cover of vegetation is maintained on the site. The composition of vegetation is a mix of native and exotic grasses, forbs and shrubs. Water was applied on a limited basis because of a wet summer in 2004. Weed control also has been limited. The establishment of native species as the dominant ground cover has not yet been realized.

The seed species, quantities and germination data are:

HERITAGE CENTER NATIVE SEED MIXES
November 3, 2003

GRASS MIX

SPECIES LATIN	COMMON	ACCESSION (other information)	GRAMS (g)	**POUNDS** (lbs)
FOUNDATION SEED (not collected in the park)				
Elymus lanceolatus	Streambank wheatgrass	469235/Cristana	10,872	24
Pascopyrum smithii	Western wheatgrass	469236/Rosana	16,308	36
Nasella viridula	Green needlegrass	476300/Lodorm '85	566.25	1.25
Nasella viridula	Green needlegrass	476300/Lodorm '94	122.31	0.270
Nasella viridula	Green needlegrass	476300/Lodorm '94	214.72	0.474
SUB-TOTAL			28,083	61.99
NATIVE SEED				
Achnatherum hymenoides	Indian ricegrass	9081551	594	1.31
Elymus trachycaulum	Slender wheatgrass	9081526	1,948	4.30
Heterostipa comata	Needle and Thread grass	9081502	3,197	7.05
Pseudorogneria spicata	Bluebunch wheatgrass	9081757	1,839	4.05
SUB-TOTAL			7578	16.71
TOTALS			35,661	78.72

NATIVE FORB MIX				
SPECIES		ACCESSION	**GRAMS**	**POUNDS**
LATIN	COMMON	(other information)	(g)	(lbs)
FOUNDATION SEED (not collected in the park)				
Krascheninnikovia lanata	***winterfat***	***9063535/Open Range***	906	2
NATIVE SEED				
Achillea millefolium	Yarrow	9081722	463	1.02
Artemisia tridentata	Big sagebrush	9082093	350	0.77
Chrysothamnous nauseous	Rubber rabbitbrush	Old seed collected in 1989 (not sent to BPMC)	9,966	22
Grindelia squarrosa	Curly-cup gumweed	(not sent to BPMC) not cleaned	981	2.16
Krascheninnikovia lanata	Winter sage	9081827	763	1.68
Lupinus argenteus	Lupine	9082217	220	0.48
Sarcobatus vermiculatus	Greasewood	(not sent to BPMC) not cleaned	3624	8
Symphotrichum chilense	Pacific aster	(not sent to BPMC) not cleaned	312	0.68
Galium sp.	Northern wild licorice	(not sent to BPMC) not cleaned	5,436	12
TOTALS				

HERITAGE CENTER NATIVE SEED MIXES
MAY 27 and NOVEMBER 3, 2004

GRASS MIX			
SPECIES		ACCESSION	**WEIGHT**
LATIN	COMMON	(other information)	(lbs)
FOUNDATION SEED (not collected in the park)			
Elymus lanceolatus	Streambank wheatgrass	469235/Cristana	50.00
Pascopyrum smithii	Western wheatgrass	469236/Rosana	49.88
Poa secunda	Sandberg bluegrass	9078408/High Plains	5.00
SUB-TOTAL			104.88
NATIVE SEED			
Achnatherum hymenoides	Indian ricegrass	9081748	1.97
Achnatherum hymenoides	Indian ricegrass	9081551	0.04
Achnatherum hymenoides	Indian ricegrass	9081862	1.02
Elymus caninus	Bearded wheatgrass	9081500	2.08
Elymus caninus	Bearded wheatgrass	9082182	.006
Elymus trachycaulus	Slender wheatgrass	9081726	20

GRASS MIX			
SPECIES		ACCESSION (other information)	WEIGHT (lbs)
LATIN	COMMON		
Hesperostipa comata	Needle and Thread grass	9081502	4.03
Koeleria macrantha	Prairie junegrass	9081885	0.06
Leymus cinereus	Basin wildrye	9087328	2.35
Pascopyrum smithii	Western wheatgrass	9081750	0.12
SUB-TOTAL			31.676
TOTALS			136.556

NATIVE FORB MIX			
SPECIES		ACCESSION (other information)	WEIGHT (lbs)
LATIN	COMMON		
FOUNDATION SEED (not collected in the park)			
Krascheninnikovia lanata	***winterfat***	***9063535/Open Range***	3.96
NATIVE SEED			
Artemisia tridentata	Big sagebrush	(not sent to BPMC) not cleaned	2.5
Chrysothamnous nauseous	Rubber rabbitbrush	(not sent to BPMC) not cleaned	1.5
Erigeron compositus	Cutleaf daisy	9081786	0.04
Eriogonum umbellatum	Sulphur-flower buckwheat	9081910	3.0
Grindelia squarrosa	Curly-cup gumweed	(not sent to BPMC) not cleaned	3.0
Helianthella uniflora	Oneflower helianthella	9082212	2.0
Linum lewisii	Prairie flax	9081592	0.7
Lupinus argenteus	Lupine	9082216	1.76
Sarcobatus vermiculatus	Greasewood	(not sent to BPMC) not cleaned	4.0
TOTALS			22.46

GERMINATION TESTS ON SPECIES SEEDED ON THE TRIANGLE

GRASSES						
SPECIES		**Where seed was cleaned?**	**Age of Seed**	**# of Seeds tested**	**How many germ.**	**Notes**
SCIENTIFIC	**COMMON**					
Stipa viridula	**Green needlegrass**	**Wild Seed**	**1989**	**100 in tray**	**26**	**Started** 3/18 **in reg. Potting soil w/ first germination on** 4/1**, 13 germ on** 4/8 **and last checked on** 4/17**.**

Elymus cinereus	**Great Basin wildrye**	**Wild Seed**	**1989**	**100 in tray**	**20 soil 12 no**	**Started** 3/18 **in reg. Pot. soil ½ w/ lt soil cover , ½ w/ no soil. w/ 1st germ. on** 4/1**, 23 on** 4/8 **and last checked on** 4/17**.**
Stipa comata	**Needle and thread grass**	**BPMC**	**1999**	**100 in tray**	**69**	**Started** 3/20 **w/ mix of ½ pot soil and ½ site soil. Partially covered w/ soil. No awns and did not break seed coat. 15-20 germ on** 3/28**. 58 on 4/8, last checked on** 4/17**.**
Elymus cinereus	**Great Basin wildrye**	**BPMC**	**1999**	**248 cones**	**204 cones w/ 3-5**	**Started on** 3/20 **in potting soil with light soil cover in cones with about 10 seeds per cone.** 4/1 **first signs of germ. Last checked on** 4/17**.**
Festuca idahoensis	**Idaho Fescue**	**BPMC**	**1999**	**>100 in tray**	**>100**	**Started on** 3/21 **with mix of ½ potting soil and ½ site soil.** 3/28 **first germination.** 4/1 **Many seedlings w/ about 90-95% germination.**
Oryzopsis hymenoides	**Indian ricegrass**	**BPMC**	**1999**	**>100 in tray**	**7**	**Started on** 3/21 **with mix of ½ site soil and ½ potting soil. Treated seed w/ soak of 4% GA for ten minutes and washed w/ water. Last checked on** 4/17 **and will re-evaluate.**
Pascopyrun smithii	**Western wheatgrass**	**BPMC**	**1999**	**67 cones**	**62 cones w/ 2-4**	**Started on** 3/21 **in potting soil with light soil cover. 2-4 seeds per cone.** 3/28 **germ of 28 cones. Last checked on** 4/17**.**
Pseudorogneria spicata	**Bluebunch wheatgrass**	**BPMC**	**1999**	**67 cones**	**64 cones w/ 2-3**	**Started on** 3/21 **in potting soil, light soil covering w/ 2-3 seeds per cone.** 4/1 **every cone has a seedling. Last checked on** 4/17**.**

SHRUBS						
SPECIES		**Where seed was cleaned?**	**Age of Seed**	**# of Seeds tested**	**How many germ.**	**Notes**
SCIENTIFIC	**COMMON**					
Chrysothamnous nauseosus	**Rubber rabbit brush**	**Wild Seed**	**1989**	**>100 in tray**	**0**	**Started** 3/18 **with ½ seeds with no soil cover and ½ with lt. Soil cover. Last checked on** 4/17**.**
Chrysothamnous nauseosus	**Rubber rabbit brush**	**BPMC**	**1999**	**201 cones**	**over 50%**	**Started** 3/14 **w light covering of soil over seed. 5 germinated on** 3/20**.** 3/25 **more germinated.** 4/15 **had to thin cones to 2-3 plants.**
Artemisia frigida	**Silver sage**	**Wild Seed**	**1989**	**>100 in tray**	**11**	**Started** 3/18 **½ w/ light soil cover and ½ w/ no soil.** 4/ 1 **germination** 4/11 **total of 11 w/ 2 no cover and 9 light cover.**
Artemisia frigida	**Silver sage**	**Not cleaned**	**2001**	**268 cones**	**30 cones**	**Started** 3/18 **in cones w/ light soil covering.** 4/1 **few germinated.** 4/17 **last checked.**
Sarcobatus vermiculatus	**Greasewood**	**Not cleaned**	**1998**	**67 cones**	**59 w/1-2 over 50%**	**Started** 3/20 **in cones w/ mix of ½ pot soil and ½ site soil. Light cover of soil.** 3/25 **Germination of many seeds.** 4/15 **Thinned to 2 plants per cone.**

SHRUBS						
SPECIES		**Where seed was cleaned?**	**Age of Seed**	**# of Seeds tested**	**How many germ.**	**Notes**
SCIENTIFIC	**COMMON**					
Artemesia tridentata	**Big sagebrush**	**BPMC**	**1999**	**124 cones**	**81 w/3-6 >50 %**	**Started** 3/27 **in cones w/ potting soil mix and light soil covering seeds.** 4/2 **Germination of 16 plants.** 4/17 **81 cones with 3-6 seedlings.**

Note: All trays and containers were placed in a plastic covered germinating tent with bottom heat. The bottom heat was set at 55 degrees over the weekend to prevent dry out. The heat was increased to 70 degrees during the week when the plants could be watered every other day. The heat seemed to increase germination success.

Definitions:
BPMC= Bridger Plant Materials Center
4% GA= Gibberelic Acid
Wild Seed = Contract seed source from Tucson.

Yellowstone National Park
Gardiner Triangle Revegetation Project
Report – April 18, 2005
Dale Reinhart & Sam Reid

Yellowstone National Park staff has implemented revegetation in the Triangle area of Yellowstone National Park's northern boundary in Gardiner Montana. These efforts were a response from a severe windstorm on January 25, 2002. Prior to this windstorm, much of the Triangle was non-vegetated from impacts to the site, drought, ungulate browsing and weed control. During the windstorm, soil erosion caused damage to neighboring lands and buildings.

A team of Yellowstone staff implemented a revegetation plan for the Triangle area. The team, with concurrence from Yellowstone National Park's Resource Council, attempted to establish native vegetation by conducting soil analysis, sowing native seed, spreading shredded fir/cedar bark mulch, watering the area and controlling weeds.

Montana State University-Plant and Soil Science Department conducted soil analysis from seven samples from the triangle. They tested for pH, electric conductivity, organic matter and nutrients. Northern Analytical Laboratories, Inc. tested for herbicide residue. Both sets of data did not show severe limits on establishing vegetation on the site and are available.

During the implementing of re-establishing native vegetation to the triangle, Yellowstone Park staff sowed native grass seed on March 28 and 29, 2002. The seed came from the park's seed increase and banking program in cooperation with the NRCS Bridger Plant Material Center (BPMC). The area of the Triangle that needed to be revegetated is 11 acres. The total seed available was 117.50 lbs of grass and 18 lbs of forbs and shrubs. The park also had eight bales of *Stipa comata,* seed and grass stalks, combined to a total of 16 lbs of seed. **An average of 13.77 lbs per acre was spread over the triangle.** The timing of the seed application was to coincide with spring rains in the Gardiner area.

Subsequently, after seeding in March, 2002, another wind storm occurred on the triangle, blowing soil, seed and mulch. After concerns from park staff that the seed either disappeared from the site or was redistributed, the team decided to sow additional seed. Park native seed was no longer available, so 'foundation seed" was used. This is seed grown by BPMC that is native to other areas of Montana and distributed through the Foundation Seed Stock programs at MSU & UWYO for commercial production. Park staff chose species that grow in the area of the triangle. The park sowed 103 pounds of 'foundation' seed in mid July.

Park staff, MCC, and volunteers spread 504 cubic yards of mulch after seeding in March in 2002. The mulch is a dry shredded bark of 2/3 fir and 1/3 cedar. This rate of mulch is less than ½ inch thick.

Park staff and MCC distributed 6 inch and 4 inch aluminum irrigation hand-lines and sprinklers. The source of water was metered municipal water from the town of Gardiner Montana. An adjacent fire hydrant was used. The plan was to water the area two nights per week at the precipitation rate of .10 inch per week. This schedule would use approximately one million gallons of water per season and added approximately 3 inches of moisture to the site. From our meter readings, approximately 2 inches of moisture was added to the site or approximately 650,000 gallons of water during the 2002 growing season.

Weed control was difficult to implement on the revegetation efforts of the Triangle. A flush of Russian thistle dominated the vegetation cover during the 2002 growing season. Spraying was not an option because of the emergence of new native seed. Yellowstone National Park orchestrated extensive efforts for weed control. MCC, Yellowstone Conservation Corp (YCC), visiting boy scouts, visiting school children and community volunteers were enlisted in the weed control efforts on this 11 acre site. Mostly hand pulling was the method of weed control. Park staff hand pulled weeds, as well as mowed them. Besides Russian thistle, kochia, white top and mustard were controlled.

Three years since revegetation efforts were underway on the Gardiner Triangle; wind erosion has not been observed. A cover of vegetation is maintained on the site. The composition of vegetation is a mix of native and exotic grasses, forbs and shrubs. Water was applied on a limited basis the second and third season. Weed control also has been limited. Russian thistle is not the dominant vegetation. The establishment of native species as the dominant ground cover has not yet been realized.

The seed species, quantities and germination data are:

GRASS MIX 1 (dry areas)

SPECIES		Where seed was cleaned?	WEIGHT	
SCIENTIFIC	COMMON		GRAMS	POUNDS
Leymus cinereus	Great Basin wildrye	Wild Seed	13590	30
Stipa comata	Needle and thread grass	BPMC	2188	4.83
Festuca idahoensis	Idaho fescue	BPMC	545	1.2
Oryzopsis hymenoides	Indian ricegrass	BPMC	363	0.80
TOTALS			16686	36.8

GRASS MIX 2 (dry areas)

SPECIES		Where seed was cleaned?	WEIGHT	
SCIENTIFIC	COMMON		GRAMS	POUNDS
Leymus cinereus	Great Basin wildrye	Wild Seed	13590	30
Stipa comata	Needle and thread grass	BPMC	1971	4.35
Festuca idahoensis	Idaho fescue	BPMC	87	0.19
Oryzopsis hymenoides	Indian ricegrass	BPMC	419	0.92
Pseudorogneria spicata	Bluebunch wheatgrass	BPMC	221	0.48
Psacopyrum smithii	Western wheatgrass	BPMC	50	0.11
Leymus cinereus	Great Basin wildrye	BPMC	1522	3.35
TOTALS			17860	39.42

GRASS MIX 3 (dry areas)

(was mixed with grass mixes 1 and 2)

SPECIES		Where seed was cleaned?	WEIGHT	
SCIENTIFIC	COMMON		GRAMS	POUNDS
Leymus cinereus	Great Basin wildrye	Wild Seed	2265	5
Stipa comata	Needle and thread grass	BPMC	1711	3.77

Leymus cinereus	Great Basin wildrye	BPMC	6232	13.75
Oryzopsis hymenoides	Indian ricegrass	BPMC	250	0.55
Koelaria macrantha	Prairie junegrass	BPMC	21	0.04
TOTALS			10479	23.13

GRASS MIX 4 (moister areas)				
SPECIES		Where seed was cleaned?	WEIGHT	
SCIENTIFIC	COMMON		GRAMS	POUNDS
Elymus trachycaulum	Slender wheatgrass	BPMC	6958	15.35
Stipa nelsonii	Nelson's needlegrass	BPMC	248	0.54
Stipa occidentalis	Western needlegrass	BPMC	228	0.50
Stipa viridula	Green needlegrass	Wild Seed	3171	7
TOTALS			10605	23.41

FORB AND SHRUB MIX				
SPECIES		Where seed was cleaned?	WEIGHT	
SCIENTIFIC	COMMON		GRAMS	POUNDS
Achillea millefolium	Yarrow	Not cleaned	453	1
Artemesia frigida	Silver sage	Wild Seed	2944.5	6.5
Artemisia tridentata	Big sagebrush	BPMC	86	0.19
Chrysothamnous nauseosus	Rabbitbrush	BPMC	854	1.88
Chrysothamnous nauseous	Rabbitbrush	Not cleaned	3086	6.81
Eriophyllum lanatum	Wooly yellow daisy	BPMC	12	0.02
Sarcobatus vermiculatus	Grease wood	Not cleaned	2434.8	5.37
TOTALS			9870.3	21.78

The seed species and quantities of foundation seed are:

SPECIES		Where seed came from?	PURITY	WEIGHT (lbs) Pure Live Seed
SCIENTIFIC	COMMON			
GRASS MIX				
Pascopyrum smithii	Rosana western wheatgrass	Foundation	97.60	36.00
Elymus lanceolatus	Critana thickspike wheatgrass	Foundation	98.29	23.00
Poa secunda	High Plains big bluegrass	Common		3.50
Stipa comata	Needle and thread	Common	89.87	4.00
Nassella viridula	Lodorm green needlegrass	Common	97.08	10.06
Elymus trachycaulus	Pryor slender wheatgrass	Foundation	97.70	25.00
			Sub-total	101.56
FORB MIX				

Krascheninnikovia lanata	Open Range winterfat	Foundation	96.94	1.5
TOTALS				103.06

GERMINATION TESTS ON SPECIES SEEDED ON THE TRIANGLE

GRASSES						
SPECIES		**Where seed was cleaned?**	**Age of Seed**	**# of Seeds tested**	**How many germ.**	**Notes**
SCIENTIFIC	**COMMON**					
Stipa viridula	**Green needlegrass**	**Wild Seed**	**1989**	**100 in tray**	**26**	**Started** 3/18 **in reg. Potting soil w/ first germination on** 4/1**, 13 germ on** 4/8 **and last checked on** 4/17**.**
Elymus cinereus	**Great Basin wildrye**	**Wild Seed**	**1989**	**100 in tray**	**20 soil 12 no**	**Started** 3/18 **in reg. Pot. soil ½ w/ lt soil cover , ½ w/ no soil. w/ 1st germ. on** 4/1**, 23 on** 4/8 **and last checked on** 4/17**.**
Stipa comata	**Needle and thread grass**	**BPMC**	**1999**	**100 in tray**	**69**	**Started** 3/20 **w/ mix of ½ pot soil and ½ site soil. Partially covered w/ soil. No awns and did not break seed coat. 15-20 germ on** 3/28**. 58 on 4/8, last checked on** 4/17**.**
Elymus cinereus	**Great Basin wildrye**	**BPMC**	**1999**	**248 cones**	**204 cones w/ 3-5**	**Started on** 3/20 **in potting soil with light soil cover in cones with about 10 seeds per cone.** 4/1 **first signs of germ. Last checked on** 4/17**.**
Festuca idahoensis	**Idaho Fescue**	**BPMC**	**1999**	**>100 in tray**	**>100**	**Started on** 3/21 **with mix of ½ potting soil and ½ site soil.** 3/28 **first germination.** 4/1 **Many seedlings w/ about 90-95% germination.**
Oryzopsis hymenoides	**Indian ricegrass**	**BPMC**	**1999**	**>100 in tray**	**7**	**Started on** 3/21 **with mix of ½ site soil and ½ potting soil. Treated seed w/ soak of 4% GA for ten minutes and washed w/ water. Last checked on** 4/17 **and will re-evaluate.**
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SHRUBS						
SPECIES		**Where seed was cleaned?**	**Age of Seed**	**# of Seeds tested**	**How many germ.**	**Notes**
SCIENTIFIC	**COMMON**					
Chrysothamnous nauseosus	**Rubber rabbit brush**	**Wild Seed**	**1989**	**>100 in tray**	**0**	**Started** 3/18 **with ½ seeds with no soil cover and ½ with lt. Soil cover. Last checked on** 4/17**.**

SHRUBS						
SPECIES		**Where seed was cleaned?**	**Age of Seed**	**# of Seeds tested**	**How many germ.**	**Notes**
SCIENTIFIC	**COMMON**					
Chrysothamnous nauseosus	**Rubber rabbit brush**	**BPMC**	**1999**	**201 cones**	**over 50%**	**Started** 3/14 **w light covering of soil over seed. 5 germinated on** 3/20**.** 3/25 **more germinated.** 4/15 **had to thin cones to 2-3 plants.**
Artemisia frigida	**Silver sage**	**Wild Seed**	**1989**	**>100 in tray**	**11**	**Started** 3/18 **½ w/ light soil cover and ½ w/ no soil.** 4/ 1 **germination** 4/11 **total of 11 w/ 2 no cover and 9 light cover.**
Artemisia frigida	**Silver sage**	**Not cleaned**	**2001**	**268 cones**	**30 cones**	**Started** 3/18 **in cones w/ light soil covering.** 4/1 **few germinated.** 4/17 **last checked.**
Sarcobatus vermiculatus	**Greasewood**	**Not cleaned**	**1998**	**67 cones**	**59 w/1-2 over 50%**	**Started** 3/20 **in cones w/ mix of ½ pot soil and ½ site soil. Light cover of soil.** 3/25 **Germination of many seeds.** 4/15 **Thinned to 2 plants per cone.**
Artemesia tridentata	**Big sagebrush**	**BPMC**	**1999**	**124 cones**	**81 w/3-6 >50 %**	**Started** 3/27 **in cones w/ potting soil mix and light soil covering seeds.** 4/2 **Germination of 16 plants.** 4/17 **81 cones with 3-6 seedlings.**

Note: All trays and containers were placed in a plastic covered germinating tent with bottom heat. The bottom heat was set at 55 degrees over the weekend to prevent dry out. The heat was increased to 70 degrees during the week when the plants could be watered every other day. The heat seemed to increase germination success.

Definitions:
BPMC= Bridger Plant Materials Center
4% GA= Gibberelic Acid
Wild Seed = Contract seed source from Tucson.

SELECTED READING #1

The only descriptions we have of the Gardiner Basin before and soon after settlement come from the journals of Lt. Gustavus Doane. Lt Doane led a small cavalry detail that escorted the "Yellowstone Expedition of 1870" (also called the Langford-Doane Expedition). His account, submitted to Congress, was the first official report on the resources of the Yellowstone region, and helped prepare the way for the Yellowstone act. He again traveled through the area in 1876, four years after Yellowstone Park was established, on his way to explore the Snake River region.

<u>Excerpts from Lt. Doane's official government report describing the Gardiner Basin as quoted in</u>*:*

Bonney, Orrin H. and Lorraine. 1970. *Battle Drums and Geysers: the Life and Journals of Lt. Gustavus Cheyney Doane, Soldier and Explorer of the Yellowstone and Snake River Region*. Swallow Press, Chicago. 622 p.

PART II The Yellowstone Expedition of 1870. Pg 235-237:

Thursday, August 25, 1870:

> On descending presently from the mountain we again entered the river valley, which was here from one and a half to two miles wide.
>
> The rock formation after passing the narrow gorge was of limestone strata, with superincumbent sandstones and shales; small deposits of gypsum appeared, and over all, drift bounders were scattered, even on the summits of the higher hills, behind these, granite peaks rose up, worn at their bases by drift currents. The soil here lost its fertility, the level lands being covered with a heavy growth of sage brush, and the few streams of water impregnated with alkali. The trend of the river is to the southeast. About noon we passed a very singular formation on the right, the strata of limestone turned up edgewise, formed a hill several hundred feet in height, on the face of which the softer portions of the strata having been washed away, caused the more solid limestones to stand out from the hillside in two immense walls, the crests of which were covered with stunted pine trees. Near these a dark stratum of coals was visible, also a red stratum reported to be cinnabar, which we did not, however, examine. From this point to the mouth of Gardiners river, a distance of twelve miles, the valley was full of original drift. The boulders were of Quincy granite, and wherever found were worn off smooth as if by the action of water. The ground rose rapidly as we progressed, passing from a dead level alkali plain to a succession of plateaus covered slightly with a sterile soil through which the limestones cropped out constantly.
>
> In many places deep ravines were worn down in the strata by the waters form the melting snow, numerous springs were seen far up on the mountains sides, but their waters sank among the arid foot hills without reaching the river.
>
> This desert region enclosed by mountains clothed with verdue, and on the banks of a large stream, is one of the anomalies common in the West, where the presence of limestone or sandstone in horizontal strata, especially, almost always means want of water, and consequent desolation.
>
> We camped at the mouth of Gardiners river, a large stream coming in through a deep and gloomy canon from the south. This was our first poor camping place, grass being very scarce, and the slopes of the range covered entirely with sage brush.

PART III The Snake River Expedition of 1876-1877. Pg 466-67:

October 16, 1876:

> Descending into the river valley once more we come to a succession of broken dikes, then pass a projecting spur and reach an open desolate little valley, the bounding wall of which is on the right, the Devil's Slide, or Cinnabar Mountain.
>
> The coal measures of this mountain were discovered by me in 1870 and are mentioned in my report of that year. Neither the Engineer Parties of the following years nor the Geological Survey reported or found this coal though both hand my report to guide them to what that did discover. These mines now produce the best cooking coal in Montana, and in unlimited quantities. The valley here is fertile but waterless. It is even now being made productive and quite well settled, being outside the Park limits.

SOILS INVESTIGATION

of the

REESE CREEK - MCMINN BENCH - MAMMOTH AREA

NORTHWESTERN

YELLOWSTONE NATIONAL PARK

WYOMING

February 28, 1991

SOILS AND WATERSHED SECTION
DIVISION OF RESEARCH

YELLOWSTONE NATIONAL PARK

This project was completed by

Soils and Watershed Section
Division of Research
Yellowstone National Park

The report was completed by

Henry Shovic
Ann Rodman
Dean Neprud

February 27, 1991

Table of Contents

List of Map Sheets

Introduction

This investigation was initiated by Yellowstone National Park, National Park Service under the direction of the Chief of Research, Yellowstone National Park. The Park Soil Scientist was responsible for its completion.

The study follows standards for soil surveys (Soil Survey Staff, 1985 draft). It is part of a larger soil survey being completed for Yellowstone National Park as part of the National Cooperative Soil Survey program coordinated through the Division of Research, Yellowstone National Park. This area was completed first to provide management with some critically needed information on the potential for restoration of past disturbance and potential for wildlife winter range.

Study Objectives

Objective 1
Determine the extent, location, and character of vegetation/soil/site combinations that relate to potential shrub and grass production for wildlife usage. This information will be used as a basis for later site productivity studies on winter range.

Objective 2
Determine the extent, location, and character of sites that have had severe soil disturbance. Insofar as possible, describe the status of vegetation disturbance. Give suggestions on site restoration practices. This information will help determine site restoration methods.

Objective 3
Determine the relative hazards for wind and water erosion.

Objective 4
Discover and document significant relationships between vegetation, landforms, lithology, and soils to enhance understanding of ecological processes operating in the survey area.

Study Area Description

The survey area is about 4065 ha.(10,050 ac.), and is located in northwestern Yellowstone National Park. It includes the Stevens Creek area, McMinn Bench, the Rainbow Lakes area, part of northern Mount Everts, and Elk Plaza. The southern boundary is Mammoth Hot Springs, Wyoming. The northern boundary is Reese Creek and the Yellowstone River (see Figure 1). Elevations range from 1585 m near the Yellowstone River to 2075 m on the slopes above McMinn Bench. Land forms include ancient landslides, landslide scarps, stream cut terraces and small valleys, glacial moraine, and steep stream breaks. Vegetation is commonly grasses and shrubs. Slopes are moderate (2% - 35%) with some steeper scarps. Topography includes rolling, chaotic hills, nearly flat terraces, and gently undulating to moderately steep slopes (see Appendix C for details on geology of the area). Most of the topography is relatively young (Pleistocene or Holocene).

Landslide vegetation is sparse, with sage, bitterbrush, greasewood, needlegrass, and other dry-environment species. Some flat terraces were farmed in the 1940's, and have a sparse cover of wheatgrass, mustards, and other annuals. Higher elevation vegetation on Mt. Everts is moist grassland. The Mammoth area has a mixture of scattered pine, sage, and grassland. Introduced or "exotic" species occur throughout the survey area.

The lithology of parent materials varies from Cretaceous sediments and Tertiary volcanics, to gravelly or bouldery glacial till derived from a variety of rock types (Appendix C). The climate is relatively warm and dry, with 25 cm to 41 cm of precipitation. The area stays relatively free of snow in the winter, and snowmelt occurs in May or early June. Mean temperatures range from -1 ^{o}C (minimum) to 13 ^{o}C (maximum) with a mean annual temperature of 5.5 ^{o}C. Winds in the area are strongly influenced by local topography. Although prevailing winds over the entire park blow from the southwest, windflow in the survey area is generally parallel to the axis of the valleys.

Soils in the Northern two thirds of the survey area are unique to the region. They are formed in periglacial and pre-glacial landslide debris, stream alluvium, glacial outwash and glacial till. High levels of sodium are common, affecting productivity, erosion potential, and plant communities. High clay contents cause the soils to compact and "seal" when wet. Wind erosion occurs during dry periods.

Soils in the southern one third of the area are formed from a variety of materials, including weathered travertine, glacial till, landslide debris, and weathered shale and sandstone. These soils are non-sodic, but are droughty.

The area is important wildlife range. The pronghorn antelope herd uses this area almost exclusively for its winter range. Elk and bison also use the area, but generally utilize the southern one third in normal winters, leaving the northern part to the pronghorn herd. The area was purchased in the 1930's by the National Park Service.

Study Area Location Map

Figure 1. Location of the study area with respect to Yellowstone National Park.

There are a residence and related outbuildings in the Stevens Creek area. Unused irrigation ditches are common in the area, with some large, eroded breaches at higher elevations. Plant communities in and near these ditches are commonly quite different than those on upland sites. There is a reservoir (known as Ice Lake) and dam in the area. An abandoned railroad grade transects the lower elevations. The Gardiner/Mammoth highway bisects the southeastern part of the area. Unused roads lead to Rainbow Lakes and Ice Lake. There is a well travelled gravel road lying along the eastern boundary from Gardner to Corwin Springs. The Slide Lake road leads from Mammoth, through Elk Plaza, to Gardiner.

Methods

Soil scientists carried out this research study to learn the nature, location, and extent of soils in the study area, as well as their response to management. They observed the steepness, length, and shape of slopes; the stream sizes and general drainage patterns; the plant type; and the kinds of rock. They dug many holes to study soil profiles. A profile is the sequence of natural layers, or horizons, in a soil. It extends from the surface down into the parent material, which has been changed very little by leaching or plant roots.

The soil scientists recorded the characteristics of those profiles, vegetation, rock types, and landforms. They classified soils according to nation-wide uniform procedures (Soil Survey Staff, 1975). They discovered relationships between soils and the visible characteristics of the land, and drew boundaries between different soils on aerial photographs. These boundaries were transferred to topographic maps for publication. The areas shown on a soil map are called map units. Most map units are made up of more than one kind of soil. Each map unit is described in the Results section.

While this investigation was in progress, samples of some soils were analyzed in a soils laboratory. Data were also assembled from test results, literature, existing knowledge of the area, and field experience. Note that all soil properties were determined on the basis of sampling. Site-specific projects should not be designed without on-site verification of those properties.

The information was compiled into a report for specialists and scientists. This report has a legend (a description of all the map units), detailed soil descriptions for representative sites, maps (showing the location of the soils), and interpretations (potential behavior of the soils). Map scale is 1:24,000. The maps have been digitized and reside in GRASS format at the Geographic Information Systems Laboratory, Yellowstone National Park. Field data, mapped on aerial photographs and on United States Geological Survey 7.5 minute topographic quadrangle maps, is on file in the Soils and Watershed Section, Division of Research, Yellowstone National Park.

Results

This map legend correlates to the map unit names used in Map Sheets 1, 2, and 3. Each map unit is a unique combination of soils, vegetation, topography, and geologic material; or a particular kind of disturbance. Each has been given an arbitrary name for ease of identification. They occur in different parts of the study area.

Map Unit Descriptions (Map Legend)

Map Unit FGT

Topography: The landforms are coalescing alluvial fans with broad, convex slopes. Slopes range from 0% to 3%. The drainage patterns are weakly radial.

Vegetation: Natural vegetation is grassland and sparse shrubland. Habitat types are primarily bluebunch wheatgrass/Sandberg bluegrass, with some big sagebrush/bluebunch wheatgrass occurring at the base of the fan and within fan channels. The native vegetation has been disturbed and the present vegetation is primarily (60% - 80%) invading exotics. Vegetative cover varies from 10% to 40%.

Parent Material (geology): The source material for the fans is Cretaceous sandstone, siltstone, mudstone, and Pleistocene glacial till. There have been some surficial additions by glacial floods of the Yellowstone and Gardner Rivers.

Soil Description: Subrounded boulders and stones make up 30 to 40 percent of the soil surface. The soils are well drained with fine to medium textures and dark colored surface layers. The surface textures are mainly loams and clay loams. Soil reaction (pH) is usually 8.0 or slightly higher. The accumulation of calcium carbonate can occur at depths greater than 20 centimeters. The soil fertility is moderate. Both local and glacially imported rock fragments occur within the soil and vary from 35% to 85% of the profile. Pedon 145 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: The percentage of sand and rock fragments generally increases upslope toward the apex of the fan and within fan channels. Some areas have more rock fragments on the surface and are similar to map unit FLD. The swales have fewer rock fragments and resemble map unit FMF.

Map Unit FLD

Topography: Landforms include glacial flood deposits and eroded terraces. Slopes range from 0% to 20%. These features are located on valley bottoms and sides. Drainage patterns are weak to absent. This unit is differentiated from map unit GTM by the higher percentage of large rock fragments on the surface.

Vegetation: Natural vegetation is shrubland. Habitat type is mainly big sagebrush/bluebunch wheatgrass, though summits and south facing slopes are limited to a bluebunch wheatgrass/Sandberg bluegrass habitat type Vegetative cover varies between 30% and 50%.

Parent Material (geology): The unit is made up of stream channel deposits from postglacial floods. The floods were probably the result of rapid draining of ice-dammed lakes during and immediately after deglaciation. In some areas, the surface material contains loess (wind blown silt). The rock types include Precambrian intrusive volcanics, Tertiary extrusive volcanics, and Cretaceous sedimentary rocks.

Soil Description: Rounded and subrounded boulders, with some cobbles and stones make up 40% to 60% of the soil surface. Soils are well drained with medium to coarse textures and dark colored surface layers. Surface textures are mainly loam, with some areas of silt loam and sandy loam. Soil reaction (pH) is slightly below 8.0 at the surface and 8.0 in the subsurface layers. Soil fertility is moderate and calcium carbonate usually occurs in the sandier, subsurface layers. Subrounded boulders, stones and cobbles make up 35% to 70% percent of the soil and become more abundant with increased depth. At 25 centimeters, rock fragments make up approximately 70% of the profile. Pedon 109 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: Finer surface textures occur on lower slope positions.

Map Unit FMC

Topography: Landforms are alluvial fans with broad, convex slopes. They are located on valley sides and bottoms. Slopes range from 8% to 20%. Drainage patterns are weakly radial to dendritic.

Vegetation: Natural vegetation is shrubland and grassland. Habitat types are mainly big sagebrush/Idaho fescue and big sagebrush/bluebunch wheatgrass with some areas of bluebunch wheatgrass/Sandberg bluegrass. Vegetative cover varies from 35% to 70%. Root density is high in the top 10 centimeters of the soil.

Parent Material (geology): The alluvial fan deposits are derived from local sandstone and rhyolitic bedrock. There are occasional glacial erratics within the soil.

Soil Description: Angular and subangular gravels and cobbles, with some subrounded stones make up from 2% to 40% of the soil surface. Soils are well drained, with medium to coarse textures and dark colored surface layers. Surface textures are mainly sandy loams with some loamy sands. Surface soil reaction (pH) varies between 7.3 and 8.1. Calcium carbonate may occur in the subsoil at depths greater than 10 centimeters. Salt and/or sodium may occur in the soil profile. The soils have moderate fertility. Rock fragments are generally angular and subangular gravels and cobbles. The amount of rock fragments within the profile varies widely (5% - 50%), but become more abundant with increasing depth. Pedon 106 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: Surface rock fragment percentage increases toward the head of slopes and within fan channels.

Map Unit FME

Topography: The landforms are coalescing alluvial fans with dissected slopes and entrenched stream channels. Slopes range from 5% to 45%. The drainage patterns are strongly parallel.

Vegetation: The natural vegetation is sparse grassland and sparse shrubland. The habitat type is usually bluebunch wheatgrass/Sandberg bluegrass, with some big sagebrush/bluebunch wheatgrass occurring at the base of the fan and in fan channels. Vegetative cover ranges from 10% to 60%.

Parent Material (geology): The source material of these fans is mainly Cretaceous sandstones, siltstones, and mudstones. Because some of the bedrock is marine in origin, there are areas high in calcium carbonate and other salts. A small percentage of the surface stones are glacial erratics.

Soil Description: Angular and subangular cobbles make up 5% to 35% of the soil surface. The soils are well drained with medium textures and light and dark colored surface layers. They are finer textured than map unit FMC. The surface textures are mainly loams. Clay accumulation can occur in the subsoil. Soil reaction (pH) varies from 8.0 to 8.5. Calcium carbonate may occur below 20 centimeters. Salt and/or sodium accumulations can occur in the subsoil below 40 centimeters. Soil fertility is usually low. The amount of rock fragments within the profile ranges from 5% to 30%. Most are subangular to subrounded gravels and cobbles. Pedon 121 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: The proportion of sand in the soil tends to increase toward the apex of the fan. Rock fragments become more abundant toward the apex and within fan channels. The base of the fans has the finest textures and the lowest abundance of rock fragments.

Map Unit FMF

Topography: The landforms are coalescing alluvial fans with broad, convex slopes. Slopes range from 2% to 10%. The drainage patterns are weakly radial.

Vegetation: Natural vegetation is grassland and sparse shrubland. The major habitat type is bluebunch wheatgrass/Sandberg bluegrass, with some big sagebrush/bluebunch wheatgrass occurring at the base of the fan and within fan channels. Vegetative cover varies from 35% to 65%.

Parent Material (geology): The source material for the fans is Cretaceous sandstone, siltstone, mudstone, and Pleistocene glacial till.

Soil Description: Less than 5% of the surface is covered by angular gravels. The soils are well drained with medium textures and light colored surface layers. The surface textures are mainly loams. Soil reaction (pH) is between 7.8 and 8.3. The accumulation of calcium carbonate can occur from the surface down to 30 centimeters below the surface. The soil fertility is high. Rock fragments within the profile vary from 0% to 20%, abundance usually increases with depth. They are rounded and generally small in size. Pedon 111 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: The percentage of sand and rock fragments in the soil generally increases upslope toward the apex of the fan and within fan channels.

Note: The area just southeast of the old Gardiner Cemetery is different from others within this map unit. Here, soils are moderately fine to fine textured with few rock fragments. Cracks up to 5 centimeters wide are common on the surface. Soils have formed in slope-wash from landslides, and may be high in sodium.

Map Unit FOW

Topography: The landforms include gently sloping glacial outwash fans and kame terraces that are both flat and hilly. They are located on valley sides. Slopes vary from 5% to 50%. Drainage patterns are weakly deranged to parallel.

Vegetation: Natural vegetation is grassland and shrubland. Habitat types are big sagebrush/bluebunch wheatgrass and bluebunch wheatgrass/Sandberg bluegrass. Vegetative cover varies from 20% to 40%.

Parent Material (geology): Both outwash fans and kame terraces are composed of stratified or semi-stratified material. Because the material originates from glaciers, it is a combination of eroded local and distant bedrock. The rock types include acid and basic extrusive volcanics, sandstones and finer grained sedimentary rocks, travertine, and intrusive volcanics.

Soil Description: Rock fragments make up 20% to 50% of the surface. The soils are well drained with coarse to medium textures and light to dark colored surface layers. Kame deposits tend to have loam or sandy loam surface textures with few rock fragments throughout the profile. Outwash deposits have a loam surface texture and contain abundant subrounded rock fragments of all sizes. The soil fertility is moderate. Because of high soil variability within this map unit, no typical pedon is given.

Soil Distribution: Soil type is primarily controlled by the method of deposition.

Map Unit FST

Topography: The landforms are alluvial fans with convex slopes. Slopes range from 5% to 15%. The drainage pattern is weakly radial.

Vegetation: Natural vegetation is shrubland. The major habitat type is greasewood/western wheatgrass. The vegetative cover ranges from 35% to 50%. Greasewood is tolerant of saline and sodic conditions in the soil. The distribution of the greasewood/western wheatgrass habitat type may indicate places where salt and/or sodium enriched water reaches the root zone.

Parent Material (geology): The source material for these fans are Cretaceous sedimentary rocks and Pleistocene landslides.

Soil Description: Angular and subangular gravels and cobbles cover up to 30% of the soil surface. The soils are well drained with coarse to medium textures and dark colored surface layers. Surface textures range from loam to loamy sand. Surface soil reactions (pH) are 8.0 and above. Soil fertility is low. Free calcium carbonate occurs throughout the soil profile. Because of parent material, these soils have high soluble salt concentrations in the root zone (see Salt and Sodium in Soils for an explanation on saline, saline-sodic, and sodic effects on soil). Subangular to subrounded rock fragments occur in the soil profile. The abundance of rock fragments usually increases with depth. No pedon description is given for this map unit.

Soil Distribution: The percentage of sand and rock fragments in the soil generally increases upslope toward the apex of the fan and within fan channels. High salt concentration may occur anywhere within the unit.

Map Unit GTC

Topography: The landforms are moderately to steeply sloping, glaciated mountain slopes with some areas of outcropping bedrock. Slopes range from 15% to 60%. The drainage pattern is weakly dendritic to deranged. Outcrops of local bedrock make up 10% to 30% of the map unit.

Vegetation: The natural vegetation is shrubland and grassland. The major habitat types are big sagebrush/bluebunch wheatgrass, big sagebrush/Idaho fescue, and bluebunch wheatgrass/Sandberg bluegrass. Vegetative cover varies from 30% to 60%. Sandy soils tend to have an bluebunch wheatgrass/Sandberg bluegrass habitat type, while loamier soils support big sagebrush/Idaho fescue or big sagebrush/bluebunch wheatgrass.

Parent Material (geology): The unit is a combination of glacial till, weathering bedrock, and colluvium. The bedrock is primarily Cretaceous sandstone and hard units of Tertiary volcanics.

Soil Description: Rock fragments make up 20% to 40% of the soil surface. The soils are somewhat excessively drained with medium to moderately coarse textures and light and dark colored surface layers. Soil color reflects weathered bedrock color. The surface textures are loams and sandy loams. Soil fertility is moderate. Free calcium carbonate may occur throughout the soil profile. Rock fragments, angular to rounded, vary from 5% to 40% within the profile. Pedon 130 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: Soils in deeper till grade into the GTM map unit. As soils become shallower (closer to bedrock), the percentage of sand and angular rock fragments increases. Soils on steep slopes are a mixture of till and residuum.

Map Unit GTF

Topography: The landforms are steep to moderately sloping glaciated mountain ridge tops and slopes. Slopes vary from 20% to 65%. Drainage patterns are weakly parallel to dendritic. Outcrops of bedrock do occur, but are rare within this unit.

Vegetation: The natural vegetation is grassland and shrubland. The major habitat types are bluebunch wheatgrass/Sandberg bluegrass and big sagebrush/Idaho fescue. Vegetative cover varies from 50% to 70%. The bluebunch wheatgrass/Sandberg bluegrass habitat type occurs on more clayey soils and southerly slopes, while the more loamy soils and northerly slopes support big sagebrush/Idaho fescue habitat type

Parent Material (geology): This unit is a combination of glacial till, weathering bedrock, and colluvium. The bedrock is Cretaceous siltstone, mudstone, and bentonite.

Soil Description: Rock fragments make up 0% to 30% of the soil surface. The soils are well drained with moderately fine textures and dark colored surface layers. Soil color reflects the color of weathered bedrock. Surface textures range from loam to clay loam. Soil fertility is high. The amount of rock fragments within the profile varies. Most rock fragments are subrounded. Pedon 107 represents the deeper soils in this map unit (see Appendix D), but has more rock fragments than is typical.

Soil Distribution: The soils in deeper till grade into the soils of map unit GTM. As the soils get shallower (closer to bedrock), the clay percentage of the soil increases. North-facing slopes tend to have more loam surface textures than do south-facing slopes.

Map Unit GTM

Topography: Landforms include moderately sloping, glaciated valley side slopes and hummocky, nearly level to rolling moraines in valleys. Slopes range from 0% to 40%. Drainage patterns are weakly dendritic or deranged. There are a few rounded, subdued rock outcrops.

Vegetation: Natural vegetation is shrubland, grassland, and moist meadow with a few Douglas fir trees on some protected sites. Major habitat types are big sagebrush/bluebunch wheatgrass, big sagebrush/Idaho fescue, and bluebunch wheatgrass/Sandberg bluegrass. Vegetative cover generally varies from 30% to 75%, and up to 90% in moist meadows. The big sagebrush habitat types usually occur on the north and northeast facing slopes in surface soils with high silt and organic matter contents. The bluebunch wheatgrass/Sandberg bluegrass habitat type generally grows on southerly slopes and has a lower percent vegetative cover.

Parent Material (geology): Surficial deposits of glacial till make up most of this unit. These deposits are Pleistocene in age and are derived from a variety of rock types, including Precambrian crystalline rocks, Tertiary volcanic rocks, Mississippian limestones, travertine, and Cretaceous sedimentary rocks.

Soil Description: Rounded and subrounded cobbles, stones, and boulders make up 10% to 40% of the soil surface in most areas. Soils are well drained with moderately coarse to fine textures and dark colored surface layers. Surface soil texture is mainly loam and sandy loam, but varies from silt loam to loamy sand. Subsoil texture is most often loam. Soils in this map unit often have an accumulation of clay in the subsoil. Surface soil reaction (pH) is between 7.0 and 8.0, and is usually slightly higher with depth. Calcium carbonate is common in subsurface layers, and sometimes occurs in the surface soil. Salt and/or sodium accumulations can occur in the subsoil, usually 20 centimeters or more below the soil surface. The soils usually have high fertility. Rock fragments make up from 10% to 50% of the profile. Pedon 107 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: Surface soils on north and northeast facing slopes often have high silt and organic matter contents. Soils on southerly slopes are shallower, and have less silt and less organic matter in the surface soil then northerly slopes.

Map Unit LSI

Topography: Landforms are a hummocky, rolling, chaotic mixture of small hills, swales, and depressions. The topography is more subdued and rounded than in map unit LSP. Slopes range from 0% to 55%. Drainage patterns are dendritic, with common eroded gullies. Upper parts of landslides are marked by steep scarps and composed of large bedrock blocks, while lower parts are lobate mudflows. Rounded and subrounded glacial stones and boulders (erratics) are common on the surface.

Vegetation: Natural vegetation is shrubland and sparse grassland. There is some Douglas fir and aspen near the upper boundary. Major habitat types are big sagebrush/bluebunch wheatgrass, bluebunch wheatgrass/Sandberg bluegrass, and meadow types. Meadows occur in swales and open depressions where the surface soil is high in silt and organic matter. Vegetative cover is greater than in map unit LSP. It ranges from 15% to 45%, and up to 85% in meadows. Cover is associated with the texture of the surface layer, clayey soils having the lowest cover and medium textured soils having higher percent cover. Root density is also related to clay content. Between 15 and 30 centimeters, the lowest root densities are associated with clayey textures and the highest with sandy loam textures.

Parent Material (geology): These landslides occurred during the last glacial period. Their appearance has been modified by glacial erosion and deposition. The unstable slopes were probably the result of glacial erosion on water-lubricated bentonitic bedrock. The bentonite is overlain by volcanic breccias. Slide debris is angular dacitic and andecitic rock fragments in a bentonitic matrix, sometimes covered by a thin mantle of glacial till.

Soil Description: Local angular and subangular gravels and cobbles, with glacially derived rounded and subrounded stones and boulders, make up 30% to 60% of the soil surface. Soils are well drained with and dark to light colored surface layers. Surface textures are mainly loam and sandy loam with some areas of clay, clay loam, and silt loam. They tend to have more silt and sand than those in map unit LSP because of a mantle of till that varies in depth. Subsurface textures are clay or clay loam. The soil reaction (pH) below 12 centimeters is generally above 8.0. In most places there is an accumulation of sodium and/or salt throughout the soil profile (see Salt and Sodium in Soils for an explanation on saline, saline-sodic, and sodic effects on soil). This reduces plant productivity and increases erodibility. Soil fertility is low to moderate. Angular gravels make up 5% to 15% of the soil profile. Rock fragments generally increase in abundance with increasing depth. Pedon 118 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: In general, the surface soil on the upper portion of these landslides is deeper and has less clay than surface soils on the lower portions of the landslides. On the lower portion of the landslide; surface soils in depressions and swales have loam, silt loam, or sandy loam textures, while the surface soils on summits, shoulders, and south facing slopes have higher clay contents because they have probably lost or never had the mantle of glacial till. This distribution of surface textures results from local erosion and redeposition of the original landslide material.

Map Unit LSP

Topography: Landforms are a hummocky, rolling, chaotic mixture of small hills, swales, and depressions. Slopes range from 0% to 55%. Drainage patterns are dendritic, with common eroded gullies. Upper parts of landslides are marked by steep scarps and composed of large bedrock blocks and till, while lower parts are lobate mudflows.

Vegetation: Natural vegetation is shrubland and sparse grassland. There is some Douglas fir and aspen near the upper boundary of the landslides. Habitat types are bluebunch wheatgrass/Sandberg bluegrass, big sagebrush/bluebunch wheatgrass, big sagebrush/Idaho fescue, greasewood/western wheatgrass, and meadow types. Bluebunch wheatgrass/Sandberg bluegrass habitat type tends to occur in soils with clay loam surface textures. Big sagebrush habitat types occur in soils with loamy surface textures. Meadows occur in swales and open depressions where the surface soil is high in silt and organic matter. Greasewood/western wheatgrass habitat type occurs in closed depressions. Vegetative cover generally ranges from 10% to 60%, and up to 70% in meadows.

Parent Material (geology): These landslides occurred just after the last glacial period. The unstable slopes were probably the result of glacial erosion on water-lubricated bentonitic bedrock. The bentonite is overlain by volcanic breccias. Slide debris is angular dacitic and andesitic rock fragments in a bentonitic matrix, with some glacial till.

Soil Description: Subrounded, subangular, and angular gravels and cobbles make up 10% to 60% of the soil surface. Soils are well drained, with fine textures, and dark colored surface layers. Subsurface textures are clay or clay loam, while surface layer textures vary with landscape position. Surface textures are mainly clay loam and loam, with some areas of clay, silt loam, and sandy loam. Soil reaction (pH) in the subsoil is generally above 8.0. In many places there is an accumulation of sodium throughout the profile and salt in the subsoil (see Salt and Sodium in Soils for an explanation on saline, saline-sodic, and sodic effects on soil). This reduces plant productivity and increases erodibility. Soil fertility is low to moderate. Angular gravels make up 0% to 20% of the soil profile. Pedon 16 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: Surface soil layers on the upper portion of landslides have loam and sandy loam textures. Soils on the lower portions of the landslides; small summits, shoulders of slopes, and south facing slopes have clay or clay loam surface textures, while surface soils in footslopes and toeslopes (depressions and swales), tend to have loam, silt loam, or sandy loam textures. This distribution of surface textures is due to local erosional and depositional modification of the original landslide deposit.

Map Unit LSV

Topography: Landforms are a hummocky, rolling, chaotic mixture of scarps, stream channels, small hills, swales, and depressions. The unit is characterized by high surface variability and indications of recent movement, such as slip scars and leaning trees. Slopes range from 0% to 55%. Drainage patterns are deranged to dendritic.

Vegetation: Natural vegetation is sparse shrubland, sparse grassland, moist meadows, and some riparian and forested areas. The forested areas occur along water courses and contain aspen and Douglas fir. The major habitat types are big sagebrush/Idaho fescue and big sagebrush/bluebunch wheatgrass, with some greasewood/western wheatgrass and bluebunch wheatgrass/Sandberg bluegrass. Meadows occur in swales and at lower slope positions where soils are high in silt and organic matter. The greasewood/western wheatgrass habitat type often occurs in depressions. Vegetative cover varies from 15% to 50% in most areas, and up to 100% in meadows and along water courses.

Parent Material (geology): This unit contains recently reactivated landslides and a post-glacial landslide with high soil variability. The slide debris is mainly a bentonitic matrix with angular rock fragments of dacitic and andesitic composition. The older landslide in the western portion of the study area (labelled LSVa on Map 1) contains mostly dacitic rock fragments.

Soil Description: Rock fragments, mostly angular gravels and cobbles with some rounded boulders and stones, make up 30% to 60% of the soil surface. The soils are well to moderately well drained with dark to light colored surface layers. Surface soil textures are highly variable. They include sandy loams, clay loams, loams, and silt loams. Soil reaction (pH) varies from 7.3 to 8.0. In many places there is an accumulation of sodium throughout the profile and salt in the subsoil (see Salt and Sodium in Soils for an explanation on saline, saline-sodic, and sodic effects on soil). This reduces plant productivity and increases erodibility. Soil fertility is low to moderate. Rock fragments make up 20% to 60% of the soil profile. Pedon 16 and Pedon 116 are typical of the soils in this map unit (see Appendix D).

Soil Distribution: Soil distribution is related to landslide deposition and is highly variable.

Map Unit RSC

Topography: The landforms are steep to moderately-sloping, straight hillslopes and cliffs, often with small fans and colluvium at the base of slopes. Slopes range from 3% on summits to 70% on hillsides. Drainage patterns are strongly to weakly parallel. Rock outcrops makes up 15% to 30% of this map unit.

Vegetation: The natural vegetation is shrubland and grassland, with some scattered trees and barren areas. The major habitat types are big sagebrush/bluebunch wheatgrass and bluebunch wheatgrass/Sandberg bluegrass. Scattered common juniper and Douglas fir occur in the unit along the Gardner River. Vegetative cover varies between 0% and 50%. The distribution of habitat types is related to surface soil textures. In general, grasslands occur on loams and clay loams, while shrublands occur on sandy loams and loamy sands.

Parent Material (geology): The soils in this unit originate from weathering bedrock and colluvium. In the area on and near Mt. Everts (southern part of the study area), the bedrock is Cretaceous sandstone, with some siltstone. Near Sepulcher Mountain to the north, bedrock is primarily hard units of Tertiary volcanics.

Soil Description: Rock fragments make up 20% to 90% of the soil surface. The soils are somewhat excessively drained with medium to coarse textures. Surface layers are light colored with loam, sandy loam, or loamy sand textures. Soil reaction (pH) at the surface varies from 7.0 to 8.0. The soils are generally shallow to bedrock. Soil fertility is low. Angular rock fragments make up from 2% to 80% of the soil profile. Rock fragment abundance generally increases with increasing depth. Pedon 128 represents soils that may occur in this map unit (see Appendix D).

Soil Distribution: Depth of soil is strongly related to bedrock proximity. Soils are deepest at the bases of slopes and midway between rock outcrops.

Map Unit RSF

Topography: The landforms are steep, straight hillslopes and cliffs, often with small fans and colluvium at the base of slopes. Slopes range from 40% to 70%. Drainage patterns are strongly to weakly parallel. Rock outcrops makes up 30% of this map unit.

Vegetation: The natural vegetation is shrubland, grassland, and scattered trees. There are also some barren areas. The major habitat types are big sagebrush/bluebunch wheatgrass, bluebunch wheatgrass/Sandberg bluegrass and areas of scattered common juniper and Douglas fir. Vegetative cover varies between 0% and 50%. The distribution of vegetation is related to slope, depth to bedrock, and surface soil textures. Scattered trees are most abundant in the northern section of the unit along the Gardiner-Mammoth road.

Parent Material (geology): The soils in this unit originate from colluvium over weathering bedrock. Along the Gardiner River, bedrock is interbedded sandstones and shales. In other areas bedrock is mudstone. The influence of till-type materials (glacial till colluvially redeposited) is strongest in the northern portion of the unit along the Gardiner-Mammoth road.

Soil Description: Angular stones, cobbles, and gravels make up 25% to 60% of the soil surface. Subrounded glacial erratics are found in the northern half of the unit along the Gardiner-Mammoth road. The soils are well drained with fine to medium textures and a few areas with coarse textures. Surface layers are dark colored with loam and clay loam textures. Soil reaction (pH) is greater than 8.0 at the surface. The soils are often shallow to bedrock. Soil fertility is low in most areas, but moderate in the northern portion of the unit along the Gardiner-Mammoth road. Angular rock fragments are generally abundant within the profile. No pedon description is given for this map unit.

Soil Distribution: Depth of soil is strongly related to bedrock proximity. Soils are deepest at the bases of slopes and midway between rock outcrops. Soil texture is related to bedrock type. Soils derived from interbedded sandstone and shales have loam and sandy loam textures, while soils forming from fine-grained rock types have loam and clay loam textures.

Map Unit SCH

Topography: Landforms are stream bottom deposits, including channels, small terraces, and flood plains. Slopes range from 0% to 15%. They abut major streams and rivers.

Vegetation: Natural vegetation is shrubland and sparse forest. Englemann spruce, Douglas fir, Lodgepole pine, and aspen occur along water courses. The major habitat types are big sagebrush/Idaho fescue and big sagebrush/bluebunch wheatgrass. Vegetative cover ranges from 30% to 50%.

Parent Material (geology): The unit is composed of alluvial material deposited from various sized streams and rivers. Material includes channel-fill, bar, and over-bank deposits. Near smaller streams, rock types are mainly local with some glacial erratics concentrated within stream channels. River deposits have a high concentration of reworked glacial drift.

Soil Description: Rock fragments make up 20% to 60% of the soil surface. Soils are well drained with medium to coarse textures and dark colored surface layers. Surface soil textures are mainly loam, with some sandy loam and loamy sand. Soil reaction (pH) is generally near 8.0. Soil fertility is moderate. Rock fragments within the profile vary from 5% to 70%. Soil texture and the percentage of rock fragments often varies abruptly with depth. Pedon 115 is typical of the soils in this map unit (see Appendix D).

Soil Distribution: Rock fragments and sand in the surface layer become more abundant near channels. The mode of deposition causes soil textures and rock fragment abundance to be highly variable both laterally and with depth.

Map Unit SFL

Topography: The landform is a broad, gently sloping floodplain from a stream. The slopes range from 0% to 2%. The drainage patterns are weakly parallel or braided.

Vegetation: The natural vegetation is grassland and shrubland. The habitat types are bluebunch wheatgrass/Sandberg bluegrass and big sagebrush/bluebunch wheatgrass. The native vegetation has been disturbed and the present vegetation is 10% to 35% invading exotics. Vegetative cover varies from 30% in the grassland to 40% in shrubland. The shrubland occurs around the edge of the unit and makes up 25% of the total.

Parent Material (geology): The material is primarily flood plain deposits from streams. This material was deposited on top of or against glacial flood deposits. The boundary area of the unit is a mixture of both types of deposit.

Soil Description and Distribution: Surface rock fragments only occur where the unit grades into glacial flood deposits (FLD) or stream deposits (SCH). In those areas, gravels and cobbles occupy up to 35% of the soil surface. The soils are well drained. Surface soils are coarse textured and dark colored. The surface soil texture is very fine sandy loam. The gradational areas referred to above have coarse sandy loam textures. Soil fertility is moderate. No pedon description is given for this map unit.

Map Unit D1

Topography: This map unit contains the town of Gardiner, Montana. The landform is a generally flat to gently sloping river terrace. Slopes range from 0% to 10%.

Vegetation: The native vegetation was probably similar to map units FMF and FLD. The present vegetation is urban plants and invading exotics.

Parent Material (geology): Sandy, gravelly, and bouldery alluvium make up most of the unit. Mode of deposition is probably flooding of the Yellowstone River, with both in-channel and over-bank deposits.

Soil Description and Distribution: Undifferentiated

Map Unit D2

Topography: This area is mainly a flood plain with some gently rolling terrain. This unit is located in the Yellowstone River valley bottom. Slopes vary from 0% to 5%. Remains of irrigation ditches cross the surface.

Vegetation: Natural vegetation is grassland or shrubland. The native vegetation in this unit has been artificially altered by irrigated agriculture. The present vegetation is mostly exotics. Vegetative cover is approximately 35%.

Parent Material (geology): The unit is composed of silty, clayey, and sandy alluvium. Irrigated agriculture has altered the top 9 centimeters with plowing, and additions of organic matter and fertilizers.

Soil Description: Surface rock fragments make up 0% to 2% of the soil surface. Soils are well drained with fine textures and dark colored surface layers. Surface soil texture is silty clay loam. The soil reaction (pH) is 8.0 at the surface, and 7.5 or slightly above in the subsurface. These soils have moderate fertility. Rock fragments in the soil make up less than 5% of the profile. Pedon 140 is typical of this map unit (see Appendix D).

Soil Distribution: The unit has been altered by irrigated agriculture. The plow layer (top 9 centimeters) has had the most additions of fertilizer and organic matter. Plowing may also have compacted the soil below 9 centimeters. The mode of deposition has resulted in textural variations with depth. These different layers are affected differently by the irrigation process and result in various vegetation patterns.

Map Unit D3

Topography: This area is flat, or gently sloping, abandoned building sites.

Vegetation: Barren areas and sparse grassland with a high percentage of exotic species are common.

Parent Material (geology): Mainly the same as map unit GTM, with one small area similar to LSP.

Soil Description and Distribution: Rock fragments make up greater than 35% of the soil surface. Soils are moderately coarse textured, shallow, and underlain by asphalt or rock foundations. Subsoil is exposed. For more soil information, see map unit GTM (or map unit LSP for the southern area).

Map Unit D4

Topography: This unit contains berms and excavations from abandoned irrigation ditches. Side-slopes are 0% to 30%, though ditches are on contours. Berms can be up to 8 feet high with ditches up to 10 feet deep on steep slopes (greater than 45%).

Vegetation: Barren areas alternate with grassland and shrubland. Exotic species are common.

Parent Material (geology): The irrigation ditches pass through map units FOW, FMC, FMF, FST, RSC, and SCH. Locate the specific area of interest on Map 1 or Map 2, then see the appropriate map unit for a description of parent material.

Soil Description and Distribution: Soils are medium to moderately coarse textured depending on location of ditch. Subsoils are exposed, with topsoil piled in berm. Soils have many rock fragments. More detailed soil information is given with map units SCH, FMC, FMF, FST, RSC, and FOW (see explanation in Parent Material section above).

Map Unit D5

Topography: The area is flat or gently sloping (excavations for borrow pits and foundations).

Vegetation: Vegetation is sparse grassland and shrubland with exotic species common. Barren areas occur within the map unit.

Parent Material (geology): See map unit FMF.

Soil Description and Distribution: Soils are moderately coarse textured with many rock fragments. Subsoils are exposed.

Map Unit D6

Topography: The area contains trenches once used as rifle range target areas, structures remaining behind the trenches, and large berms, up to 3 m in height.

Vegetation: Vegetation is sparse grassland or shrubland with exotic species common. Barren areas occur within the map unit.

Parent Material (geology): See map unit FMF.

Soil Description and Distribution: Soils are moderately coarse textured with some rock fragments. Subsoils are exposed. For more soil information, see map unit FMF.

Map Unit D7

Topography: Landforms are a mixture of benches, terraces, and hills. Slopes vary from 0% to 40%. Part of this area is an abandoned landfill. Trash, concrete slabs, asphalt, and other refuse are common in the area. A section of the area has been recontoured.

Vegetation: Vegetation is grassland and shrubland, sparse in places. Exotic species are common.

Parent Material (geology): See map units LSP and FST.

Soil Description and Distribution: Some soils are salt and sodium affected. For more soil information, see map units LSP and FST.

Map Unit D8

Topography: The unit contains abandoned road grades.

Vegetation: Vegetation cover is variable, depending on the severity of cuts and fills, and age of abandonment. The variability does not match that of the surrounding, undisturbed areas. Species are a mixture of natives and exotics.

Parent Material (geology): The abandoned road grades pass through map units LSI, LSP, RSC, and SCH. Locate the specific area of interest on Map 1 or Map 2, then see the appropriate map unit for a description of parent material.

Soil Description and Distribution: Soils are generally moderately coarse to medium textured with many rock fragments. Subsoils to subsurface layers are exposed, depending on road and slope gradients. Some areas are compacted. More detailed soil information is given with map units LSI, LSP, RSC, and SCH (see explanation in Parent Material section above).

Map Unit D9

Topography: The map unit contains an earth-fill dam for the abandoned Ice Lake reservoir.

Vegetation: Vegetation is grassland and sparse shrubland, with a combination of native and exotic species.

Parent Material (geology): See map unit LSI.

Soil Description and Distribution: Soils are moderately coarse to medium textured with many rock fragments. The dam is mainly composed of substratum material.

Map Unit D10

Topography: The area is gently sloping and contains abandoned irrigated fields and the settlement of Stevens Creek.

Vegetation: Vegetation is a mixture of native and exotic species.

Parent Material (geology): The map unit has been influenced by a variety of depositional events. Locate the specific area of interest on Map 1 then look up the adjacent map unit (FMC, GTM, SCH, or SFL) for a description of parent material.

Soil Description and Distribution: Soils are variable, but probably have been either plowed or compacted. More detailed soil information is given with map units FMC, GTM, SCH, and SFL (see explanation in Parent Material section above).

Map Unit D11

Topography: This unit contains an abandoned railroad grade. The grade has either been built up into a berm or cut into the hillside.

Vegetation: The vegetation is sparse grassland with barren areas.

Parent Material (geology): The abandoned railroad grade passes through map units D2, D16, FGT, FLD, LSP, and SCH. Locate the specific area of interest on Map 1 or Map 2, then see the appropriate map unit for a description of parent material.

Soil Description and Distribution: Soils on the track bed and part-way down berm sides are human-made. Soil materials are clinker, ashes, and cinders. Soils are coarse textured with many small rock fragments. Subsoils and substrata are exposed on cuts. More detailed soil information of undisturbed units in the area is given with map units LSI, LSP, RSC, and SCH (see explanation in Parent Material section above).

Map Unit D12

Topography: This area contains abandoned gravel pits.

Vegetation: The vegetation is sparse grassland with some barren areas.

Parent Material (geology): See map unit FLD.

Soil Description and Distribution: Soils are coarse textured, with many rock fragments. Subsoils or compacted substratum is exposed. For more soil information see map unit FLD.

Map Unit D13

Topography: The area is flat to gently sloping, and contains remnants of building sites or parking areas.

Vegetation: Vegetation is sparse grassland with exotic species common. The unit contains some barren areas.

Parent Material (geology): See map unit FLD.

Soil Description and Distribution: Soils are moderately coarse textured with many rock fragments. They are shallow and underlain at 5 to 10 centimeters by asphalt paving or foundations. For more soil information see map unit FLD.

Map Unit D14

Topography: This unit is an abandoned coal mine. Structures have been removed, and slopes have been somewhat recontoured. A waste rock pile and some timbers remain in the area.

Vegetation: The vegetation has been covered or removed and barren areas remain.

Parent Material (geology): See map unit RSF.

Soil Description and Distribution: Soils are fragmental. Rock fragments make up 90% of the soil profile. For more soil information see map unit RSF.

Map Unit D15

Topography: The landforms are alluvial fans with slopes ranging from 5% to 15%. The areas have been impacted by trampling and contain small ditches, refuse, stone foundations, and remnants of road grades.

Vegetation: The vegetation is primarily exotic species with some greasewood. There are some barren areas in the unit.

Parent Material (geology): See map unit FST.

Soil Description and Distribution: The soils are similar to those in map unit FST, but have been compacted.

Map Unit D16

Topography: The landform is mainly a flood plain with some gently rolling terrain. This unit is located in the Yellowstone River valley bottom. Slopes vary from 0% to 5%. Remains of irrigation ditches cross the surface.

Vegetation: Natural vegetation is grassland or shrubland. The native vegetation in this unit has been artificially altered by irrigated agriculture. The present vegetation is mainly exotic species. Vegetative cover is approximately 35%.

Parent Material (geology): The unit is composed of silty and sandy alluvium. Irrigated agriculture has altered the top 9 centimeters with additions of organic matter and fertilizers.

Soil Description: Surface rock fragments make up 0% to 2% of the soil surface. Soils are well drained with medium textures and dark colored surface layers. The surface texture is loam. The soil reaction pH is 8.1 at the surface, and varies between 8.3 and 7.6 in the subsurface. These soils have moderate fertility. Rock fragments in the soil make up less than 5% of the profile. Pedon 141 is typical of this map unit (see Appendix D).

Soil Distribution: The unit has been heavily impacted and altered by irrigated agriculture. The plow layer (top 9 centimeters) has had the most additions of fertilizer and organic matter. Plowing may also have compacted the soil below 9 centimeters. The mode of deposition has resulted in textural variations with depth. These different layers are affected differently by the irrigation process and result in various vegetation patterns.

Map Unit Extent

Table 1 contains a list of map units, areal extent, and relative proportions in the survey area. Symbols refer to the delineations on map sheets 1, 2, and 3.

Table 1. Areal extent of map units in the survey area.

Map Unit	Acres	Hectares	% of total
FGT	130	53	1.3
FLD	291	118	2.9
FMC	492	199	4.9
FME	209	85	2.1
FMF	526	213	5.2

Map Unit	Acres	Hectares	% of total
FOW	99	40	1.0
FST	137	55	1.4
GTC	883	357	8.8
GTF	196	79	1.9
GTM	2126	860	21.1
LSI	1250	506	12.4
LSP	1132	458	11.2
LSV	509	206	5.1
RSC	712	288	7.1
RSF	139	56	1.4
SCH	631	255	6.3
SFL	79	32	0.8
D01	86	35	0.9
D02	89	36	0.9
D03	10	4	0.1
D04	51	20	0.5
D05	7	3	0.1
D06	1	1	0.1
D07	12	5	0.1
D08	28	11	0.3
D09	1	1	0.1
D10	35	14	0.3
D11	70	28	0.7
D12	3	1	0.1
D13	2	1	0.1
D14	3	1	0.1

Map Unit	Acres	Hectares	% of total
D15	10	4	0.1
D16	99	40	1.0
Totals	10,048.00	4,065.00	100.4

Management Interpretations

Management interpretations are designed to provide predictions of soil behavior for various uses. They provide resource planners with information to develop projects. They guide scientists in selecting appropriate and applicable study sites. They can be used to focus management plans on the most appropriate uses for the area. Soil productivity, site productivity, and erosion are important interpretations that are described below. Because salt and sodium status is related to these interpretations, it is discussed first.

Salt and Sodium in Soils

Some soils in the survey area are affected by sodium salts. This occurs because of salts inherited from parent materials, the dry climate, and the high clay content in some areas. Areas affected by sodium are noted in the map unit descriptions.

Second to the dry climate, the most important factor limiting plant growth is the sodium and salt status of the soils (Sposito, 1989, Szabolcs, 1989). In arid and semi-arid regions, when evaporation exceeds water input, salts affect surface soils. When this happens soils are classified in one of three ways: saline, saline-sodic, and sodic.

Saline soils contain concentrations of neutral soluble salts that interfere with the growth of most plants. These soils have an electrical conductivity greater than 4 millimhos per centimeter and pH is usually less than 8.5. Saline soils can have a light colored surface crust that can impede plant seedling emergence and reduce infiltration. They do not contain appreciable amounts of exchangeable sodium.

Sodic soils contain large amounts of exchangeable sodium and hydroxyl ions (OH^-) without neutral soluble salts. Exchangeable sodium is sodium held on the soil colloids. Sodium concentration is high enough to be "toxic" to plants. These soils have an electrical conductivity less than 4 millimhos per centimeter and usually a pH greater than 8.5, as well as an exchangeable sodium percentage (ESP) greater than 15.

Saline-sodic soils contain appreciable amounts of neutral soluble salts and enough exchangeable sodium to seriously affect most plants. Saline-sodic soils have pH less than

8.5 and electrical conductivity greater than 4 millimhos per centimeter. In both saline-sodic and sodic soils the high concentration of sodium ions can disperse or deflocculate the mineral soil particles. This leads to an unsatisfactory soil physical condition. It can lead to a soil crust that is relatively impermeable to water. In addition, sodic soils may have a discolored surface caused by dispersed soil organic material (humus). Where this occurs, they are called black alkali soils.

Certain plant species are more tolerant of saline and sodic conditions than others. As conditions become unfavorable, more kinds of plants are affected, leading to reduced plant vigor, lower plant cover, and eventually, to species limitations in the affected area. Saline and saline-sodic soils have a detrimental effect on plants due to their high soluble salt concentration. This salt concentration affects the osmotic movement of water from the plant cell towards the more concentrated soil solution causing loss of water, cell collapse and eventually, death.

Sodic soils, dominated by sodium ions, affect a plant in three ways: 1) caustic influence of the high alkalinity (pH) induced by sodium carbonate and bicarbonates, 2) toxicity of the bicarbonate and other anions, and 3) the adverse effects of the sodium ions on plant metabolism and nutrition.

The capacity of higher plants to grow satisfactorily on saline or sodic soils depends on a number of interrelated factors. The physiological constitution of the plant, its stage of growth, and its rooting habits are some of the factors. The nature of the various salts, their proportionate amounts, their total concentration, and their distribution in the soil must be considered. Soil texture, structure, drainage, and aeration are also important.

Criteria for Map Unit Interpretations

Soil Productivity: Soil productivity is a component of site productivity. Ratings are relative and are based on soil texture, rock fragment content in the soil, rock fragments on the soil surface, fertility (as indicated by presence of calcium carbonate), and sodium status in the soil.

"High" soil productivity means there are no soil limitations to plant growth. Soils with "high" ratings generally have medium textures, few rock fragments, high fertility, and are on moderate slopes. "Moderate" soil productivity means there are no severe limitations to plant growth, but there are more rock fragments, and lower water holding capacity (less clay) than from soils rated "high". "Low" soil productivity means there are significant limitations to plant growth, such as high sodium status, or large numbers of rock fragments.

Soil productivity ratings for map units are based on the criteria in Table 2, with some exceptions. Soils having moderate levels of salt (as evidenced by high pH) are rated as moderate. Significant disturbance to the soils, such as high compaction levels, removal of surface soil, or covering with asphalt rate a "low" soil productivity. Irrigation in some disturbed fields may have raised salt levels above natural conditions.

Table 2. Criteria for rating soil productivity

Soil Productivity Rating	Soil Texture	% Rock Fragments (surface/subsurface)	Soil Fertility	Sodium or Salt	Landform
high	medium(silty)	<20 / <20	high	low	swales
moderate	mod. coarse, medium(loam)	>20 / <50	moderate	low	rolling
low	mod. fine, fine	>50 / >50	low to moderate	high	any

Site Productivity: Site productivity is a measure of potential productivity expected on a site in terms of plant growth. Ratings are based on soil productivity, habitat types, erosion potential, and plant cover.

"High" site productivity means that average long term annual production is the highest in the survey area. "Moderate" and "low" site productivity indicate relative intermediate and low long-term production, respectively. See Table 3 for rating criteria. A range of production is given for each rating, based on limited data from southwestern Montana (Appendix B), with no available data in the Survey Area tied to sample locations. These values are not meant to be site specific. Because "native" plant communities are absent, "D" or disturbed map units are not rated for site productivity.

Table 3. Criteria for rating site productivity

Site Productivity Rating (lbs/ac)*	Soil Productivity	Common Habitat Type	Erosion Potential	Average Cover (%)
high (1542-2480)	high	ARTR/FEID or FEID/AGSP	low	>50
moderate (560-1541)	moderate to low	ARTR/FEID or FEID/AGSP	low	>50
low** (240-559)	low	AGSP/POSA or SAVE/AGSM or	high to moderate	<20

		others		

* range of values is in air dried annual production
** ARTR/AGSP always rated as having low productivity

Erosion Potential: Erosion potential is a relative measure of the soil's tendency to erode under grazing pressure, wind, and water. Factors used in rating are slope steepness, plant cover, soil texture, sodium status, and number of rock fragments on the surface. An exception is Map Unit D11, which is rated "low" in spite of steep slopes. The soils in the railroad grade are very permeable and not likely to produce runoff. See Table 4 for rating criteria. These are used with map unit descriptions to rate each map unit.

"High" erosion potential is defined as having significant sediment produced from a major site in the short term (1-10 year frequency), either by snowmelt, significant summer events, or hydraulic action within or near streams. An example is the SCH map unit which is located next to active stream and river channels. "High" sites have active rills, gullies, landslides, or evidence of sheet erosion. Vegetation is absent or sparse and is affected by erosion processes. The coarse fraction of soil is less than 20% of total soil volume. There is no significant erosion pavement, nor other armoring by gravel or larger materials. Material commonly reaches perennial streams the same year as eroded.

"Moderate" erosion potential refers to areas that have noticeable erosional features, but the proportion of the site actively eroding is low, or erosion occurs only during extreme precipitation events. There may be no perennial stream impact under most conditions because of sediment trapping areas on the eroding slope. The eroded material eventually moves off-site, but not as quickly as in the "high" category.

"Low" erosion potential refers to cases where no evidence of active erosion is present. There may be relict forms of past erosional processes, such as post glacial channels or scarps.

Table 4. Criteria for rating erosion potential

Erosion Rating	Slope* (%)	Cover (%)	Soil Texture	Sodium or Salt	% Rock Fragments
high	>45	<15	mod. fine, fine	any	<20
moderate	45>...>10	50>...>15	any	yes	50>...>10
low	<10	any	any	any	>50

* When parent material is glacial till, slope category is not used unless texture is moderately fine. In this case erosion rating is "moderate".

Map Unit Interpretations

Map units are rated in Table 5. These are based on the criteria given above and map unit descriptions, and are modified as necessary by field experience.

Table 5. Management interpretations for each map unit

Map Unit	Soil Productivity	Site Productivity	Erosion Potential	Comments
FGT	moderate	low to moderate	low	unit near Gardiner has compacted layers and exotic species
FLD	low	low	low	large number of rock fragments
FMC	moderate	moderate	low	
FME	low to moderate	low	high	salt and/or sodium can occur; entrenched erosive stream channels
FMF	moderate to high	low to moderate	low	units near Gardiner have irrigation channels, some foundations, and evidence of plowing
FOW	low to moderate	low	low	large number of rock fragments can occur
FST	low to moderate	low	moderate	unit near Gardiner has some evidence of use as stockyard, with many exotic species; salt can occur in root zone
GTC	low to moderate	low to moderate	low	
GTF	moderate	moderate	moderate	
GTM	moderate	moderate	low	
LSI	low	low	moderate	salt and/or sodium can occur in root zone
LSP	low	low	high	salt and/or sodium in root zone
LSV	low to moderate	low to moderate	moderate to high	salt and/or sodium can occur in root zone; LSVa has low productivity
RSC	low	low	moderate	many rock fragments
RSF	low	low	moderate	many rock fragments

Map Unit	Soil Productivity	Site Productivity	Erosion Potential	Comments
			to high	
SCH	moderate	moderate	low to high	active stream and river channels; high erosion only near active streams
SFL	moderate	low	low	many exotics in part of unit; probably grazed or plowed
D01	low		low	actively used site
D02	moderate		low	highly disturbed
D03	low		low	highly disturbed
D04	low		high to moderate	highly disturbed
D05	low		low	highly disturbed
D06	low		low	highly disturbed
D07	low		moderate	highly disturbed
D08	low to moderate		low	highly disturbed
D09	low		low	highly disturbed
D10	moderate		low	highly disturbed
D11	low		low	highly disturbed
D12	low		low to moderate	highly disturbed
D13	low		low	highly disturbed
D14	low		low	highly disturbed
D15	low		low	highly disturbed; soil productivity "moderate" in un-disturbed parts
D16	moderate		low	highly disturbed

Restoration Recommendations

Following are precautions and suggestions to consider when planning the restoration of an area to natural conditions. They are interpretations of soil characteristics. All recommendations are based on restoring the soil ecology of a site to as near a pre-disturbance condition as possible. This is a long-term process, and it will be years before the site approaches natural vegetative cover. However, once the previous systems are restored, the process is largely self maintaining.

The pre-disturbance condition is difficult to define. It is inferred from observations of less disturbed soils in the area and from experience with relatively undisturbed soils in the Rocky Mountains. Soil and site data are used to indicate which areas have been affected by plowing, construction, compaction, topsoil removal, human-caused erosion, recontouring, or the presence of altered plant communities.

All map units prefaced with "D" are highly disturbed (Table 1 and Map Unit Descriptions). The dominant kinds of disturbance are described. In some units, most of the original soil profile has been destroyed. Slopes have unnatural contours and the remaining soil is highly compacted. Foreign materials such as asphalt, concrete, stone rows, clinker, or gravel are present in other areas. Ditches and berms have been built. Some areas were used as townsites, corrals, stockyards, roads, or irrigated fields These commonly have unusual vegetation and compacted soils. On the maps, units suffixed by "*" are disturbed in some places.

Reconstructing natural-appearing landscapes (and an appropriate seed bed for revegetation) will involve some, or all of the following practices:

* Removal of all foreign materials
* Recontouring to natural land profile (including irrigation ditches)
* Reduction of compaction levels
* Reconstruction of the soil profile
* Smoothing and seedbed preparation
* Native seed collection by habitat type
* Propagation of seed and reseeding, with sterile mulch on sites of low productivity
* Some areas require eradication of noxious weeds or exotic species.

The map unit descriptions given above can be used to develop restoration plans for each disturbed site. However, field investigations are needed to complete the planning effort and for site-specific research studies.

Discussion and Conclusions

This investigation was completed to describe and help understand the ecosystems of the area, as well as to provide practical assistance in planning for its future. Whether used for site restoration, predicting erosion, assessment of wildlife impacts, or winter range suitability, it gives valuable insight for interpreting the area's baseline conditions, the characteristics of its landscapes, and their effects on its present (and future) appearance.

For example, there has been discussion on the impact of wildlife usage in this area. Suggested impacts are high erosion, low plant cover, and the increase in introduced or "exotic" species. There are, however, some inherent landscape properties and historical events that also affect erosion potential, soil conditions, and vegetation.

About 33 percent of the project area has clayey, salt affected soils(Table 1, Table 5, and Map Unit Descriptions). These soils are poor plant growth media, with low water holding capacity, high root resistance, poor aeration, and possible sodium toxicity (Appendix D, Table D1, and Table D2). They have many surficial rock fragments, further reducing productivity (Map Unit Descriptions).

All of the area has "low" or "moderate" long term site productivity (Table 5). Small areas (too small to separate at this scale of investigation) have "high" productivity, e. g. swales with silty soils in map unit GTM (Map Unit Descriptions). Those areas make up only a small part of the entire survey area. Site productivity is also highly correlated to soil productivity and habitat type (Table 3, Table 5). These parameters are relatively unaffected by animal impacts.

About six percent of the area has been highly disturbed in the past (Table 1, Map Unit Descriptions). Most of this disturbance is in highly visible areas (Map Sheets). These areas look "unnatural" because of low vegetative cover, debris, foundations, or soil disturbance. This disturbance has significantly altered soil properties, which in turn affects vegetation composition and productivity. Historical records indicate a large part of the area was heavily grazed by cattle in the early part of this century. The effects of this wide spread disturbance undoubtedly are still present.

Almost one-half of the survey area has "moderate" or "high" erosion potential, with 23 percent "moderate", and 26 percent "high" (Table 1, Table 5). A significant part of the area is unstable compared to surrounding landscapes. It is geologically young (Appendix C) and is still adjusting to current environmental conditions. Though causative factors were not separated in this study, it is probable that steep slopes, high clay content, salt concentration, and other inherent properties of the landscape are primarily responsible for the erosion potential.

The survey area is used for winter range by pronghorn antelope, elk, bighorn sheep, mule deer, and bison. This use has undoubtedly contributed to average vegetative coverage, vegetative species dominance, and erosion status. However, its importance is confounded by inherent ecosystem properties and past disturbance described above. The ecosystems in the survey area are combinations of parameters: landforms (unstable landslides, steep slopes, erodible mudstones), soils (salt and clay concentration, large numbers of rock fragments), and vegetation (salt tolerant, or otherwise unproductive habitat types with inherently low cover; exotic or introduced species) all influenced by the relatively dry climate. These factors (and past disturbance) significantly influence soil productivity, site productivity, and erosion potential. Given the character of these environmental variables, the effects of present wildlife use are not likely to be the most important control on the long-term appearance and productivity of the survey area.

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Appendix A: Classification of the Soils

Classification of Soils

The system of soil classification used by the National Cooperative Soil Survey (NCSS) has six categories (Soil Survey Staff, 1975). Beginning with the broadest, these categories are order, suborder, great group, subgroup, family, and series. Classification is based on soil properties observed in the field or inferred from those observations, or from laboratory measurements. The soils of the Survey Area are classified according to the system. The taxonomic categories are defined in the following paragraphs.

Order
Ten soil orders are recognized. The differences among orders reflect the dominant soil-forming processes and the degree of soil formation. Each order is identified by a word ending in "sol". An example is Entisol.

Suborder
Each order is divided into suborders primarily on the basis of properties that influence soil genesis and are important to plant growth, or properties that reflect the most important variable within the soil order. An example is Aquent "aqu", meaning water, plus "ent", from Entisol.

Great Group
Each suborder is divided into great groups on the basis of close similarities in kind, arrangement, and degree of development of pedogenic horizons; soil moisture and temperature regimes; and base status. Each great group is identified by the name of a suborder and by a prefix that indicates a property of the soil. An example is Haplaquents ("Hapl" meaning minimal horizonation, plus "Aquent" the suborder of the Entisols that have an aquic moisture regime).

Subgroup
Each great group has a typic subgroup. Other subgroups are intergrades or extragrades. The typic is the central concept of the great group; it is not necessarily the most extensive. Intergrades are transitions to other orders, suborders, or great groups. Extragrades have some properties that are not representative of the great group but do not indicate transitions to any other known kind of soil. Each subgroup is identified by one or more adjectives preceding the name of the great group. The adjective "Typic" identifies the subgroup that typifies the great group. An example is Typic Haplaquent.

Family

Families are established within a subgroup on the basis of physical and chemical properties that effect management. The properties are mostly those of horizons where there is much biological activity below plow depth (about 20 cm). Among the properties considered are particle-size class, mineral content, temperature regime, depth of root zone, consistence, moisture equivalent, slope and presence of permanent cracks. A family name consists of the name of a subgroup and a series of adjectives. The adjectives are the class names for the properties used as family differentia. An example is Typic Haplaquents, fine loamy, mixed, mesic.

Series
This level was not used in this survey.

Soils identified during the course of this survey have been classified in the NCSS Soil Taxonomy. The soils are named using the nomenclature in this taxonomy.

See Appendix D for classification of typical pedons. Several assumptions are made in classifying the soils of this area because criteria for classification sometimes requires laboratory data not available when classification decisions are made. This is particularly true of classes dependent on temperature, moisture, and chemical data. See Tables D1 and D2 (in Appendix D) for representative physical and chemical data.

Most soils in Yellowstone National Park are in either cryic or frigid temperature regimes. The boundary between these two classes is considered to be the lower subalpine fir climax forest boundary or equivalent elevation-aspect combination. Little data is available for specific local definition, but the data for much of the Northern Rocky Mountains suggests this is a close approximation. Since the survey area is at a lower elevation than the rest of the Park, and the dominant vegetation is not subalpine fir, the frigid temperature regime was used in classifying the soils found in this area.

Soil moisture regimes occurring in and around Yellowstone National Park are aridic, udic, ustic and xeric. Aridic soils are those that are hot and dry. A udic moisture regime implies that the soil is not dry in any part for as long as 90 days cumulative. An ustic moisture regime is intermediate between the aridic and udic regime. The concept is one of limited moisture but moisture is present at a time when conditions are suitable for plant growth. The ustic moisture regime is not applied to soils that have cryic or pergelic temperature regimes. Xeric moisture regimes occur where winters are moist and cool and summers are warm and dry.

Soils in Yellowstone National Park are probably in either udic or ustic moisture regimes. Due to the low elevation and low annual precipitation, soils in the survey area are assumed to fall in the ustic moisture regime. Aridic moisture regimes occur at lower elevations surrounding the survey area. These soils probably do occur as inclusions on some dryer slopes in the survey area. The xeric moisture regime occurs west of the survey area where the Pacific maritime influence is more pronounced.

Descriptions do not include soil pores, because they were not described in the field. Clay films were not always described in the field except where easily identified. Poorly expressed clay films may have been masked by carbonates, and other salts. Also, conditions during the field season of 1988 were very dry, and the air very smokey due to the wildfires of that year.

A few soils of the survey area have special classification aspects. Some of the geologic parent materials contain large amounts of sodium (Na^+). Because sodium is present throughout soil profiles, and due to the limits placed on classification by Soil Taxonomy (Soil Survey Staff, 1975), a special class was added at the family level. This "sodic" class was used for those soils that did not meet the criteria for a natric horizon, yet were determined to have sodium in amounts that may be detrimental to plant growth and soil physical condition. This designation does not occur in the hierarchy presented by Soil Taxonomy but was established here to provide the information that these soils have high sodium levels without an argillic horizon.

Appendix B: Major Habitat Types and Productivity

Habitat types represent potential plant communities on a site. Those below are from tentative habitat types developed by Don Despain (unpublished data) in Yellowstone National Park.

Habitat type data from Table B1 is used with soils and site data to estimate site productivity. The Gallatin National Forest lies directly north of the survey area. The Mueggler and Stewart (1980) western Montana data is used with data from the Gallatin National Forest to estimate potential yearly productivity.

Table B1. Forage production range by habitat type

Habitat Type	Mueggler and Stuart** (lb/ac/yr a.d.h.)	Gallatin N. F.* (lb/ac/yr a.d.h.)	Composite Range (lb/ac/yr a.d.h.)
ARTR/FEID	769-1,443	560-2,480	560-2,480
FEID/AGSP	655-1,293	625-2,460	625-2,460
ARTR/AGSP	740-860	not available	740-860
AGSP/POSA	300-500	240-850	240-850
SAVE/AGSM	low	not available	low

** Mueggler and Stuart, 1980
* Davis, C. E. and H. F. Shovic, 1984. Shovic, H.,unpublished files

The following is a list of common names of all important plant species in the above mentioned habitat types:

Agropyron canium - Bearded wheatgrass
Agropyron smithii - Western wheatgrass
Agropyron spicatum - Bluebunch wheatgrass
Artemisia frigida - Fringed sagewort
Artemisia tridentata - Big sagebrush
Bouteloua gracilus - Blue grama
Carex spp. - Sedge
Chrysothamnus spp. - Rabbitbrush
Geranium viscosissimum - Sticky geranium
Poa sanbergii - Sandberg's bluegrass
Potentilla gracilus - Cinquefoil

Sarcobatus vermiculatus -	Black greasewood
Stipa comata -	Needle and thread
Stipa occidentalis -	Western needlegrass

AGSP/POSA - *Agropyron spicatum/ Poa sandbergii* habitat type

A grassland habitat dominated by *Agropyron spicatum*; *Poa sandbergii* and *Koeleria cristata* are present but of lesser importance. *Stipa comata* is abundant in some areas. A wide variety of forbs may comprise up to 40% of the canopy cover. Low and medium shrubs may be present.

On good condition range in western Montana, the vegetative production estimate for the AGSP\POSA habitat type is between 300 to 500 lb/ac/yr air dry herbage (a.d.h.). Approximately 70% to 80% of this will consist of grasses that are good to excellent in palatability. The data from the Gallatin National Forest indicates production of 240 to 850 lb/ac/yr a.d.h. for this habitat type.

ARTR/AGSP - *Artemisia tridentata/ Agropyron spicatum* habitat type

Artemisia tridentata is the dominant shrub with some low shrubs (*Artemisia frigida*) usually present. The grasses are dominated by *Agropyron spicatum*; other species usually present are *Koeleria cristata*, *Poa sandbergii, Stipa comata*, and *Bouteloua gracilis*. Forbs may be present, but usually aren't abundant.

In western Montana, this habitat type averages between 704 to 860 lb/ac/yr a.d.h. with considerable variation between sites and between years. Approximately 40% to 50% of this production was perennial grasses, mainly *Agropyron spicatum*.

ARTR/FEID - *Artemisia tridentata/ Festuca idahoensis* habitat type

Artemisia tridentata is the dominant shrub and *Festuca idahoensis* is the dominant grass understory. *Agropyron spicatum* and *Koeleria cristata* are usually present and forbs may be abundant. The drier portions of this habitat type may contain shrubs such as *Artemisia frigida* and *Chrysothamnus spp.*. The wetter portions contain a wide variety of graminoids (*Agropyron canium, Stipa occidentalis*, and *Carex spp.*) and an abundance of forbs (*Geranium viscosissimum* and *Potentilla gracilis*).

In western Montana, this habitat type produces more than the ARTR/AGSP habitat type. The amount of production between sites has a wide range. The wetter sites can produce twice as much air dry vegetation as the drier sites while all sites averaged between 769 to 1,443 lb/ac/yr a.d.h.. The graminoids made up 20% to 40% of the total biomass and contained mostly palatable grasses. The Gallatin N.F. found that the ARTR/FEID habitat type produced between 560 to 2,480 lb/ac/yr a.d.h.

FEID/AGSP - *Festuca idahoensis/ Agropyron spicatum* habitat type

Festuca idahoensis and *Agropyron spicatum* are the dominant grass types. Other graminoids usually present are *Koeleria cristata, Poa sandbergii*, and either *Stipa comata* or *Stipa occidentalis*. The number of forbs is highly variable and medium shrubs may be present.

Average vegetative production varies between 655 to 1293 lb/ac/yr a.d.h. with graminoids making up between 35% to 75%. North facing slopes tend to produce the most vegetation. The Gallatin National Forest found that this habitat type produced between 625 to 2460 lb/ac/yr/a.d.h.. *Festuca idahoensis* and *Agropyron spicatum* tend to produce the most forage, making up 30% to 60% of the total.

SAVE/AGSM - *Sarcobatus vermiculatus/ Agropyron smithii* habitat type

Sarcobatus vermiculatus is the dominant shrub while *Agropyron smithii* is the dominant understory species. *Bouteloua gracilis, Stipa comata*, and *Artemisia frigida* may also be present. This series contains fewer plant species than any other grassland or shrubland described in Montana.

For western Montana, it has been estimated that two-thirds of the vegetation in this habitat type is palatable grasses while the shrubs and forbs do not contribute very much to forage.

Appendix C: Geology of the Survey Area

The variability of soils in the study area is greatly influenced by differences in parent material (PM). Hillslopes are dominated by glacial till and weathering bedrock in the Mt. Everts area, and landslide deposits in the Sepulcher Mt. area. The bottom-lands contain a variety of materials including flood, fan, landslide, and stream deposits. This brief history of PM origin has been summarized from the works of Fraser et al. (1969) and Morrison-Maierle, Inc. (1981) on bedrock geology, Pierce (1979) on glacial history, and Waldrop and Hayden (1962) on landslide history.

During the late Precambrian through the early Cambrian, the study area was located on the eastern flank of the Cordilleran geosyncline. The area subsided during the Paleozoic and Mesozoic Eras and was covered by shallow marine water. The 400+ million years of marine deposition was broken by many short periods of uplift and erosion that created numerous unconformities in the geologic record. During the Upper Cretaceous, uplift occurred and there was a change from marine to continental sedimentation. The bedrock of the Eagle Sandstone, Everts Formation, and Landslide Creek Formation record this transition. From the late Cretaceous through the middle Tertiary there was a period of mountain building, called the Laramide Orogeny, that included intense deformation and faulting of the sedimentary rocks. The NW trending Gardiner Fault resulted in approximately 10,000 ft of displacement. Most Paleozoic and Mesozoic rocks not protected in the fault troughs were eroded from the area. The early Eocene dacitic and andecitic breccias were probably deposited at the end of the Laramide Orogeny.

Travertine has been deposited in the Mammoth area from the Pleistocene to the present. Travertine boulders are found locally in glacial till.

The glacial deposits in the area include till and fluvial material, primarily from the Pinedale glaciation. The main differences between soils formed from different tills result from initial differences in the clay and calcium carbonate content of the PM. Associated deposits include kame deposits, outwash, and flood deposits.

At least two catastrophic floods, 45m to 60m deep, occurred during Late Pinedale time. These floods are associated with fluvially transported boulders and giant ripple marks. The deposits are moderately well sorted with many boulders on the surface and an interior composed primarily of sand. The largest deposits are found in the Stephens Creek area.

Landslide debris deposited during the Quaternary Period moved down the slopes of Sepulcher Mt. towards the Yellowstone and Gardner Rivers. Moving from top to bottom, the slides are a continuum of slump blocks through mudflows. The slide debris is composed of a bentonitic matrix and rock fragments, primarily from the Landslide Creek Formation and the Eocene dacitic and andecitic breccias. The fragments in the western-most slide are primarily dacitic breccias. Landslides that occurred before the most recent glaciation have surficial glacial erratics and are less hummocky than later slides. The most recent, reactivated slides are mainly located in water courses or below impounded ponds.

Appendix D: Soil Descriptions

Introduction

These soil descriptions represent the central concept of each map unit. Refer to the map unit description for other kinds of soils present. Physical and chemical properties of the soils are given for reference (Tables D1 and D2 in Appendix D). Properties vary within map units. See Appendix A for a discussion and justification for classification of the soils.

Descriptions

SOIL DESCRIPTION 16 - Typic Ustocrept; fine, mixed, calcareous, sodic

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-22 cm) Grayish brown (2.5Y 5/2) clay, dark grayish brown (2.5Y 4/2) moist; strong coarse angular blocky structure breaking to moderate fine angular blocky structure; very hard, very friable, slightly sticky, plastic; many very fine roots; many thick clay films on ped faces; strongly alkaline (pH 8.5); slightly effervescent; clear smooth boundary.

Btn (22-43 cm) Brown (10YR 5/3) clay, dark grayish brown (2.5Y 4/2) moist; moderate medium angular blocky structure; hard, firm, slightly sticky, plastic; common fine roots; continuous thick clay films on ped faces; common to few salt concretions; moderately alkaline (pH 8.3); slightly effervescent; clear smooth boundary.

Bn (43-50 cm) Brown (10YR 5/3) silty clay, dark grayish brown (2.5Y 4/2) moist; weak medium angular blocky structure; slightly hard, very friable, slightly sticky, plastic; few very fine roots; common moderately thick clay films on ped faces; many small salt concretions; 5 percent gravel; moderately alkaline (pH 7.9); slightly effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 523850 east 4982860 north. The pedon has formed in post-glacial landslide deposits mixed with glacial till. The slope is 8%. Aspect is east. Elevation is 1750m. The habitat type is big sagebrush/bluebunch wheatgrass (ARTR/AGSP) with 30% vegetative cover.

Notes: Gravels, cobbles, and boulders make up 30% of the soil surface. Soil described by Ann Rodman and Henry Shovic on 8/2/88. This pedon has too small a clay increase in the Btn horizon to qualify for an argillic horizon. However, other pedons probably have a greater clay increase and would be classified as Alfisols.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 106 - Typic Eutroboralf; coarse-loamy, mixed

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-10 cm) Brown (10YR 4/3) gravelly sandy loam, dark grayish brown (10YR 4/2) moist; strong fine granular structure; soft, loose, nonsticky, nonplastic; many very fine and fine roots, and few medium roots; 15 percent gravel; mildly alkaline (pH 7.7); abrupt smooth boundary.

Bt (10-33 cm) Brown (10YR 5/3) gravelly sandy loam, dark grayish brown (10YR 4/2) moist; moderate medium granular structure; slightly hard, firm, slightly sticky, slightly plastic; common very fine and fine roots, and few coarse roots; 15 percent gravel; moderately alkaline (pH 7.9); abrupt wavy boundary.

Bk1 (33-51 cm) Light gray (10YR 7/2) very gravelly sandy loam, very dark grayish brown (10YR 3/2) moist; weak medium angular blocky structure; slightly hard, firm, slightly sticky, slightly plastic; common very fine and fine roots; 40 percent gravel; moderately alkaline (pH 8.2); strongly effervescent; clear wavy boundary.

Bk2 (51-90 cm) Light gray (10YR 7/2) gravelly sandy loam, dark brown (10YR 3/3) moist; moderate coarse angular blocky structure breaking to moderate medium angular blocky structure; slightly hard, very friable, slightly sticky, nonplastic; few very fine roots; 20 percent gravel; mildly alkaline (pH 7.7); strongly effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 518070 east 4988210 north. The pedon has formed in fan deposits derived from volcanic bedrock. The slope is 12 %. Aspect is east. Elevation is 1615 m. The habitat type is big sagebrush/bluebunch wheatgrass (ARTR/AGSP) with 45 % vegetative cover.

Notes: Gravels, cobbles and stones make up 9 % of the soil surface. Soil described by Ann Rodman and Liz Colvard on 7/18/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 107 - Typic Argiboroll; loamy-skeletal, mixed, calcareous

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-6 cm) Grayish brown (10YR 5/2) loam, dark brown (10YR 3/3) moist; moderate coarse granular structure; soft, very friable, slightly sticky, slightly plastic; many very fine and fine roots; 10 percent gravel; mildly alkaline (pH 7.7); abrupt smooth boundary.

Bt (6-26 cm) Brown (10YR 4/3) very bouldery sandy clay loam, dark brown (10YR 3/3) moist; moderate medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; common very fine and fine roots; few thin clay films lining pores; 40 percent boulders; mildly alkaline (pH 7.4); diffuse irregular boundary.

Bk (26-52 cm) Light grayish brown (10YR 6/2) very gravelly sandy loam, very dark grayish brown (10YR 3/2) moist; weak coarse subangular blocky structure; soft, very friable, nonsticky, nonplastic; common very fine and fine roots; 40 percent gravel; mildly alkaline (pH 7.4); strongly effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 518240 east 4988250 north. The pedon has formed in glacial till. The slope is 9 %. Aspect is northeast. Elevation is 1605 m. The habitat type is bluebunch wheatgrass/Sandberg bluegrass (AGSP/POSA) with 50 % vegetative cover.

Notes: Boulders, stones, and gravels make up 40 % of the soil surface. Soil described by Ann Rodman and Liz Colvard on 7/18/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 109 - Aridic Haploboroll; loamy-skeletal, mixed

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-17 cm) Brown (10YR 5/3) very stony loam, very dark grayish brown (10YR 3/2) moist; moderate medium subangular blocky structure; slightly hard, friable, nonsticky, nonplastic; many very fine and common fine roots; 50 percent stones and gravel; mildly alkaline (pH 7.8); diffuse irregular boundary.

Bk (17-33 cm) Light grayish brown (10YR 6/2) extremely stony sandy loam, dark brown (10YR 3/3) moist; moderate fine subangular blocky structure; soft, very friable, nonsticky, nonplastic; common very fine roots; 70 percent stones, gravel, and boulders; moderately alkaline (pH 8.3); strongly effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 518420 east 4988430 north. The pedon has formed in glacial flood deposits. The slope is 3 %. Aspect is northeast. Elevation is 1595 m. The habitat type is big sagebrush/bluebunch wheatgrass (ARTR/AGSP) with 30 % vegetative cover.

Notes: Rounded and subrounded boulders make up 60 % of the soil surface. Soil described by Ann Rodman and Liz Colvard on 7/18/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 111 - Typic Eutroboralf; fine-loamy, mixed, calcareous

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-8 cm) Light grayish brown (10YR 6/2) loam, dark grayish brown (10YR 4/2) moist; moderate medium subangular blocky structure breaking to moderate fine granular structure; soft, very friable, nonsticky, nonplastic; many very fine and fine roots, and common medium roots; moderately alkaline (pH 7.9); abrupt smooth boundary.

Bk (8-17 cm) Light gray (10YR 7/2) loam, dark grayish brown (10YR 4/2) moist; moderate medium subangular blocky structure breaking to moderate fine subangular blocky structure; soft, friable, slightly sticky, nonplastic; many very fine and fine roots; moderately alkaline (pH 8.2); strongly effervescent; abrupt smooth boundary.

Btk (17-50 cm) Light gray (10YR 7/2) loam, dark grayish brown (10YR 4/2) moist; weak coarse angular blocky structure; slightly hard, friable, sticky, slightly plastic; common very fine and fine roots, and few medium roots; moderately alkaline (pH 8.3); strongly effervescent; diffuse smooth boundary.

Bn (50-70 cm) Light gray (10YR 7/2) loam, dark grayish brown (10YR 4/2) moist; weak coarse angular blocky structure; slightly hard, very friable, slightly sticky, nonplastic; few very fine and fine roots; mildly alkaline (pH 7.8); strongly effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 524570 east 4983030 north. The pedon has formed in fan deposits derived from sedimentary bedrock. The slope is 2 %. Aspect is southwest. Elevation is 1800 m. The habitat type is bluebunch wheatgrass/Sandberg bluegrass (AGSP/POSA) with 60 % vegetative cover.

Notes: Rock fragments make up 1 % of the soil surface. Soil described by Ann Rodman and Liz Colvard on 7/19/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 115 - Typic Ustochrept; loamy-skeletal, mixed

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-21 cm) Light yellowish brown (10YR 6/4) loam, very dark grayish brown (10YR 3/2) moist; moderate coarse subangular blocky structure breaking to moderate medium granular structure; soft, very friable, slightly sticky, slightly plastic; common very fine and fine roots; 5 percent gravel; moderately alkaline (pH 8.0); clear smooth boundary.

Bw1 (21-32 cm) Very pale brown (10YR 7/4) loam, dark brown (10YR 3/3) moist; moderate coarse subangular blocky structure breaking to moderate medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; common very fine and few fine roots; 10 percent gravel; moderately alkaline (pH 8.0); abrupt smooth boundary.

Bw2 (32-50 cm) Very pale brown (10YR 7/3) gravelly loam, dark grayish brown (10YR 4/2) moist; moderate coarse angular blocky structure; soft, very friable, slightly sticky, slightly plastic; few very fine and fine roots; 15 percent gravel; moderately alkaline (pH 8.0); abrupt wavy boundary.

BC (50-60 cm) Brown (10YR 5/3) extremely gravelly sandy loam, very dark grayish brown (10YR 3/2) moist; hard, very friable, nonsticky, nonplastic; common very fine and fine roots; 70 percent gravel and cobbles; moderately alkaline (pH 8.0).

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 518860 east 4987110 north. The pedon has formed in stream deposits. The slope is 4 %. Aspect is north. Elevation is 1630 m. The habitat type is big sagebrush/bluebunch wheatgrass (ARTR/AGSP) with 50 % vegetative cover.

Notes: Gravel and cobbles make up 20 % of the soil surface. Soil described by Ann Rodman on 7/20/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 116 - Typic Natriboroll; fine-loamy, mixed

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-19 cm) Dark grayish brown (10YR 4/2) gravelly sandy loam, very dark grayish brown (10YR 3/2) moist; moderate medium subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; common very fine and fine roots; 25 percent gravel; moderately alkaline (pH 7.9); clear smooth boundary.

Bn (19-34 cm) Light grayish brown (10YR 6/2) gravelly sandy loam, dark grayish brown (10YR 4/2) moist; moderate coarse subangular blocky structure; soft, friable, slightly sticky, slightly plastic; few very fine and fine roots; 25 percent gravel; moderately alkaline (pH 8.2); gradual irregular boundary.

Btn (34-45 cm) Light grayish brown (10YR 6/2) gravelly loam, dark grayish brown (10YR 4/2) moist; moderate coarse subangular blocky structure; slightly hard, friable, slightly sticky, plastic; common very fine and fine roots; 25 percent gravel; mildly alkaline (pH 7.7); clear irregular boundary.

Bnz (45-66 cm) Brown (10YR 5/3) very gravelly sandy loam, very dark grayish brown (10YR 3/2) moist; weak coarse subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; common very fine and fine roots; 35 percent gravel; neutral (pH 7.3).

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 519170 east 4986870 north. The pedon has formed in landslide deposits. The slope is 35 %. Aspect is northeast. Elevation is 1655 m. The habitat type is big sagebrush/bluebunch wheatgrass (ARTR/AGSP) with 20 % vegetative cover.

Notes: Angular gravels make up 60 % of the soil surface. Soil described by Ann Rodman and Jana Mohrman on 7/20/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 118 - Typic Eutroboralf; fine, mixed, calcareous, sodic

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-7 cm) Light grayish brown (10YR 6/2) gravelly sandy loam, very dark grayish brown (10YR 3/2) moist; moderate coarse subangular blocky structure breaking to moderate fine granular structure; soft, very friable, nonsticky, nonplastic; common very fine and fine roots; 15 percent gravel; neutral (pH 7.1); abrupt smooth boundary.

2Btk (7-33 cm) Light grayish brown (10YR 6/2) clay, very dark grayish brown (10YR 3/2) moist; strong coarse angular blocky structure; very hard, very friable, sticky, plastic; few very fine and fine roots; common moderately thick clay films on ped faces; 10 percent gravel; moderately alkaline (pH 8.1); slightly effervescent; gradual smooth boundary.

2Bk (33-45 cm) Light brownish gray (2.5Y 6/2) clay, dark grayish brown (2.5Y 4/2) moist; moderate medium angular blocky structure; hard, very friable, slightly sticky, plastic; few very fine and fine roots; 10 percent gravel; moderately alkaline (pH 8.1); slightly effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 518420 east 4986080 north. The pedon has formed in interglacial landslide deposits. The slope is 25 %. Aspect is northeast. Elevation is 1740 m. The habitat type is big sagebrush/bluebunch wheatgrass (ARTR/AGSP) with 40 % vegetative cover.

Notes: Angular gravels with some cobbles and stones make up 30 % of the soil surface. Soil described by Ann Rodman and Liz Colvard on 7/20/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 121 - Typic Eutroboralf; fine-loamy, mixed, sodic

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-20 cm) Light grayish brown (10YR 6/2) cobbly loam, very dark grayish brown (10YR 3/2) moist; moderate fine to medium granular structure; slightly hard, very friable, slightly sticky, slightly plastic; many very fine and fine roots; 30 percent cobbles and gravel; strongly alkaline (pH 8.5); clear smooth boundary.

Btk (20-47 cm) Light grayish brown (10YR 6/2) gravelly loam, dark grayish brown (10YR 4/2) moist; moderate coarse subangular blocky structure; hard, very friable, slightly sticky, slightly plastic; common very fine and fine roots, and few medium roots; few thin clay films in pores; 20 percent gravel; strongly alkaline (pH 8.5); gradual smooth boundary.

Bkn (47-60 cm) Pale brown (10YR 6/3) loam, dark grayish brown (10YR 4/2) moist; moderate medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; few very fine and fine roots; 5 percent gravel; moderately alkaline (pH 8.0).

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 524900 east 4981650 north. The pedon has formed in fan deposits. The slope is 10 %. Aspect is west. Elevation is 1790 m. The habitat type is bluebunch wheatgrass/Sandberg bluegrass (AGSP/POSA) with 40 % vegetative cover.

Notes: Gravels and cobbles make up 25 % of the soil surface. Soil described by Ann Rodman on 7/21/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 128 - Lithic Ustochrept; loamy-skeletal, mixed, calcareous

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-8 cm) Light brownish gray (10YR 6/2) gravelly loamy sand, dark grayish brown (10YR 4/2) moist; moderate medium granular structure; nonsticky, nonplastic; many very fine and fine roots, and few medium roots; 30 percent gravel; moderately alkaline (pH 8.0); violently effervescent; abrupt irregular boundary.

B (6-27 cm) Light gray (10YR 6/1) extremely cobbly sandy loam, dark grayish brown (10YR 4/2) moist; weak medium subangular blocky structure; nonsticky, slightly plastic; common very fine and fine roots; 80 percent gravel and cobbles; moderately alkaline (pH 8.0).

R (27 cm) Consolidated sedimentary bedrock.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 525860 east 4985220 north. The pedon has formed from weathering sandstone. The slope is 18 percent. Aspect is west. Elevation is 1715 m. The habitat type is bluebunch wheatgrass/Sandberg bluegrass (AGSP/POSA) with 40 % vegetative cover. Erosion is low to moderate.

Notes: Rock fragments make up 20 % of the soil surface. Soil described by Ann Rodman and Jana Mohrman on 7/18/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 130 - Typic Eutroboralf; fine-loamy, mixed, calcareous

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-12 cm) Pale brown (10YR 6/3) loam, brown (10YR 4/3) moist; moderate medium subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; many very fine and fine roots; 5 percent gravel; moderately alkaline (pH 8.1); strongly effervescent; gradual smooth boundary.

Btk1 (12-24 cm) Light grayish brown (10YR 6/2) sandy loam, dark grayish brown (10YR 4/2) moist; moderate medium to coarse subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; common very fine and fine roots; 5 percent gravel; moderately alkaline (pH 8.1); violently effervescent; abrupt smooth boundary.

Btk2 (24-40 cm) Light gray (10YR 7/2) loam, brown (10YR 5/3) moist; moderate fine to medium subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; few very fine and fine roots; 5 percent gravel; moderately alkaline (pH 8.3); violently effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 526010 east 4885130 north. The pedon has formed in glacial till over weathered sandstone and shale. The slope is 32 %. Aspect is north. Elevation is 1750 m. The habitat type is big sagebrush/bluebunch wheatgrass (ARTR/AGSP) with 60 % vegetative cover.

Notes: Cobbles and gravels make up 20 % of the soil surface. Soil described by Ann Rodman and Jana Mohrman on 7/29/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 140 - Typic Ustochrept; fine, mixed, calcareous

Pedon Description: (Colors are for dry soil unless otherwise stated.)

Ap (0-9 cm) Brown (10YR 5/3) silty clay loam, dark brown (10YR 3/3) moist; moderate medium subangular blocky structure parting to weak fine granular structure; soft, very friable; common very fine and fine roots; 1 percent gravel; moderately alkaline (pH 8.0); abrupt smooth boundary.

Bt (9-23 cm) Light brownish gray (10YR 6/2) silty clay, very dark grayish brown (10YR 3/2) moist; moderate coarse subangular blocky structure; slightly hard, very friable; common very fine and few fine roots; mildly alkaline (pH 7.5); gradual smooth boundary.

2Bk (23-61 cm) Pale brown (10YR 6/3) clay loam, brown (10YR 4/3) moist; moderate coarse angular blocky structure; slightly hard, very friable; few very fine roots; few thin clay films in pores; mildly alkaline (pH 7.5); slightly effervescent; abrupt wavy boundary.

2Bc (61-70 cm) Light gray (10YR 7/2) sandy clay loam, dark brown (10YR 3/3) moist; moderate coarse subangular blocky structure; soft, very friable; few fine roots; moderately alkaline (pH 7.8).

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 518200 east 4989310 north. Elevation is 1580 m. The pedon has formed in alluvial deposits on a floodplain in an area of historic irrigated agriculture. Vegetation is introduced exotic species with 35 percent vegetative cover.

Notes: Soil described by Ann Rodman and Dean Neprud on 5/4/89.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 141 - Typic Argiboroll; fine-loamy, mixed

Pedon Description: (Colors are for dry soil unless otherwise stated.)

Ap (0-10 cm) Dark grayish brown (10YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; moderate medium subangular blocky structure; soft, very friable, nonsticky, slightly plastic; many very fine and few fine roots; very few clay films in pores; 2 percent gravel; moderately alkaline (pH 8.1); abrupt smooth boundary.

Bt1 (10-32 cm) Dark grayish brown (10YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; moderate coarse subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; common very fine roots; few clay films in pores; 2 percent gravel; moderately alkaline (pH 8.3); clear smooth boundary.

Bt2 (32-50 cm) Grayish brown (10YR 5/2) silt loam, very dark grayish brown (10YR 3/2) moist; moderate coarse subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; common very fine roots; few moderately thick clay films; 2 percent gravel; mildly alkaline (pH 7.6); clear smooth boundary.

Bt3 (50-58 cm) Grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 3/2) moist; weak coarse subangular blocky structure; slightly hard, very friable, sticky, slightly plastic; common very fine roots; many moderately thick clay films in pores; 2 percent gravel; moderately alkaline (pH 8.2).

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 5188200 east 4988610 north. The pedon has formed in fine textured flood deposits. The slope is 2 %. Elevation is 1580 m. Vegetation is introduced exotic species such as crested wheatgrass and mustards. Vegetative cover is 35 %.

Notes: The surface 5 cm is dry and loose. Soil described by Henry Shovic on 6/21/88.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

SOIL DESCRIPTION 145 - Typic Argiboroll; loamy-skeletal, mixed, calcareous

Pedon Description: (Colors are for dry soil unless otherwise stated.)

A (0-5 cm) Brown (10YR 4/3) very gravelly loam, dark brown (10YR 3/3) moist; moderate fine platy structure; soft, very friable, slightly sticky, nonplastic; many very fine and common fine roots; 40 percent gravel, cobbles, and stones; moderately alkaline (pH 8.0); abrupt smooth boundary.

Bt (5-19 cm) Brown (10YR 4/3) very gravelly clay loam, dark brown (10YR 3/3) moist; moderate coarse subangular blocky structure; slightly hard, very friable, sticky, plastic; many very fine and common fine roots on ped faces; few thin clay films lining pores and on ped faces; 50 percent gravel, cobbles, and stones; moderately alkaline (pH 8.0); clear smooth boundary.

Bk (19-45 cm) Pale brown (10YR 6/3) extremely gravelly sandy loam/sandy clay loam, grayish brown (2.5Y 5/2) moist; weak medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; many very fine roots; 80 percent gravel, cobbles, and stones; moderately alkaline (pH 8.3); strongly effervescent.

Location and Topography: Southwestern Montana, Yellowstone National Park, UTM 524040 east 4985380 north. The pedon has formed in glacial till reworked by glacial floods. The slope is 3 %. Aspect is north. Elevation is 1625 m. The vegetation is introduced exotic species with 30 % vegetative cover.

Notes: Boulders, stones, and gravel make up 40 % of the soil surface. Soil described by Ann Rodman on 9/20/89.

Soil data is on file at Division of Research, Yellowstone National Park, Box 168, Mammoth, WY 82190.

Table D1. Physical properties of typical pedons.

Pedon #	Horizon	Texture	% Sand	% Silt	% Clay	% Organic Matter
16	A	clay	25	23	52	1.08
	Btn	clay	20	24	56	0.96
	Bn	silty clay	15	42	43	0.51
106	A	sandy loam	61	31	8	1.88
	Bt	sandy loam	54	29	17	1.14
	Bk1	sandy loam	61	25	14	0.35
	Bk2	sandy loam	61	29	10	0.14
107	A	loam	49	35	16	2.43
	Bt	sandy clay loam	54	23	23	1.60
	Bk	sandy loam	74	16	10	0.62
109	A	loam	49	33	18	2.77
	Bk	sandy loam	69	18	13	1.81
111	A	loam	41	41	18	2.56
	Bk	loam	45	39	16	1.53
	Btk	loam	37	44	19	1.47
	Bn	loam	37	43	20	1.08
115	A	loam	Data not available			
	Bw1	loam				
	Bw2	loam				
	BC	sandy loam				
116	A	sandy loam	53	29	18	1.74
	Bn	sandy loam	55	36	9	0.84
	Btn	loam	49	32	19	0.90
	Bnz	sandy loam	55	28	17	0.62

Pedon #	Horizon	Texture	% Sand	% Silt	% Clay	% Organic Matter
118	A	sandy loam	61	30	9	3.76
	2Btk	clay	17	20	63	2.11
	2Bk	clay	27	26	47	1.02
121	A	loam	47	32	21	1.60
	Btk	loam	39	36	25	1.85
	Bkn	loam	45	34	21	1.27
128	A	loam	Data not available			
	B	sandy loam				
	R	bedrock				
130	A	loam	47	42	11	3.87
	Btk1	sandy loam	53	39	18	2.35
	Btk2	loam	43	36	21	1.67
140	Ap	silty clay loam	7	54	39	8.30
	Bt	silty clay	6	49	45	2.51
	2Bk	clay loam	35	25	40	0.62
	2Bc	sandy clay loam	50	26	24	0.45
141	Ap	loam	34	46	20	1.96
	Bt1	loam	28	48	24	1.40
	Bt2	loam	24	50	26	0.90
	Bt3	loam	32	46	22	1.05
145	A	loam	Data not available			
	Bt	clay loam				
	Bk	sandy loam/sandy clay loam				

Table D2. Chemical properties of typical pedons.

Pedon #	Horizon	pH	- - - - - - - - Exchangeable (meq/100 g)- - - - - -					ESP %	EC mmhos/ cm
			CEC	Na	K	Ca*	Mg*		
16	A	8.5	44.8	7.4	0.9	45.6	8.2	16.5	1.2
	Btn	8.3	51.4	12.0	0.7	39.1	9.3	23.3	2.5
	Bn	7.9	46.6	10.4	0.7	48.9	9.3	22.3	7.3
106	A	7.7	10.3	0.1	1.3	8.8	2.1	1.0	1.0
	Bt	7.9	14.1	0.2	0.6	11.4	3.3	1.4	0.8
	Bk1	8.2	11.2	0.4	0.3	30.6	3.3	3.6	0.7
	Bk2	7.7	11.0	0.8	0.5	28.8	3.5	7.3	0.6
107	A	7.7	11.0	0.1	1.0	8.6	2.8	0.9	1.2
	Bt	7.4	18.4	0.1	0.7	13.8	4.6	0.5	0.8
	Bk	7.4	11.4	0.6	0.1	30.4	3.3	5.3	3.9
109	A	7.8	14.5	0.1	1.4	11.0	3.2	0.7	0.8
	Bk	8.3	9.2	0.1	0.1	31.8	1.7	1.1	0.2
111	A	7.9	12.3	0.1	1.0	11.0	2.8	0.8	0.7
	Bk	8.2	12.0	0.1	0.8	21.0	2.7	0.8	0.8
	Btk	8.3	14.7	0.3	0.6	19.1	3.8	2.0	0.7
	Bn	7.8	12.7	1.0	0.4	26.9	4.5	7.9	2.1
115	A	8.0**	Data not available						
	Bw1	8.0**							
	Bw2	8.0**							
	BC	8.0**							
116	A	7.9	25.1	2.5	1.7	12.7	5.8	10.0	0.7
	Bn	8.2	27.0	6.1	1.8	22.7	6.7	22.6	1.4

Pedon #	Horizon	pH	-------- Exchangeable (meq/100 g)- - - - - -					ESP %	EC mmhos/ cm
			CEC	Na	K	Ca*	Mg*		
	Btn	7.7	27.8	7.1	2.5	31.3	8.2	25.5	4.7
	Btnz	7.3	24.4	7.2	2.1	30.4	7.2	29.5	13.0
118	A	7.1	16.3	3.7	2.3	8.6	2.0	22.7	0.5
	2Btk	8.1	51.3	8.7	0.9	41.8	8.0	17.0	2.2
	2Bk	8.1	39.5	9.5	0.9	42.2	6.8	24.1	4.5
121	A	8.5	11.6	0.1	0.4	23.0	2.7	0.9	0.7
	Btk	8.5	10.5	0.6	0.3	24.4	5.5	5.7	1.0
	Bkn	8.0	10.5	2.1	0.4	25.5	6.0	20.0	5.4
128	A	8.0**	Data not available						
	B	8.0**							
	R	---							
130	A	8.1	13.2	0.1	0.9	14.3	1.7	0.8	1.1
	Btk1	8.1	12.3	0.1	0.5	33.3	1.3	0.8	1.0
	Btk2	8.3	11.7	0.1	0.4	35.4	2.7	0.9	0.8
140	Ap	8.0	30.7	0.2	5.9	21.1	6.8	0.7	1.5
	Bt	7.5	27.6	0.4	1.8	23.3	6.2	1.4	0.6
	2Bk	7.5	25.8	0.7	0.8	20.2	6.8	2.7	0.5
	2Bc	7.8	18.3	0.6	0.4	38.7	5.0	3.3	0.6
141	Ap	8.1	25.0	0.3	1.1	17.7	7.7	1.2	0.6
	Bt1	8.3	29.3	0.7	0.3	21.2	9.0	2.4	0.6
	Bt2	7.6	33.1	0.9	0.3	22.5	11.1	2.7	0.6
	Bt3	8.2	32.8	0.9	0.3	21.6	10.3	2.7	0.5
145	A	8.0**	Data not available						
	Bt	8.0*							

Pedon #	Horizon	pH	- - - - - - - - Exchangeable (meq/100 g)- - - - - -					ESP %	EC mmhos/ cm
			CEC	Na	K	Ca*	Mg*		
		*							
	Bk	8.3**							

* Exchangeable cations may be over estimated due to soluble salts in the profile.
** pH determined in the field

History of pronghorn population monitoring, research, and management in Yellowstone National Park

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CONTENTS

INTRODUCTION

Pronghorn antelope in Yellowstone National Park (YNP) persist in a small population that historically has experienced recurrent, sometimes dramatic declines. They apparently are isolated from other pronghorns, depend partly on private lands for winter range, experience heavy predation of fawns, and concentrate during winter in a relatively small area, thereby increasing their vulnerability to factors like disease or locally extreme weather. Overall, the situation raises serious concerns about the long-term viability of this population. Although such concerns are not new, evidence of a dramatic population decline since 1991 and continued poor recruitment has created a renewed sense of urgency.

Recent efforts to revitalize pronghorn research in YNP began with fawn recruitment and habitat use studies, initiated in 1999 and 2000. With those studies drawing to a close, YNP is reviewing the status and direction of its pronghorn program. The Yellowstone Pronghorn Conservation Assessment Workshop was convened in YNP in January, 2002, to appraise the current state of knowledge about this pronghorn population and make recommendations about future management and research needs. A review of pronghorn population change, management, and research in YNP was commissioned in May, 2001, to provide historical background for workshop participants. Following is a written summary of that review.

The process of locating materials for this review was limited to 3 months. Not all relevant materials were discovered or reviewed in that time. In particular, it was not possible to find and review all original sources of information. Also, except for occasional anecdotal accounts, weather records were not reviewed, leaving a potentially serious gap in our understanding of the forces driving changes in pronghorn population counts and estimates over time. Despite these deficiencies, considerable information was reviewed, earlier summaries of population classification and count data were updated, and previously uncited sources of information were identified that challenge important aspects of previous interpretations of the history of pronghorns and pronghorn management in YNP. Information is grouped into 4 major subject areas: distribution and habitat use, demographics and management, genetics, and disease.

DISTRIBUTION AND HABITAT USE

General Patterns

Pronghorns were once widely distributed in the upper Yellowstone drainage, likely migrating large distances to low-elevation winter ranges. In a description reminiscent of the 100- to 170-mile pronghorn migrations that occur today between Grand Teton National Park and winter ranges in southwestern Wyoming (Sawyer and Lindzey 2000), Grinnell (1918) observed that in YNP,

> "The antelope never wintered in the Park, but went down the Yellowstone River toward the lower country. T. E. Hofer has spoken of seeing their trails where Livingston now stands, where at first he thought that bands of several thousand sheep had passed along."

Hofer himself wrote that pronghorns did not winter in YNP (Hofer 1887a), but "used to go to a less snowy region to pass the winter months" (Hofer 1890). Quoting Gamekeeper Young from 1881, Skinner (1922*a*:93) wrote that "very few of the deer or antelope wintered anywhere in the park." Based on his review of the historical record, Houston (1982:24) also believed that "pronghorn wintered historically in the Paradise Valley…and further down the Yellowstone River."

Following settlement, the situation changed dramatically. Skinner (1922*a*:93) painted an especially bleak picture when he stated that "migration now to the plains would be slaughter, for if an antelope gets out of the park, it is gone as if swallowed up." Contributing factors are reviewed below (see Demographics and Management). The net impact, however, was that the pronghorn migration north from YNP was effectively eliminated during settlement (Houston 1982:24), although the exact timing is unclear. Barmore (1981, citing Skinner 1922*a*, Nelson 1925, and Beer 1944) concluded only that extirpation occurred "sometime before 1920." An article in Forest and Stream (Anonymous 1905*b*) suggests that it may have occurred by 1905, as it quotes YNP's Acting Superintendent as stating that "[t]he valley of the Yellowstone north of the park is now completely taken up by ranchers, and their wire fences running in every direction have completely shut off the old winter range of the antelope." Whatever the timing, migrations that historically funneled "thousands of antelope" (Skinner 1922*a*:92) to spring and summer ranges in YNP ended with settlement of the Paradise Valley. Pronghorn sightings between YNP and Livingston remain sparse today (Scott and Geisser 1994), and the population is presumed to be demographically and, perhaps, genetically closed.

Within YNP, historical accounts of seasonal distributions paint a picture that broadly accords with most of what is known about pronghorn distributions today. Rangeland habitats along the Yellowstone and Lamar Rivers, and on the Blacktail Deer Plateau have long been recognized as preferred pronghorn habitat (Scott and Geisser 1994, citing Norris 1878). Hofer (1887*b*; 1889*b*; 1890; 1891*a,b*; 1905*a*) reported pronghorns wintering on Mt. Everts and along the northern boundary near Gardiner; and spring and summer sightings near Yancey's and Junction Butte, on the hillsides between Hellroaring and Slough Creek, and on the Blacktail Deer Plateau and Specimen Ridge. Skinner (1922*a*:92) reported that "the [pronghorn] range is restricted to the great open section in the north, comprising the Gardiner Valley, Mount Everts, Blacktail Deer Valley, the slopes on both sides of Hellroaring Creek, Junction Valley, the lower slopes of Mount Washburn on the north, the lower and upper valleys of the Lamar River, and Specimen Ridge." Murie (1940:89) observed that, in summer, pronghorns were "distributed from the Game Ranch all the way to Tower Falls and to the high grassy ridges bordering Cache Creek on the east," and that "[t]hey are commonly found on top of Specimen Ridge."

Various accounts suggest that at least 3 important changes have occurred in summer distributions. First, pronghorn use of the Hayden Valley apparently has declined. Scattered reports confirm that, historically, at least small numbers of pronghorns regularly summered in the Hayden Valley (Anonymous 1885, Wilson 1885, Hofer 1887*c*). However, Skinner (1922*a*:92) stated that pronghorns no longer used the Hayden at the time of his study, while Murie (1940:89), Scott (1993*a*), and Scott and Geisser (1994) regarded sightings there as "unusual." Declining use of the Hayden Valley may have significance beyond the simple fact of a reduced pronghorn distribution. Scott and Geisser (1994:16–17) speculated that the Hayden might have been an historical "mixing site for pronghorns from the Yellowstone and Madison Valleys," with pronghorns from the Madison area migrating into the Hayden Valley via the Madison-Firehole-Nez Perce Creek route used today by bison. Sporadic sightings of pronghorns in the Lower

Geyser Basin and along the Madison and Gibbon Rivers (Scott and Geisser 1994) are consistent with this hypothesis.

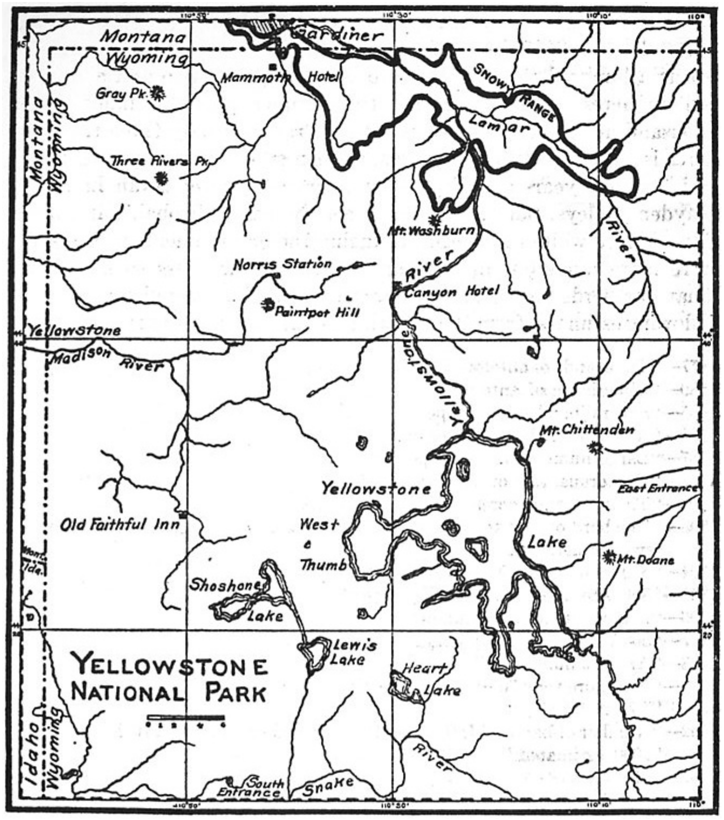

Fig. 1. Seasonal distribution of pronghorn antelope in Yellowstone National Park, as mapped by Skinner (1922). Summer range is indicated by the heavy outline, winter range by cross-hatching.

Second, there is some suggestion that pronghorn use in Gardners Hole has declined. Skinner (1922*a*:91) stated that "[f]orty years ago, limited numbers [of pronghorns] ranged the Swan Lake and Hayden Valleys, but such is no longer the case." Although pronghorns have been sighted in Gardners Hole area in recent times (J. Mack, National Park Service, pers. commun.), it is believed that use has been sporadic.

Finally, pronghorns may have been extirpated from the Antelope Creek summer range. Pronghorns undoubtedly once used this area, as Skinner (1922*a*:92) included "the lower slopes of Mount Washburn on the north" in his description of pronghorn range. Also, the Antelope Creek area is clearly contained within his mapped "Distribution of Prong-horn Antelope in Yellowstone Park" (Skinner 1922*a*:91) (Fig. 1). Greer (*c.* 1930–1931:3) similarly noted pronghorns in this area. Scott (1991:4) reported, however, that "pronghorns stopped migrating to the Antelope Creek Valley after the Montana Department of Fish, Wildlife, and Parks and the National Park Service removed 240 of them from the Reese Creek area in January, 1947," and that "[t]his summer habitat has not been used since." Following their review of sighting records, Scott and Geisser (1994:15) reported that "[p]ronghorns were last seen in the Antelope Valley area on 8 May 1946."

Winter Distribution and Habitat Use

For over a century, quantity and quality of pronghorn winter range has been a chronic concern; one that is inextricably tied to the history of settlement and land use in the Gardiner Basin. Mining operations began at Bear Gulch in 1866 and were followed by the creation of YNP (1872), Gardiner (1880–present), Cinnabar (1883–1902), Horr (later renamed Electric, 1894–1910), Aldridge (1896–1910), and Jardine (1898–present) (Whithorn and Whithorn *c.* 1965, *c.* 1977; Anonymous 1997). Of these, Cinnabar and Electric figured most prominently in early commentaries on pronghorns. Cinnabar stood near the present-day junction with the Stephens Creek road, and was sustained by agriculture and business associated with the town's railroad terminus (Whittlesey 1995). With a combined population of 1,500, Electric and the associated community of Aldridge were built around coal mining operations near Beattie Gulch (Whithorn and Whithorn *c.* 1965). Electric occupied the flats east of the Yellowstone River (Fig. 2) and north of the present park boundary, while Aldridge was situated above Aldridge Lake, west of Cinnabar Mountain.

Settlement brought major habitat changes due primarily to agriculture, mining, and associated development. Effects of cultivation near Cinnabar and north to Reese Creek can be seen in the park today, with irrigation ditches still visible and fields dominated by exotic plant species. Areas once occupied by the town of Electric (Fig. 2) have since been

Fig. 2. Looking up the Yellowstone River toward Mt. Everts (background) from above the coal mining community of Electric, Montana (1894–1910). Electric was situated on pronghorn winter range between Spring Creek and Beattie Gulch. (Photograph courtesy of Bill and Doris Whithorn)

converted mostly to agricultural use, although recent increases in home site development in the Gardiner Basin threaten to reverse those changes. Livestock once ranged widely in this area; even within the Park, "the area between Mammoth and the north boundary of the park [was grazed] without any restrictions as to season of use, numbers or class of stock" (Houston 1982:421, citing Rush 1932). YNP's north boundary was fenced in 1903 (Acting Superintendent 1913). Afterward, Pitcher (1905) indicated that "all stock has been kept off this range during the past year [1904], or ever since the fence near Gardiner has been completed." Following addition of the boundary line area (BLA) to YNP in 1932, however, cattle continued to graze areas within the Park's northern boundary at least through 1971 (Houston 1982:338).

Using comparative photography, Houston (1982) documented vegetation changes in the BLA and north to Dome Mountain, among other areas. Changes in the amount of big sagebrush (*Artemesia tridentata*) were evident (Houston 1982:292–293 and 338–351), but generalizations about the nature and causes of the changes remain problematic. For example, Houston (1982:338) characterized areas of high sage densities in parts of the current pronghorn winter range as a disclimax induced by a combination of livestock overgrazing and fire suppression. Photos from 1871 (Houston 1982:346–351) suggest, however, that sagebrush during pre-settlement times was denser than occurs today on many parts of the pronghorn winter range within YNP. Murie (1940:88) pointed to overgrazing by native ungulates as a cause of the decline of sage within the Park, but other factors also may have been important. For example, Bauer (1938, quoted in Houston 1982:425) stated, "the drouth which persisted more or less from 1933 to 1936 had a definite adverse effect on [sagebrush]," killing off "large areas" of sage. More recent studies in the northern Rocky Mountain region also implicated drought as a major factor in the decline of sagebrush (Anderson and Inouye 2001).

Other habitat changes affected pronghorns in ways that were more calculated than those induced by settlement. Feeding of ungulates, including pronghorns, began in YNP as early as 1902 (Hofer 1902, Anonymous 1905*b*). In 1904, the Park began cultivating and irrigating alfalfa on the flats near Gardiner, providing an estimated 100–200 tons of alfalfa hay annually during winter (Pitcher 1905, Anonymous 1906*a*). This program affected the pronghorn population in at least 2 ways. First, pronghorn numbers increased dramatically (for details see Demographics and Management). Second, the presence of irrigated alfalfa apparently caused some animals to remain on the winter range year around, likely creating the non-migratory subpopulation that exists today. Evidence that migratory habits changed is found in a series of Forest and Stream articles. Explaining the benefits of Superintendent Pitcher's new alfalfa cultivation program, one article (Anonymous 1904) stated that the flats containing the alfalfa field were "used by the antelope *only in winter*" (my italics). Within a year, that had changed (Hofer 1905*b*):

> "In the spring almost all the antelope left their winter range in front of Gardiner and the alfalfa patch; but about twenty concluded it was a favorable place to show themselves, and every evening came down from the nearby hills. They are quite tame for antelope, and thousands have seen them, where if they had returned to their old range for the summer not one tourist would have known what the animal looked like."

Hofer's (1908*b*) account suggests that mule deer summer distributions were similarly affected and that the number of pronghorns remaining on the winter range during summer continued to increase:

> "In front of town [Gardiner] every evening we can see from forty to fifty antelope and thirty to forty mule deer feeding on the alfalfa field…About twenty-five antelope used the field every evening all last summer, and there is a prospect that more will camp there this summer with the addition of the mule deer. I do not remember that any deer summered here last year."

Overall, the record suggests that YNP's alfalfa field induced unforeseen, long-term consequences for distributions and habitat use patterns of pronghorns and mule deer.

Other management activities also likely influenced pronghorn winter distributions and habitat use. A policy of containing pronghorns within YNP began soon after the U.S. Army assumed responsibility for the Park in 1886, with "soldiers acting as herders" to drive pronghorns back into the Park (Anonymous 1887*a*). This practice continued at least through the winter of 1911–1912 (Anonymous 1911*a*,*b*; Acting Superintendent 1912). By 1900, the Superintendent was lobbying for a boundary fence, with the express purpose of protecting pronghorns and excluding livestock (Anonymous 1901, citing Superintendent's Annual Report 1900). Four miles of wire fence were completed by the U.S. Engineer Department in 1903 (Anonymous 1905*b*, quoting the Acting Superintendent; Acting Superintendent 1913). The fence apparently succeeded in limiting livestock use of winter range in the Park (Pitcher 1905) and in preventing pronghorns "to some extent from moving out of the park" (Murie 1940:88). However, repeated references to fence repair and escaping animals (e.g., Anonymous 1907; Superintendent 1910, 1911; Anonymous 1911*a*,*b*; Acting Superintendent 1913; Bailey 1930:30, as quoted by Murie 1940:101) indicate that fencing was not fully effective. Fencing also produced unintended impacts, as some pronghorns were trapped against fence lines and killed by predators (Heller 1925:466, Anonymous 1934) — a strategy still seen today (McEneaney 1997).

Although the old boundary fence was removed shortly after the BLA was added to the Park (Anonymous 1934, 1936), fences erected by private landowners are still a concern. In 1987 and 1988, for example, the Royal Teton Ranch (RTR) constructed over 2 miles of buck-and-pole fence along the park boundary near Reese Creek (Barbee 1990). Scott (1992) found that the fence inhibited trans-boundary movements by pronghorn. Subsequent increases in annual counts (see Demographics and Management, Fig. 7) and continued depredation hunts to control pronghorn numbers on the RTR suggest, however, that the fence had little affect on the distribution or dynamics of the population.

In 1919, the National Park Service (NPS) issued the Graves Nelson Report, which "recommended the acquisition by the federal government of a great many small tracts of private land in the territory between Gardiner and Yankee Jim Canyon." (Whittlesey 1995:53). With that report, the focus of YNP's pronghorn policy expanded beyond feeding and predator control efforts to include acquisition of additional range, for by then it was believed that more winter range was needed to assure the herd's future. But how much winter range was enough? Superintendent Albright argued that "… if we could get the Hoppe Ranch, which immediately adjoins the Park on the north, we would have no more trouble with the [pronghorn] herd" (Albright 1922). Skinner (*c.* 1924:2) apparently envisioned a larger herd, for he reaffirmed that about 5,000 additional acres were needed for the herd that existed at that time, but argued for acquiring a much larger area, writing that "[i]f we had the entire valley from Gardiner to the Canyon below Electric, the continuation of our herd and the preservation of the species would be assured." Skinner's vision, apparently, was never pursued. In 1922, Thomas Cochran and George D. Pratt founded the Game Preservation Company, which eventually purchased and donated thousands of acres to YNP and the Gallatin National Forest (Whittlesey 1995:54). The Game Preservation Company purchased the Hoppe ranch in 1925 and other parcels in the BLA in the years thereafter, but the federal government could not accept title until 1931 and the 7,609-acre area was not formally appended to YNP until October 20, 1932 (Whittlesey 1995:57, 71). During the interim, the land was placed at the disposal of YNP "for the care of elk, deer and antelope in winter" (Whittlesey 1995:57). YNP operated the former Hoppe Ranch (by then known as the Game Preservation Ranch) for the feeding of native ungulates and government horses; plowing, seeding, and irrigating large areas into hay almost as soon as it was acquired (Whittlesey 1995:57). The operation yielded 144 tons of hay the first year, and by 1931 the Park was cultivating 300 acres (Whittlesey 1995:57). Following addition of the BLA, "razing of fences and old buildings on the antelope winter range…added considerable area to the available range" (Anonymous 1936). By this time, pronghorns could move freely beyond the former boundary fence and onto the lands that had once been occupied by the town of Cinnabar.

The expanded feeding program enabled by acquisition of the BLA was short-lived. During the winter of 1931–1932, 1200 pounds of cottonseed cake and 118 tons of hay were fed at the Game Ranch (Anonymous 1933), but only 36 tons of hay were fed the following winter, and by the winter of 1933–1934 the feeding program in the BLA ended (Anonymous 1933, 1934). One year later (1934–1935) YNP's predator control program also ended (Murie 1940:16). Discontinuation of both feeding and predator control terminated a management strategy that in various guises over a 50-year period (1886–1935) had sought to preserve YNP's pronghorn herd by simultaneously increasing the food supply and limiting predation.

Within 10 years after feeding and predator control ended, management objectives were emphasizing habitat rather than herd protection. In summer 1946, a plan was approved to reduce the pronghorn herd to 400 animals (Barmore 1981:Table 105, citing Anonymous 1946). In 1950, a target population of 200 animals was recommended (Barmore 1981:Table 105, citing Anonymous 1950*a*). By 1953, the Park's management plan called for limiting the herd to 100–125 pronghorns (Hamilton 1953, Rogers 1956). The target population apparently remained in this range until the herd reduction program ended in 1967 (McLaughlin 1965). This dramatic shift in management philosophy almost certainly affected pronghorn distributions and habitat use patterns, particularly on the winter range where feeding and predator control efforts had previously been concentrated.

Studying seasonal habitat selection by pronghorns in the area between Mammoth Hot Springs and Reese Creek, Barmore (1981) found that 79% of feeding was in xeric grasslands, the only habitat type that was preferred throughout the October–May study period. Old fields, mesic grasslands, and especially sagebrush grasslands generally were avoided, although old fields were preferred during October–December and mesic grasslands were preferred in May (Barmore 1981:236, 240, Fig. 28). Pronghorns strongly preferred level to gentle slopes throughout the study period, and also showed some preference for moderate west-facing slopes and ridge tops (Barmore 1981:241, 244, Fig. 29). No pronghorn were observed feeding in snow >15 cm deep, and most foraged in <8 cm of snow (Barmore 1981:241, 245, Fig. 30). Significant variation in habitat selection was observed within and between years, a fact that Barmore (1981:241, 246) attributed to (1) varying environmental conditions, and (2) disproportionately high mortality during 1967–1968 among pronghorns wintering west of the Gardiner River, where “essentially all the areas of old fields and considerable sagebrush grassland occurred.”

More recently, pronghorn habitat use also has been monitored on areas outside YNP. During the winters of 1996–1997 through 2000–2001, pronghorn activity outside the park accounted for an estimated 13–51% of total habitat use during mid-November to mid-March (Caslick and Caslick 1997, 1998, 1999, 2000, 2001). However, such figures may underestimate the importance of these habitats for 2 reasons. First, the importance of habitats outside the park was not constant throughout the 4-month monitoring period. For every year monitored, Caslick and Caslick (1997, 1998, 1999, 2000, 2001) documented at least one 4-week period in which estimated use of habitats outside YNP exceeded 40% of total use, and during December, 2000, exogenous habitats received an estimated 68% of total use. Second, the importance of habitats outside YNP varies among years. Major movements out of YNP in response to severe conditions were reported for pronghorns during the winters of 1897, 1908, 1910, 1911, 1917, 1939, 1968, and 1985 (Anonymous 1897, 1910; Lindsley 1897; Superintendent 1910, 1911; Murie 1940; Barmore 1970; Singer 1988). Although many of these movements took place before the park boundary was moved to include the BLA in 1932, there is little doubt that habitats outside the park remain vital in some years. Barmore (1970) indicated that all but 40 of an estimated 210 pronghorns left the park during the severe winter of 1967–1968, and that “[t]his exodus plus associated [42%] reduction in herd size emphasizes the current importance of lands outside the park to the herd's maintenance and wellbeing." Singer (1988) similarly wrote that,

> “In November–December of 1985, about 90% of the pronghorn herd migrated north of Yellowstone National Park due to heavy snows. Antelope remained out of the park for about three weeks until the snows began to melt. These migrations out of the park have occurred at periodic intervals (Scott 1987), and the movements may be critical to the herd's long-term survival (Barmore 1981; Houston 1982:168).”

Recent habitat changes outside YNP have not been thoroughly studied or documented, but may have affected pronghorn distributions and habitat use patterns. During 1981–1988, there was a net gain of 190 acres of irrigated land available to wildlife on the RTR (Francis 1987). Affected areas included Cutler Meadow (100 irrigated acres added in 1982), Beattie Gulch Meadows (45 irrigated acres added in 1985), and Electric Meadow (50 irrigated acres added in 1987 or 1988) (Francis 1987; Chris Kelley, The Church Universal and Triumphant [CUT], pers. commun.). Changes other than irrigation also occurred. For example, Singer (1988) observed that, "[i]n 1983, the [Royal Teton Ranch] plowed and reseeded two fields near Spring Creek, to which 20–25 antelope were attracted each summer." Subsequent complaints from the RTR resulted in pronghorn damage control hunts beginning in 1985 (see Demographics and Management).

Recent monitoring has included efforts to assess habitat use patterns on lands outside YNP. Of the 42% of pronghorn use-days observed outside YNP during 1996–1997, 43% were in irrigated hay or fenced pastures, 35% were in grass/shrub habitats, and 22% were in grass/forb communities (Caslick and Caslick 1997). Of the 43% of the use observed in irrigated hay or fenced pastures, most presumably was in fenced pasture, as it was later reported that observations over multiple years consistently indicated little use of cultivated or irrigated croplands, and continued use of grass/shrub and grass/forb habitats (Caslick and Caslick 1998, 1999, 2000). These findings underscore the importance of pronghorn winter habitats outside YNP, but provide no information about pronghorn use of such habitats during other seasons. Also, the various analyses by Caslick and Caslick did not consider habitat availability and, therefore, do not support inferences about habitat preference or selection.

In addition to documenting habitat use patterns, Caslick and Caslick (1997) considered effects of bison management activities on pronghorn winter distributions. They noted that during "times of high human activity, pronghorns were strikingly absent from the entire [Stephens Creek] area, for at least one-half mile around the corrals" (Caslick and Caslick 1997). Their observation is similar to earlier comments regarding effects of trapping on pronghorn distributions. Following trapping during the fall of 1946, for example, "many of the pronghorns moved to other range sectors where they remained for several weeks," and some "were reported to be in an area several miles north of the usual range" (Anonymous 1946). An important difference, however, is that trapping in 1946 was directed at reducing pronghorns, not bison. Caslick and Caslick (2000, 2001) further suggested that increased use of Beattie Gulch by hunters, following public acquisition of that area, might have displaced pronghorns from sage habitats west of the park boundary at Reese Creek.

Observations also suggest that pronghorn distributions on winter ranges in or near YNP may have shifted over time. Caslick and Caslick (2000) reported that, for six consecutive winters and in contrast to reported distributions during the 1960s, pronghorns were not observed on Target Flats or the northern slopes of McMinn Bench before mid-March. Barmore (1981:Table 105) confirmed that this general area was used regularly by wintering pronghorns for over a century. Caslick and Caslick (1999:6) also commented on the lack of recent pronghorn sightings north of the Yellowstone River, noting that “in the 1960s a few were seen outside Yellowstone in the vicinity of Gardiner airport and west of Bear Creek.” Murie (1940:87) similarly reported pronghorn sightings “on the bench lands outside the park north of the Yellowstone River in the vicinity of Bear Creek,” but noted that “[i]t was unusual for this species to be found here even though the range is better than within the park." It is unclear, therefore, whether pronghorn distributions in the Bear Creek area have changed appreciably.

In 1989 an advisory committee was convened to advise YNP on pronghorn research and management. The committee recommended 2 major lines of research regarding habitat use (Anonymous 1990): (1) determine the quantity and quality of food and cover needed by pronghorns, and (2) measure the quantity and quality of food and cover available to pronghorns. Results are pending from a study of pronghorn winter habitat use begun in 2000 under the direction of Dr. R. A. Garrott, Montana State University. Other research proposed by the committee generally has not been pursued, including recommended studies of yearlong food preferences and availability, interspecific dietary overlap, interannual differences in food habits, nutritive values of major forage species, distributions of critical cover (e.g., fawning areas), yearlong habitat use and selection, habitat classification and mapping, long-term trends in vegetation cover and production, and effects of humans and other species on pronghorn habitat use patterns (Anonymous 1990).

DEMOGRAPHICS AND MANAGEMENT

Overview

Information regarding pronghorn counts, population estimates, and artificial removals during 1877–2001 is summarized in Appendix A. In developing this summary I relied heavily on Barmore's (1981:Table 105) compilation, with some corrections and additions. Dr. M. D. Scott also updated Barmore's (1981) compilation, apparently reexamining many of the original sources and locating additional information. But details of Scott's work are known only from a digital spreadsheet (Scott 1994) that contains no written summary and does not reference sources, making it difficult to judge the quality of Scott's (1994) information. Apparent population trends were broadly comparable, regardless of who compiled the data. However, differences in details affect the amount of "noise" around those trends, a fact that has important implications for viability analyses (see Population Viability, below).

Counts, estimates, and removal data are summarized in the following sections. These should be interpreted cautiously. For example, I uncovered "counts" for 1889 and 1890, and evidence of artificial removals in 1949–1950 that were not included in the compilations of Barmore (1981) or Scott (1994), and I expect that further work would yield additional information. Also, none of the estimates or counts can be regarded as unbiased or statistically rigorous. In many cases they are not even strictly comparable, either spatially or temporally. Some counts were conducted during the fall, while many others were conducted during late-winter or early-spring; some counts included areas outside the park, while others did not; and some counts were made under poor conditions, causing them to be highly incomplete (Barmore 1981).

Despite their limitations, I believe the data presented in this section give a useful indication of long-term pronghorn trends in YNP. Following are detailed discussions of pronghorn counts and estimates in YNP, interwoven with a timeline of events deemed important in interpreting the history of this population. I have divided the discussion into 5 time periods that reflect major shifts in park management. I conclude this section with a discussion of Goodman's (1996) viability analysis, which has greatly influenced recent perceptions about the long-term risks faced by this population.

1872–1885

Congress established YNP in 1872. No counts or estimates of pronghorn numbers are available for this early period, but reports indicate that the park's population initially numbered in the thousands (Skinner 1922*a*, *c.* 1924). Unfortunately, thousands also were slaughtered. Angler (1883) wrote that "antelope of the Yellowstone Valley have been nearly exterminated" and provided figures indicating that over 12,000 pronghorn skins were shipped from Bozeman in 1874 alone. Focusing on pronghorns in YNP, Skinner (*c.* 1924:7) wrote that "[f]rom 1872 to 1883 it is reported that antelopes were killed each year in the park 'by the thousands.'" By 1883, the slaughter of antelope had abated, "but this [was] the result more of the scarcity of the game than of any respect felt by the skin hunters" (Anonymous 1883*b*). By order of the Secretary of the Interior, hunting in the park was prohibited in 1883 (Anonymous 1883*a*), "but considerable market hunting apparently continued until an ineffective and understaffed civilian administration was replaced by the U.S. Army in the summer of 1886" (Houston 1982:11). During this same period, both hunting and poisoning impacted predator populations. "Wolves and coyotes were reported abundant in 1870, but scarce in 1880 because of poisoning activities" (Murie 1940:11).

1886–1917

Arriving in 1886, the U.S. Army provided the first real protection for wildlife in YNP. Park policy toward pronghorns during this period was clearly aimed at increasing population size. Tactics for doing so evolved over time, but focused on limiting predation and providing supplemental feed.

Efforts to limit predation on pronghorns took various forms. Initially, the Army focused on enforcing the prohibition against hunting in the park. Also, by 1887, soldiers were herding pronghorns back into the park to prevent them from being killed in areas north of the boundary (Anonymous 1887*a*,*b*). In addition to limiting predation by humans, the Army took an increasingly active role in predator control, but attitudes varied greatly among years. Murie (1940:12) reported that "Supt. Moses Harris in his annual report of 1887 was not greatly concerned over the depredations of predators." By 1889, however, "the new Superintendent, Capt. F. A. Boutelle, recommended control of predators" (Murie 1940:12). In 1896, Superintendent Anderson ordered some coyotes killed, but apparently limited the scope of that order (Murie 1940:13). In 1899, the annual report (cited in Murie 1940:14) stated that poisoning "will be tried during the winter," but the following year (1900) Superintendent George W. Goode "appeared to be little concerned about coyote predation" (Murie 1940:14). By 1905, however, a long-term coyote control program was in place that included shooting, trapping, and poisoning (Fig. 3) (Pitcher 1905, Anonymous 1910, Lindsley 1922, Murie 1940:14–15).

Counts and population estimates from the late 1800s, together with anecdotal assessments, suggest the pronghorn population increased almost immediately after the Army began protecting park wildlife in 1886 (Fig. 3) (Appendix A). Records indicate an increase from an estimated 200 animals in 1887 to a minimum count of 323 in 1890 (Anonymous 1887*a*; Hofer 1889*a*, 1890), while Skinner (1922*a*:92) described the population as "[n]umerous, and on the increase" by 1891. Thereafter and until 1900, estimates ranged between about 500 and 1,000 animals, with peaks of 700–1,000 animals in 1891, 1896, and 1899 (Fig. 3, Appendix A).

Although Army protection undoubtedly led to increased pronghorn numbers, a detailed interpretation of pre-1900 estimates is greatly confounded by lack of population closure, as historical migration patterns probably had not been eliminated by then. Consider, for example, the 1891 estimate of ≥800 animals due to Hofer (1891*b*), who wrote:

> "There are about 250 antelope on the flat across Gardiner River from the town. Several large bands are on the hillsides between Hellroaring and Slough Creek. Others are about Junction Butte and the Blacktail country. There cannot be less than 800 antelope in the Park."

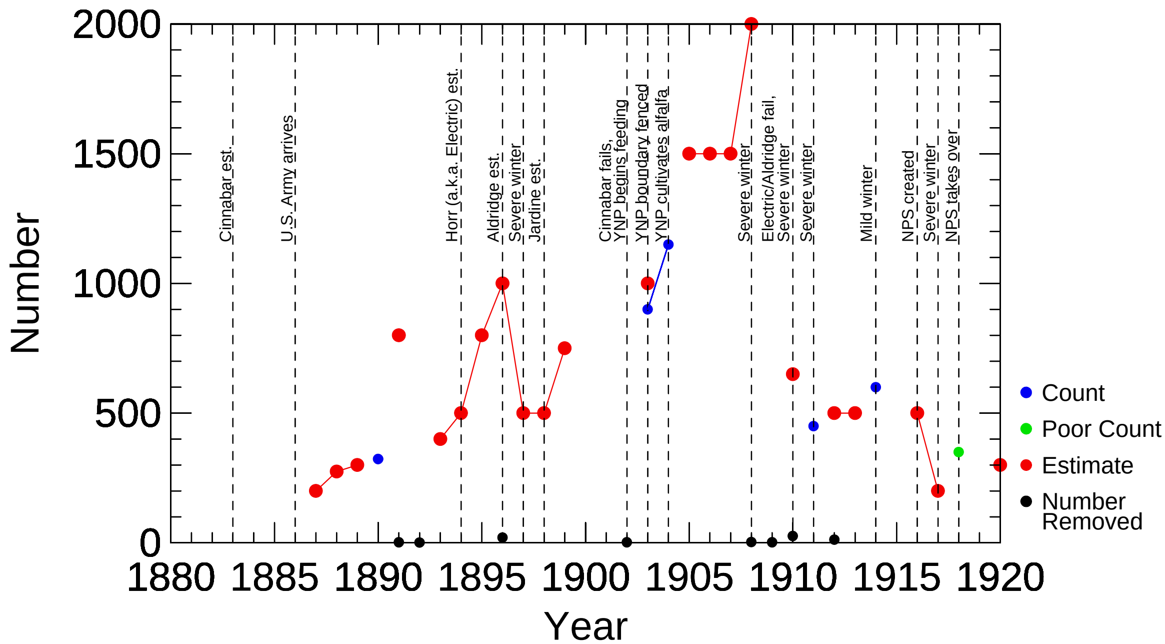

Fig. 3. Pronghorn population counts, estimates, and removals in Yellowstone National Park, 1880–1920, together with comments (see Appendix A for details). A "Poor Count" is one that was labeled as such in the historical record. Notable events that occurred before 1880 included the creation of Yellowstone National Park (1872) and establishment of the town of Gardiner (1880). At the time the park was created, it was estimated that pronghorns numbered in the thousands (Skinner 1922*a*).

Dated March 10, this account clearly is based on observations made during spring migration and, thus, may have included animals that wintered north of the park. Alternatively, the fact that pronghorns were widely distributed in the park by March 10 suggests that there was lower-than-average snowfall for that winter, combined with an early spring. Under such conditions, a greater-than-usual proportion of the herd may have wintered in the park, rather than migrating northward. Under either scenario, it is clear that large year-to-year fluctuations in population estimates could have been caused by immigration to or emigration from the park — processes that have little to do with changes in the underlying population size.

To improve pronghorn nutrition, the park began artificial feeding experiments, apparently in 1902. Before then, authors that mentioned feeding conditions (e.g., Anonymous 1887*a*, Hofer 1887*b*, Anonymous 1901) consistently failed to mention artificial feeding. In 1902, however, "[a]s a matter of experiment...a few bales of alfalfa hay were scattered about the parade ground" (Anonymous 1905*b*), and a Field and Stream article stated that "Major Pitcher will feed the antelope when they require it" (Hofer 1902). This program expanded quickly. In the summer of 1904, YNP planted and irrigated 50 acres of alfalfa inside the park near Gardiner, and soon was harvesting about 100 tons/year (Pitcher 1905, Anonymous 1906*a*). With the additional resources provided by the feeding program, and in combination with predator control, pronghorn population estimates doubled from 1,000 in 1903 to 2,000 in 1908 (Fig. 3). Barmore (1981:88) wrote that "[e]stimates of 1,000–2,000 [pronghorn] between 1903 and 1908 probably refer to summer rather than winter populations, which were apparently half or less as large." His interpretation is contradicted, however, by first-hand accounts clearly indicating that these were the numbers of animals that *wintered* in the park, and that access to traditional wintering areas down the Yellowstone Valley had, by this time, been largely cut off (see Anonymous 1904, 1905*a*, 1905*b*, 1906*a*, 1906*b*; Pitcher 1905).

The alfalfa-fed increase in the pronghorn population ended abruptly with a series of harsh winters (Nelson 1925). Because of ambiguities in some accounts, I found it difficult to be entirely certain of dates and recommend a detailed review of the weather record. However, severe winters appear to have occurred during 1907–1908, 1909–1910, 1910–1911, and 1916–1917 (Hofer 1908*a*; Superintendent 1910, 1911; Anonymous 1910, 1913; Murie 1940:101, quoting Bailey 1930:30; Barmore 1981:Table 105). As expected, population counts and estimates tended to decline for these years. For 1907–1908, no decline was seen. However, the estimate of 2,000 animals apparently was obtained early in the winter and the decline occurred later when “all but 25 escaped through the park fence below Gardiner and went down to the lower valleys, where at that time they were unprotected, and many never returned" (Murie 1940:101, quoting Bailey 1930:30).

1918–1945

The National Park Service (NPS), newly created in 1916, took control of YNP in 1918 (Anonymous 1997). Pronghorn counts and population estimates remained relatively low (<400 animals) for several years thereafter. There was, however, evidence of an increase during 1922–1925, as counts steadily climbed from 253 to 417 animals (Fig. 4, Appendix A). Interpretations are confounded by the lack of count data for 1926–1928, but counts increased from 510 animals in 1929 to 668 in 1932 (Fig. 4, Appendix A), suggesting an overall increasing trend for the decade 1922–1932. Counts declined during 1934–1936, and estimates declined during 1936–1937. Counts also were notably low in 1942 and 1944, although estimates for those same years showed little change.

Interpretations of counts and estimates for this period are confounded by the many changes, both natural and man-caused, that occurred during this time. The NPS initially continued the predator control and, presumably, feeding programs begun by the Army (Murie 1940, Fig. 5). Feeding was expanded as important winter ranges were acquired from private landowners and cultivated starting in 1925 (Whittlesey 1995). These same areas were annexed to the park as the BLA in 1932 (Whittlesey 1995). In 1933, however, the park began to phase out artificial feeding, and in 1934 the program was terminated. Predator control ended in 1935 (Fig. 5). Prolonged drought during the early- to mid-1930s dramatically affected range condition (Grimm 1937, as quoted by Houston 1982:424–425) and may have contributed to a decline in big sagebrush (Bauer 1938, as quoted by Houston

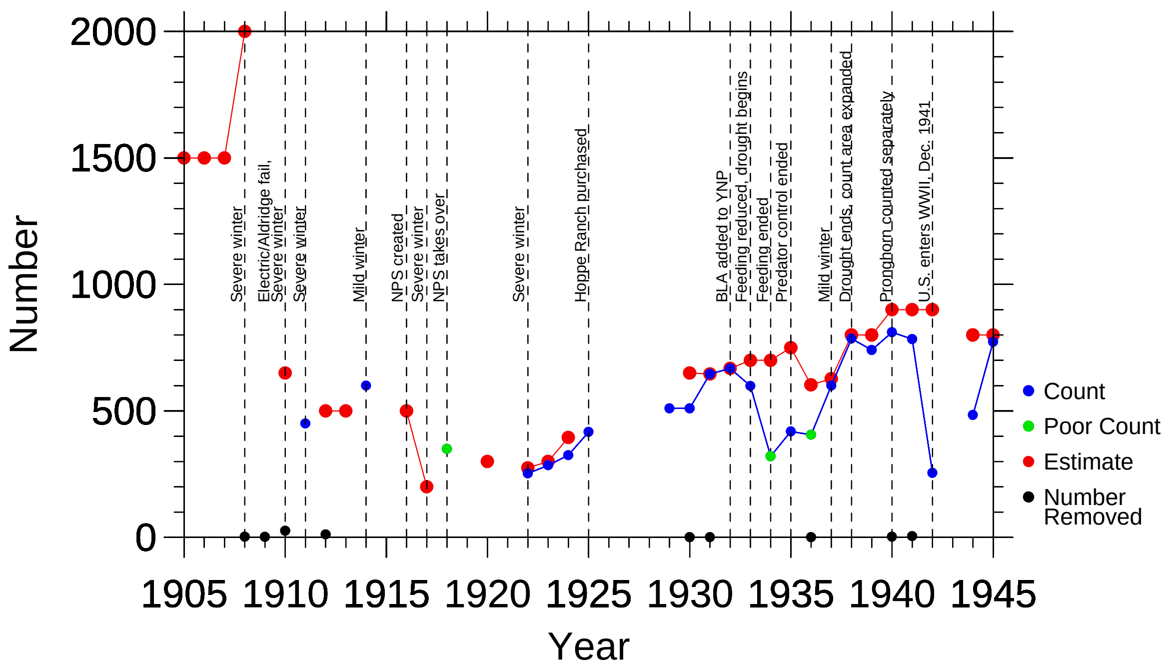

Fig. 4. Pronghorn population counts, estimates, and removals in Yellowstone National Park, 1905–1945, together with comments (see Appendix A for details). A "Poor Count" is one that was explicitly labeled as such in the historical record.

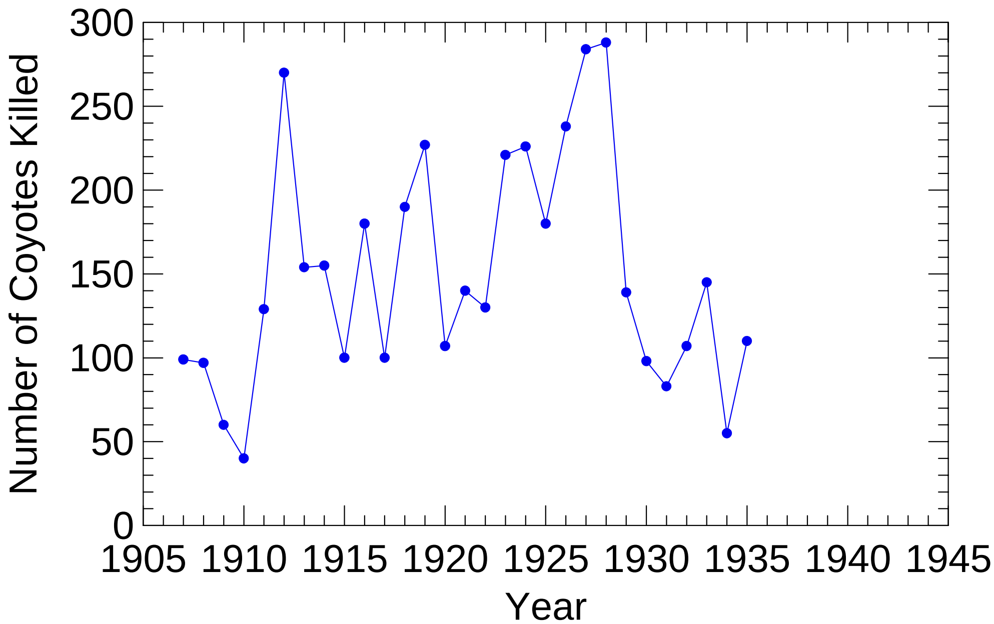

Fig. 5. Distribution of deaths for the 4,352 coyotes killed in Yellowstone National Park during 1907–1935 (from Murie 1940:15).

1982:425). Count completeness likely improved in 1937 as the count area was expanded to include areas outside the park, and again in 1940 when the park began to survey pronghorns separately (Barmore 1981). However, count completeness fell dramatically as the park experienced a personnel shortage during 1941–1945, due to U.S. involvement in World War II. Weather records (which I did not review) might also show a correlation between low counts during the early 1940s and winter severity (D. Houston, pers. commun.).

Previous interpretations of pronghorn population trends during this time have accounted for only some of these factors — sometimes in ways that do not jibe with either the count data or the chronology of events. For example, Houston (1982, citing Barmore 1981) wrote that,

> "Ground counts suggest stable winter populations of 500–700 pronghorns from 1930 to 1937. The pronghorn population increased to 600–800 from 1938 to 1947 after addition of private land to the park and removal of a boundary fence increased their winter range."

I offer a different interpretation. When the NPS assumed control of YNP, the pronghorn population had already been greatly reduced by a series of severe winters during 1908–1917. Following another harsh winter in 1921–1922 (Heller 1925), the pronghorn count was at a then-record low of 253 animals. Increased counts during 1922–1925 probably reflected normal population recovery from these events. Purchase of the Hoppe Ranch in 1925 marked the beginning of a series of important land acquisitions that culminated in annexation of the BLA in 1932, but there is no reason to believe that effects of these acquisitions on the pronghorn population were delayed until 1932, as the Game Preservation Company made the lands available for park use immediately after purchase (Whittlesey 1995). Pronghorn carrying capacity may have increased somewhat in 1933 as fences and buildings in the BLA were razed (Anonymous 1934, 1936), but many of the benefits of annexing the BLA likely accrued during 1925–1932 as the lands were purchased. Overall, I suggest that increased pronghorn counts during 1925–1932 were fueled, at least in part, by: (1) continued population recovery from the series of harsh winters, (2) increased winter range availability, and (3) continued feeding and predator control programs. Weather records during this period should be reviewed for additional explanatory variables. Pronghorn counts and estimates dipped during 1933–1937 (Fig. 4). Although counts in 1934 and 1936 were considered poor, I note that this was a period of severe drought on the northern Yellowstone winter range (Grimm 1937, as quoted by Houston 1982:424–425). Given negative effects of drought on big sagebrush (Anderson and Inouye 2001) and the importance of sage to wintering pronghorns, it is reasonable to suggest that the drought negatively affected pronghorn numbers. Interpretations regarding the post-drought population are confounded by changes in counting protocols (Fig. 4, Appendix A), but it seems likely that, during 1938–1945, the population was relatively stable at a size equal to or, perhaps, somewhat greater than its pre-drought level. The observed decline in pronghorn counts during World War II was likely due to reduced observer effort rather than a real decline in the underlying pronghorn population, although a detailed review of the weather record might alter this interpretation somewhat.

1946–1967

Pronghorn policy shifted dramatically when, in the summer of 1946, YNP approved a plan to reduce the population to 400 animals (Barmore 1981:Table 105, citing Anonymous 1946), thereby initiating a long-term decline in pronghorn numbers (Fig. 6). By 1950, further

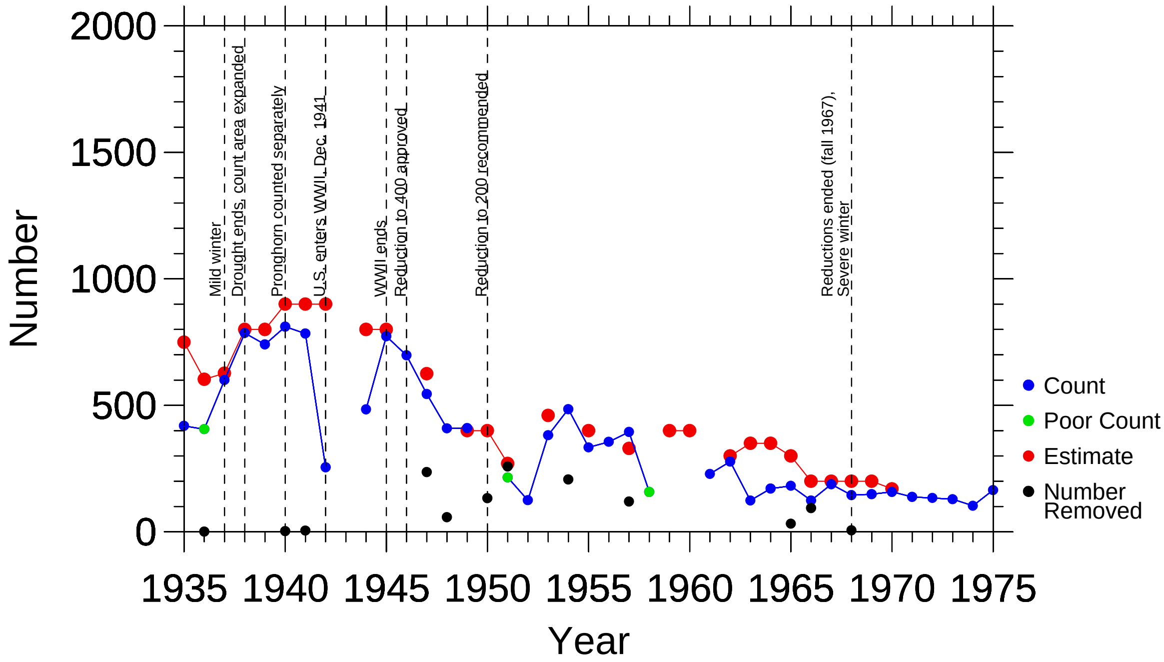

Fig. 6. Pronghorn population counts, estimates, and removals in Yellowstone National Park, 1935–1975, together with comments (see Appendix A for details). A "Poor Count" is one that was labeled as such in the historical record.

reductions were recommended, based on studies that "show[ed] that not over 200 pronghorn should be retained until seriously over-used winter range improves" (Barmore 1981:Table 105, citing Anonymous 1950*a*). By 1953, herd reduction to 100–125 animals was planned (Anonymous 1953, Hamilton 1953). The target population size apparently remained in this range until the reduction program ended in 1967 (Howe 1965*a*, McLaughlin 1965).

At least 1,144 pronghorns were removed during the 1947–1967 herd reduction program (Appendix A). Scott (1988) tallied 1,015 removals during this period, but apparently did not include 133 animals transplanted to Nevada in 1950 (Scott 1994, Anonymous n.d.). I cannot account for the remaining discrepancy of 4 animals. Also, I emphasize that 1,144 should be regarded as a minimum, as I seldom found evidence that a reduction did *not* occur during those years for which no removals are listed.

1968–2001

After the reduction program ended, pronghorn counts remained relatively stable for 15 years (1968–1982), fluctuating between 102 and 165 animals (Fig. 7, Appendix A). Concern over "precariously low numbers" led Houston (1973) to recommend that the population be augmented by a "reintroduction of 100 animals." Superintendent Jack Anderson pursued this recommendation (Freeman 1973), but apparently it was never implemented. Counts climbed to 310 animals in 1983 and peaked at 588 animals in 1991. During this period of growth the only major decline followed the post-fire winter of 1988–1989 when the count fell 17%, from 495 to 411. However, it is unclear whether the 1988–1989 count indicated a real change in population size, as it was considered a poor count, probably due to dry conditions resulting in a scattered distribution of animals. In 1992 and 1993, counts declined to 536 and 439, respectively. No count was made in 1994. The count then fell to 235 in 1995, and subsequent counts have remained relatively stable at 204–235 animals.

Causes of population trends during this period are unclear. Scott (1988) reasoned that even the decline in pronghorn numbers seen during 1946–1967 was not due to YNP's reduction program, as evidenced by density-dependent responses in 1951, 1954, and 1966, and by the fact that "the slide continued for 15 years after the removal program stopped in 1967." Instead, Scott (1988) maintained that, based on "[a]nalysis of historical management records and climatological data," 5 major interacting factors have historically determined pronghorn population trends: (1) November–March precipitation, (2) access to native winter range, (3) availability of hay and grain crops, (4) June precipitation, and (5) total annual precipitation available to food plants. Scott (1988) further concluded that:

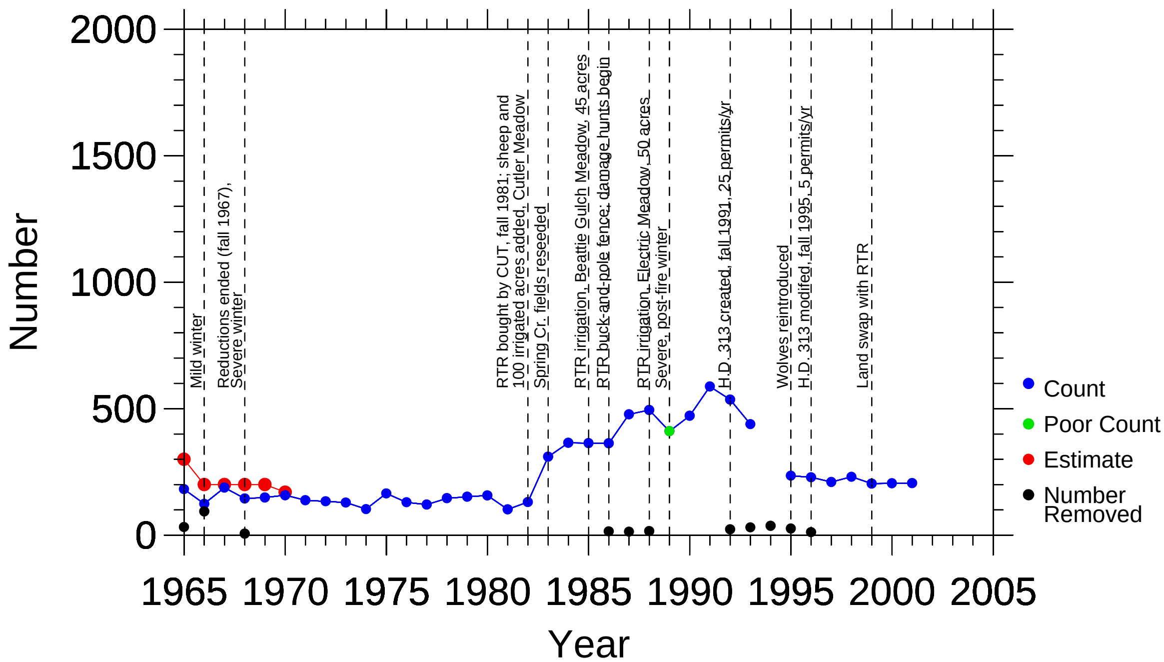

Fig. 7. Pronghorn population counts, estimates, and removals in Yellowstone National Park, 1965–2001, together with comments (see Appendix A for details). A “Poor Count” is one that was labeled as such in the historical record.

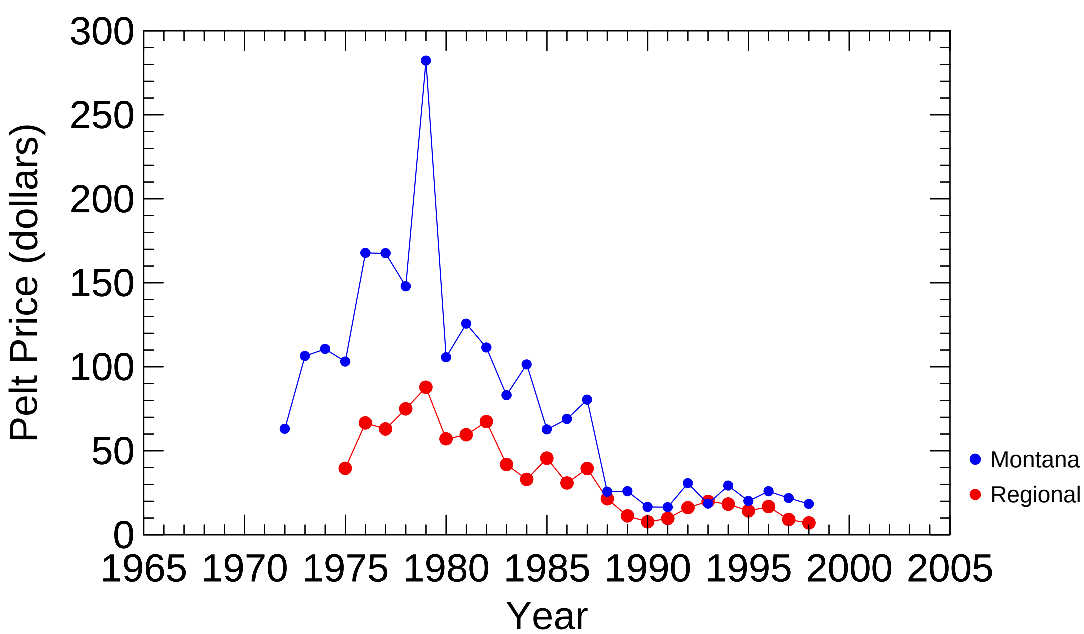

Fig. 8. Average coyotes pelt prices for Montana (Appendix B) and for the region including Montana and Wyoming (Appendix C), 1972–1998. Figures are adjusted for inflation and are given in 2000 U.S. dollars.

> "When three or more of these five factors were favorable for a number of consecutive years, the herd increased or maintained a high population level. When three or more factors were neutral or unfavorable, the herd declined or maintained a low population level. During any given time period, only one limiting factor may have been most decisive."

Unfortunately, Scott's (1988) results are known only from a 1-page abstract; thus, his data and methods, as well as details of his reasoning are beyond meaningful review. Because an analysis of weather data was beyond the scope of this review, I did not attempt to independently test Scott's conclusions, but do recommend further study of possible relationships between population trend and weather.

Another hypothesis regarding population trend is that numbers began to increase in 1983 due to increased predator control near the park boundary, prompted by high pelt prices (J. Mack, NPS, pers. commun.). According to this hypothesis, pronghorn counts should be positively correlated with coyote pelt prices, perhaps with some reasonable time lag. However, pelt prices began to climb by at least 1973 and peaked in 1979 (Fig. 7), 4–l0 years before pronghorn counts began to increase. Visual comparison of Figs. 7 and 8 suggests that, although trends in pelt prices and pronghorn counts share a similar overall shape, the chronology of pelt prices is roughly 10 years ahead of the chronology of pronghorn counts. Given the reproductive potential of both coyotes and pronghorns, it is difficult to imagine a biological explanation for such a time lag. However, it is possible that prolonged control may have been necessary before an effect was evident. Also, the RTR ran domestic sheep from 1982 until the early- to mid-1990s, and with the sheep came opportunistic control of coyotes (C. Kelley, CUT, pers. commun.). Thus, RTR activities may have influenced coyote densities near the park boundary, independently of pelt prices.

Land-use changes during 1981–1991 may have increased pronghorn carrying capacity. The RTR borders YNP north of Reese Creek and contains areas used by a large part of the pronghorn population at various times of the year (see Distribution and Habitat Use). The RTR was purchased by CUT in 1981. By

1987, "[t]he total amount of irrigated fields on the [RTR] available for wildlife winter range use near the Park [was] increased a total of at least 190 acres" (Francis 1987). Increased irrigation included 100 acres at Cutler Meadow (added in 1982), 45 acres at Beattie Gulch Meadows (added in 1985), and 50 acres at Electric Meadow (added *c.* 1987/1988) (Francis 1987; C. Kelley, CUT, pers. commun.). In addition, fields near Spring Creek were plowed and reseeded in 1983 (Singer 1988). Complaints from the RTR resulted in damage control hunts beginning in the fall of 1985, and suggest that pronghorn use of these habitats may have been substantial. Under this hypothesis, irrigation of Cutler Meadow is the necessary explanation for increased pronghorn numbers in 1983 because irrigation had not been expanded to the other areas at that time. The explanation does not appear to be a viable one, however. Singer (1988:10) reported that "[i]n the winter of 1985–86 and 1986–87 a small group of 13–15 antelope colonized winter range on private land near Cutler Lake." However, I found no record of earlier use and it is not clear that pronghorn use of Cutler Meadow was substantial enough to account for a large increase in numbers, as anecdotal accounts have consistently placed most pronghorn use south of Cinnabar Mtn.

Other events have been suggested, implicitly or explicitly, as possible contributing factors in the post-1991 decline in pronghorn numbers. These include: (1) wolf reintroduction, (2) fencing of the park's northern boundary, (3) disturbance associated with bison management activities, and (4) pronghorn hunting outside the park. The fact that wolves were not reintroduced to YNP until 1995 (Anonymous 1997) — after pronghorn numbers had already crashed — clearly absolves wolves of responsibility for the pronghorn decline. The RTR constructed a buck-and-pole fence along the park boundary in 1986 and Scott (1992) reported that the fence partially inhibited trans-boundary movements by pronghorns. However, population counts continued to mostly increase during the 5 years after the fence was built; thus, there is no prima facie evidence that the fence affected pronghorn numbers. Caslick and Caslick (1997) indicated that pronghorns avoided disturbances associated with bison management activities, which suggests the hypothesis that recent pronghorn trends might be tied to bison-related disturbances in the BLA. However, pronghorn numbers crashed before intensive bison management began. Also, bison management activities along the park's northern border have been minimal since the severe winter of 1996–1997, yet pronghorn counts have not increased (Fig. 7). Hunting pressure apparently increased when antelope hunting district 313 was created in the fall of 1991 and the number of permits increased from 5 to 25. Given the reproductive potential of pronghorns, this level of hunting pressure, by itself, is insufficient to have limited the population (then estimated at over 500 animals). While it might be argued that hunting-related disturbance could have excluded animals from important habitats, it seems unlikely that a fall hunt would have excluded them during a critical period.

An additional hypothesis that emerged from discussions at the Yellowstone Pronghorn Conservation Assessment Workshop is that during recent decades pronghorn trends in YNP have been driven by regional rather than local factors. Count data for Grand Teton National Park, Wyoming, and Hart Mountain National Antelope Refuge, Oregon, were cited as support for this hypothesis. Numbers of pronghorns recorded in these areas increased during the 1980s, peaked during the early 1990s, then declined precipitously — a pattern quite similar to trends in YNP pronghorn counts (Fig. 9). Although these data provide tentative support for the hypothesis that pronghorn population trends are driven by regional factors, they should be interpreted cautiously. Observations in and near Grand Teton National Park apparently were conducted for the purpose of herd classification (McWhirter 1999). It is not clear that they provide a legitimate measure of population trend. Moreover, associated counts from Hunting Areas 86–90 in Wyoming's Sublette Management Area indicate that the general pattern observed in YNP, Grand Teton National Park, and the Hart Mountain Refuge was not universal. For example, some areas showed relatively steady increases in numbers of animals observed during 1984–1999 (Fig. 9). Overall, no definitive conclusion is possible from these data, but this hypothesis clearly merits further study.

Population Viability

Using Scott's (1994) compilation of historical counts and artificial removals, Goodman (1996) assessed population viability both qualitatively and quantitatively for the YNP pronghorn herd. Details of this work (and the database it relied upon) merit careful consideration, as this assessment has greatly influenced perceptions about the seriousness of risks facing this population.

Goodman's (1996:5) qualitative assessment of population status was that "[t]his antelope population is extremely vulnerable to wide swings in numbers, and the risk of extinction is high." Factors believed to contribute to the high risk of extinction included heavy coyote predation of young, crowding on the winter range, and concentration in one

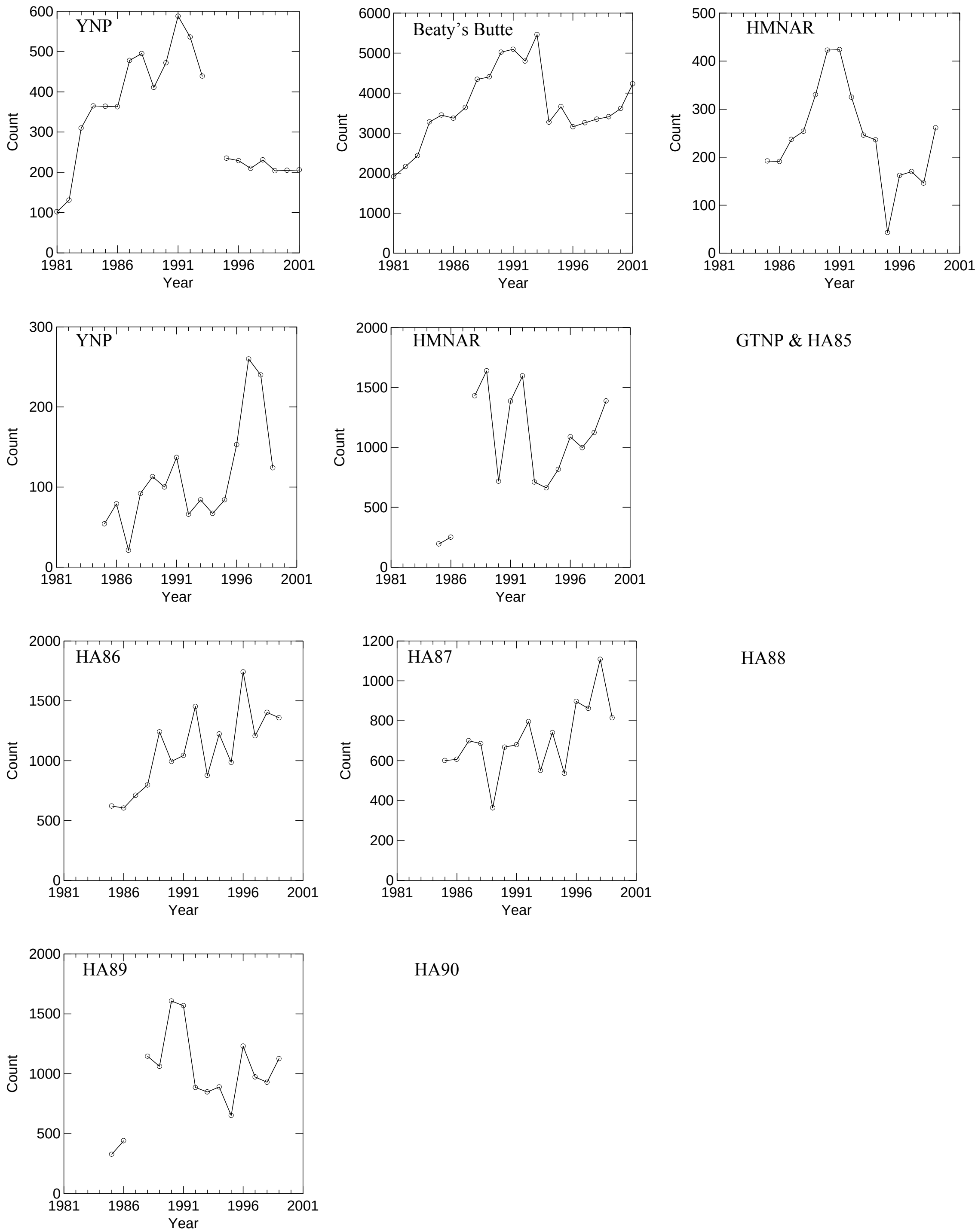

Fig. 9. Trends in numbers of pronghorns counted in Yellowstone National Park (YNP), Wyoming, and on the Hart Mountain National Antelope Refuge (HMNAR), Oregon, and surrounding areas. Also shown are numbers of animals classified during August classification counts in Grand Teton National Park (GTNP), Wyoming, and the surrounding Hunting Area 85 (HA85), as well as Hunting Areas 86–90 (HA86–HA90) in Wyoming's Sublette Management Area.

wintering area, raising "the possibility of disease or freak weather conditions" (Goodman 1996:5). Goodman (1996:5) also noted that "[t]he highest quality winter and spring habitat for this population is the agricultural land outside the park," and that the availability of these lands "is affected by hunting and other attempts to reduce the depredation of herbivores on the property…"

In his quantitative assessment of population viability (Goodman 1996:5) used a random walk process, in which annual multiplicative factors of population increase were drawn randomly and independently from a distribution formed from the observed factors of increase for 1887–1993. Observed values were corrected for recorded removals and were adjusted to achieve a geometric mean of 1.0 so that the model population would not be predisposed to either increase or decrease. Goodman's (1996) analysis yielded a mean time to extinction of 343 years, an 18% probability of extinction within 100 years, and a 41% probability of extinction within 200 years. Assumptions important to Goodman's (1996) findings include:

- No future artificial removals.
- No errors in the compiled census or removal data.
- No density dependence.
- A future distribution of dynamic variation like the historic variation corrected for effects of removals.
- A single, closed population, demographically regulated together.
- A population ceiling of 2000 animals.
- No additional demographic stochasticity at population numbers smaller than those in the historical record.

Now that the State of Montana has proposed to close antelope hunting district 313 in 2002 (MDFWP 2001), it appears that the first assumption will soon be met. However, the remaining assumptions are violated, sometimes seriously. For example:

- As detailed above, known and sometimes significant errors exist in Scott's (1994) census and removal data.
- Relative stability of the population in the face of environmental variation during 1968–1982, and failure to decline from already low numbers in response to harsh winters (e.g., the winters of

1921–1922 and 1996–1997) suggests density dependence.

• To a large degree, annual factors of increase historically were driven by management actions that are no longer operative (e.g., feeding, predator control, and acquisition of habitats in the BLA).

• Early counts and estimates may reflect inter-annual differences in pronghorn distribution rather than population size, as they were based on observations of an open population at the upper elevational limit of that population's winter range.

• The present day herd apparently is composed of migratory and non-migratory sub-populations that exhibit different dynamics (J. Mack, National Park Service, pers. commun.).

• A ceiling of 2000 animals is unrealistically high, being based on figures from 1908 when the population was either open or only recently closed, and numbers were inflated by artificial feeding, predator control, and the practice of containing migratory animals within the park via fencing and/or hazing.

Overall, I believe the assumptions of Goodman's (1996) analysis are violated in a way that exaggerates the true variance in the distribution of factors of annual increase. This would lead to underestimating population persistence time and overestimating extinction risk. It is not clear that legitimate alternative approaches to viability analysis exist using available data. To the extent that a rigorous viability analysis is required, data needs should be identified and sampling protocols implemented to gather the necessary data.

GENETICS

Genetic concerns regarding YNP pronghorns have been raised only recently. In 1989, an outside advisory committee recommended research to "determine genetic relationships between Yellowstone pronghorns and herds outside the park" (Anonymous 1990:8). This item ranked sixth among the committee's recommendations and stemmed from concerns over preserving the genetic purity of Yellowstone's pronghorns, minimizing the risk of inbreeding, and understanding the degree of genetic interchange with and relatedness to adjacent pronghorn populations (Anonymous 1990). There have been 2 attempts to address this recommendation.

Lee et al. (1994) assessed allozyme and mitochondrial DNA (mtDNA) variation among 29 North American pronghorn populations, including the YNP herd. Examining tissues from 11 YNP animals, they reported that mean heterozygosity = 0.006, mean number of alleles per locus = 1.10, and 9.1% of loci were polymorphic (Lee et al. 1994:309, Table 1). These values were less than mean values based on all 29 populations, suggesting that allozyme variation in YNP pronghorns is relatively low. In contrast, YNP animals exhibited the highest mtDNA variation of any population sampled, with 4 haplotypes reported from 7 animals (Lee et al. 1994:313, Table 4). Of those, haplotype J was found only in a single animal from YNP, leading Scott and Geisser (1994:1) to label YNP pronghorns as "genetically-unique." The claim of genetic uniqueness is contradicted, however, by Reat et al. (1999), who observed haplotype J in 16 of 389 pronghorns sampled in Arizona.

Following the study by Lee et al. (1994), Dr. Douglas Scott (YNP) initiated a project with Dr. Ernest Vyse (Montana State University) to address five questions (Scott *c.* 1993):

- Is there less heterozygosity in the Yellowstone herd as compared to the nearest herds outside the Park?
- Are there significant genetic differences between Yellowstone pronghorns and the nearest other herds that are not descendents of Yellowstone transplants?
- Are there significant genetic differences between migratory and nonmigratory pronghorns in Yellowstone?
- Which, if any, of the herds surrounding the park is the Yellowstone herd most closely related to?
- Is there evidence that animals from outside herds have immigrated to the Yellowstone herd in recent decades?

In correspondence with Dr. Vyse, Scott (1993*b*) indicated he had acquired 132 liver samples for this work. Of these, 116 were provided earlier to Lee et al. (1994), but only 30 were used — leaving 102 samples that were never analyzed. A freezer failure at Montana State University ultimately caused the loss of all samples, and the proposed work with Dr. Vyse was never completed (P. Gogan, USGS Northern Rocky Mountain Science Center, pers. commun.). Ultimately, definitive answers to the major genetic questions posed by the 1989 advisory committee are still lacking.

DISEASE

Numerous diseases and parasites have been documented in pronghorns from YNP. Skinner (*c.* 1922*b*) emphasized concerns about actinomycosis (lumpy jaw), stomach worm, tapeworm, wood tick and scab mite. Rush (1932:105) reported that, of 13 carcasses examined, "[s]ix showed necrotic ulcers in mouth (foxtail mouth); all showed decayed teeth to a greater or lesser degree; four were infested with lung worms *Dictyocaulus sp*., two with intestinal worms *Ostertagia sp*. and *Nematodirus antilocaprae*, one with tape worms *Moniezia sp*., all of them with wood ticks." Examining 48 fecal samples from pronghorns shot during YNP's herd reduction program, Todd and Hammond (1967) reported that 21% were infected with *Eimeria antelopcaprae*. Necropsy of a single male pronghorn (Cornish 2000) revealed lung nematodes ("probably *Protostrongylus* sp.") and the respiratory pathogen *Pasteurella hemolytica*, as well as bacterial kidney and spleen infections. Benson (1909) provided the only suggestion that disease may have significantly affected pronghorn population dynamics:

> "…one or two antelope die each week, from what cause is not known, though they do not die violent deaths. The outpost in that vicinity have on one or two occasions seen them stagger and fall and have immediately gone to them and found them unable to arise, dying some two or three hours later. I inspected one of these immediately after death and found a large ulcer on the side of the face, but in two other cases no sore or injury of any kind could be discovered."

In the largest analysis to date, samples from 32 YNP pronghorns were examined for a variety of health parameters. The copy of the report I examined failed to indicate the author or organization responsible for the analysis, but other correspondence leads me to believe that the Wyoming State Veterinary Laboratory might have performed the tests. Trace mineral analyses were normal and gave no evidence of exposure to significant levels of arsenic or lead. Tests revealed that 75% (n = 24 animals) had been exposed to the bacterium *Chlamydia psitacci*, 59% (n = 19) to parainfluenza virus type 3, 9% (n = 3) to bovine viral diarrhea virus, and 3% (n = 1) to bovine respiratory syncytial virus. Tests revealed no evidence of exposure to *Brucella abortus*, bluetongue virus, epizootic hemorrhagic disease, *Mycobacterium avium paratuberculosis*, or *Leptospira interrogans*. Only low parasite loads were found. Overall, the report concluded that "there are no obvious health problems detectable by antemortem sampling in this pronghorn herd," but that the high incidence of *Chlamydia* exposure warrants further study.

No clear evidence of management response to pronghorn disease concerns was found in the materials I reviewed. Skinner (*c.* 1922*b*) recommended preventive measures to deal with diseases and parasites, including control of certain exotic grasses, limiting contact between pronghorns and domestic livestock, fencing and fall plowing of irrigated fields within the Park, burning infected pronghorn carcasses, predator control for all native canid species and strict control of domestic dogs, and fencing or burning areas where animals congregate, particularly feeding grounds. Many of his views were later repeated and expanded (Skinner *c.* 1924), but it is unclear as to which recommendations, if any, were actually implemented. Predator control was already underway before 1922. Domestic cattle were removed from YNP, but no indication of the timing of and reasons for removals was uncovered.

As part of an overall research strategy, the outside pronghorn advisory committee, convened by YNP in 1989, recommended limited monitoring for diseases like brucellosis and leptospirosis, as insurance against possible claims that pronghorns might transmit these diseases (Anonymous 1990). They cautioned, however, that such monitoring should not be a major research item (Anonymous 1990). Subsequent analyses generally support their recommendation, as no evidence exists of a population-level health problem and serological tests yielded no evidence of exposure to brucellosis or leptospirosis. An exception is the previously cited analysis, which makes a case for studying effects of *Chlamydia*.

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Appendix A. Summary of pronghorn maximum counts, estimates, and removals on the northern Yellowstone winter range, 1872–2001.

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1872				"From 1872 to 1883 it is reported that antelopes were killed each year in the park 'by the thousands.' "	Skinner (c. 1924:7)
1877				"Thousands of antelope."	Skinner (1922*a*)
1880				"Abundance of antelope."	Skinner (1922*a*)
1886				"Antelope are here in large numbers."	Skinner (1922*a*)
1887, winter		200		"Large numbers of antelope"	Anonymous (1887*b*), Hofer (1887*a*)
1888, Jan. 1		275			Scott (1994)[1]
1889, early winter		300			Hofer (1889*a*)
1890, Feb. 20	323				Hofer (1890)
1891, Mar. 10		≥800	2	Especially mild winter, at least thru January 9.	Hofer (1891*a*,*b*), estimate and comments; Scott (1994)[1], number removed
1892			1	"Thriving and increasing."	Scott (1994)[1], number removed; Skinner (1922*a*), quote
1893, winter		300–500		"Saw great numbers of antelope, surely 300 (probably 400 or 500)…" "One herd of four to five hundred wintered on Mt. Everts and one or two smaller herds elsewhere."	Anonymous (1893), estimate and first quote; Skinner (1922*a*) second quote
1894, winter		500		"500 wintered on Mt. Everts."	Skinner (1922*a*)
1895, winter		800			Anonymous (1895)
1896, winter		1,000	20	"…great increase of numbers."	Lindsley (1897), estimate; Scott (1994)[1], number removed; Murie (1940:13, quoting Superintendent's Annual Report 1896), quote.

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1897, winter		500		"The large herd of antelope that has always wintered on the flat near Gardiner was driven out during the first severe storm after the crust formed. They passed on down beyond Gardiner and Cinnabar, and many of them have been killed.	Lindsley (1897); Skinner (1922*a*); Murie (1940:13); Anonymous (1897) for comments
1898		500			Anonymous (1898)
1899		700–800			Skinner (1922*a*)
1900				"Increasing."	Skinner (1922*a*)
1901				"all varieties, including antelope,…are increasing…"; "…an easy open winter."	Anonymous (1901), first quote, Hofer (1901), second quote
1902			2	"I do not notice any particular increase in the number of antelope." "Number of bands of from 50 to 100 wintered on slopes of Mt. Everts."	Scott (1994)[4], number removed; Hofer (1902), first quote; Skinner (1922*a*) (see, also, Anonymous 1902), second quote.
1903, fall	900	1,000		"About 900 antelope have already been seen this fall on the northern slope of Mount Everts, and near the town of Gardiner, and I believe the number in the park to be about 1,000."	Anonymous (1903)[5]
1904, winter	1,150[6]			"About 1,150 were seen and counted…" "…the average of several counts showed 1,100 antelope…"	Pitcher (1905) for first quote, Anonymous (1905*a*) for second quote
1905, winter		1,500[7]		"…there are between 1,500 and 1,700 [pronghorns]…"; "The park herd consists of about 1,500 animals and seems to be increasing in numbers quite rapidly."	Anonymous (1905*a*), first quote; Anonymous (1905*b*), second quote.
1906		1,500			Anonymous (1906*b*)
1907, winter		1,500		Scott (1994) gives an estimate of 2,000, but does not list the source of his information	Skinner (1922*a*)
1908, winter[9]		2,000	3	"…about 2,000 were estimated in the park but during the following winter all but 25 escaped through the park fence…and many never returned."	Anonymous (1908) and Skinner (1922*a*), estimate; Scott (1994)[1], number removed; Bailey (1930:30), quote.

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1909			2	"Increasing."	Scott (1994)[1], number removed; Skinner (1922*a*), quote.
1910		600–700[10]	26	Removals included animals sent to the Witchita National Game Preserve, Oklahoma, and the National Bison Range, Montana.	Skinner (1922*a*), estimate; Scott (1994)[1], number removed; Nelson (1925), comments.
1911, Feb.	450[11]			"The snow along their range has been unusually deep, and…they insist on getting over or through the fence…"; "The antelope…are scattered more than usual and so quite difficult to count."	Superintendent (1911), estimate, first quote; Anonymous (1911*a*,*b*), second quote.
1912, ?[12]		500	12	"Estimate based on actual counts or very close observations and are pretty nearly correct."	Barmore (1981, citing Superintendent's Annual Report 1912 and Halloran and Glass 1959), estimate and quote; Scott (1994)[1], number removed.
1913		500		"Increased slightly."	Scott (1994)[1], estimate; Skinner (1922*a*), quote.
1914	600			"The winter of 1913–1914 was one of the mildest ever known in the…Park…"	Skinner (1922*a*), estimate; Anonymous (1914), estimate and quote.
1916		500			Barmore (1981:Table 105, citing Bailey 1930)
1917, spring before fawning		200		"…in 1916, 500 [antelope were estimated in the park herd]. In the spring of 1917 most of these left the park and later, when driven back, only about 200 were accounted for."	Murie (1940:101, quoting Bailey 1930:30)
1918	350			"This was the number seen in one day. '…no special pains were taken to make a complete count of the herd.'"	Barmore (1981:Table 105, citing Superintendent's Annual Report 1918)
1920		300			Barmore (1981:Table 105, citing Superintendent's Annual Report 1920)
1922, spring count	253	275			Anonymous (1931), count; Skinner (1922*c*) and Superintendent (1922), estimate

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1923, spring count	285	300			Anonymous (1931), count; Barmore (1981, citing Superintendent's Annual Report 1923), estimate
1924, Jan. count	325	395			Barmore (1981:Table 105, citing Woodring 1924)
1925, late Apr.	417				Barmore (1981:Table 105, citing Superintendent's Annual Report 1925)
1929, Mar. 29	510				Scott (1994)[1], date; Anonymous (1931), count
1930			1		Scott (1994)[1], first date; Barmore (1981:Table 105, citing Baggley n.d.), counts and estimate; Scott (1994)[1], number removed
Sept. 21, 1929	638[14]				
Feb.	510				
Spring		650			
1931			1		Anonymous (1931) and Baggley (1932), count; Barmore (1981:Table 105, citing Baggley 1931), estimate; Scott (1994)[1], number removed
Feb.	646				
Spring		646			
1932, Apr.	668	668[15]			Scott (1994)[1], date; Tell (1932)
1933, spring	599	700			Barmore (1981:Table 105, citing Anonymous 1936), Anonymous (1933)
1934, Mar. 14–16	321	700		"Incomplete count."	Barmore (1981:Table 105, citing Anonymous 1936), Anonymous (1934), Murie (1940:101)
1935, Mar.	419	750			Scott (1994)[1], date; Barmore (1981:Table 105, citing Anonymous 1936) and Murie (1940:101), count and estimate
1936				"Count by 7 men considered not fully successful."	Barmore (1981:Table 105, citing Skinner 1936), Skinner (1936), and Murie (1940:101), count and estimate; Scott (1994)[1], removal data
Sept. 16, 1935			1		
Apr. 2	406	603			
1937, Mar. 2–3	600	627		"Count by 10 men was one of the most accurate and complete ever taken. Increase over last year reflects better count rather than actual increase."	Barmore (1981:Table 105, citing Barrows 1937)

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1938, Feb. 24	786	800		"Six men, excellent weather, thorough coverage of counting units. Outside count by Forest Service. Antelope are increasing."	Barmore (1981:Table 105, citing Barrows 1938)
1939, Mar. 21–24	741	800		"Park count by 12 men, excellent weather, but animals widely scattered which might account for lower count than year before. Outside count by Forest Service."	Barmore (1981:Table 105, citing Barrows 1939)
1940, Feb. 7	811	900	3	"Pronghorn, deer, sheep counted separately for first time and may have increased count accuracy. Normal to mild winter. Includes 70 reported by Forest Service and ranches near Corwin Springs which wasn't covered." Removal in March.	Barmore (1981:Table 105, citing Skinner 1941); Scott (1994)[1], removal data
1941, Mar. 24	784	900	5	"Though weather and snow not favorable for easy and thorough count, it was considered reasonably successful. Less accurate than 1940. Count by 9 men. Herd size same as in 1940." Removals: 4, spring; 1, Aug. 23	Barmore (1981:Table 105, citing Skinner 1941); Scott (1994)[1], removal data
1942, Mar. 19	255	900			Scott (1994)[1], count; Barmore (1981:Table 105, citing Superintendent's Annual Report 1942), estimate
1943				"Some losses occurred during the winter and 58 carcasses were found during the dead animal count."	Barmore (1981:Table 105, citing Superintendent's Annual Report 1943)
1944					Scott (1994)[1], count; Barmore (1981:Table 105, citing Anonymous 1944), estimate
Mar. 19	484				
Fall		800			
1945, Feb. 21–22	773	800		"Eleven men; probably missed very few."	Barmore (1981:Table 105, citing Anonymous 1945*a*,*b*)
1946, Mar. 26	698			"Favorable counting conditions. Count by 10 men in park was reasonably accurate. Lower count that in 1945 probably due to wider distribution out of park (not covered) rather than reduced numbers. Authority to reduce herd to 400 granted in summer, 1946. Trapping in fall, 1945, caused unusual disturbance."	Barmore (1981:Table 105, citing Anonymous 1946)

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1947			236[16]	"236 trapped in Jan. 1947, 58 on Dec. 16, 1947. During Dec. 16 trapping 12" of heavy, crusted snow at the tree nursery. After January trapping, most pronghorn remained out of park as far as Carbella but returned by March 1." "Estimate is based on census of April 1947 and probable summer increase."	Barmore (1981:Table 105, citing Rogers 1948 for the count, Kittams 1947 for the estimate, and LaNoue 1948 for the reduction); Barmore 1981), first quote; Kittams (1947) second quote
April	545				
Fall		625			
1948, Jan. 6	409		58[17]	"Poor weather; favorable counting conditions; count a fair appraisal of current numbers. Aerial checks during trapping prior to ground count indicated not many more than 400."	Barmore (1981:Table 105, citing Grimm 1948)
1949, Feb. 1	410	400		"Highly successful count. Weather and other conditions unusually favorable. All known pronghorn range covered."	Barmore (1981:Table 105, citing Joffe 1949 for count, Anonymous 1949 for estimate)
1950				"Despite protection, these animals do not appear to increase in number."	Anonymous (1950*b*), estimate and first quote; Anonymous (n.d.), removals and second quote
?		400			
October?			133[18]	"A total of 133 animals were trapped. Twenty head were lost in trap accidents, and 9 others died while enroute to the release site. Fifty-one antelope were released in the southwestern edge of Ruby Valley, Elko County on October 16, 1950. On the same day, an additional 53 antelope were released in the vicinity of Potts Ranger Station in Monitor Valley, Nye County."	
1951				"Livetrapping done Jan. and Feb. Winter range almost snowfree and animals were widely scattered with many much higher than usual. Recent airplane herding partly responsible." "This figure represents the estimated winter population of the district and is based on last census plus annual increase."	Barmore (1981:Table 105, citing Johnston 1951 for count, Evans 1951 for estimate), first quote; Anonymous (1951), estimate and second quote
Jan.–Feb.			258		
Feb. 21–22	215				
Fall		270			
1952					Scott (1994)[1,19]
Dec., 1951	125				

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1953				"Mild, little snow, pronghorn in small bands and scattered, but counters felt they saw nearly all animals and avoided duplication."	Barmore (1981:Table 105, citing Chapman 1953)
Feb. 12	382				
Fall		460			
1954				"All range to Corwin Springs was covered by 10 men. Count believed to be fairly accurate." "Livetrapping was early in 1954." "On January 13, 1954, a total of 131 antelope were released in Nevada. Seventy-one were released at a site 3 1/2 miles west of the J. D. Ranch in Pine Valley, Elko County. Another group of 60 animals were released on the west side of Smith Creek Valley at a site two miles north of U.S. Highway 50, in Lander County."	Barmore (1981:Table 105, citing Chapman 1953 and Anonymous 1955), estimate, removals, and first and second quotes; Anonymous (n.d.), third quote.
Dec. 15, 1953	485				
~Jan.			207		
1955				"Trapping tried in early 1955, but unsuccessful."	Barmore (1981:Table 105, citing Anonymous 1955)
Dec., 1954	334				
Fall		400			
1956, Mar. 20–26	356–431			"Helicopter census. Good conditions. Total seen was 356 with possibly 75 more on North end Mt. Everts where separation of bands was questionable."	Scott (1994)[1], dates; Barmore (1981:Table 105, citing Kittams 1956), estimate and quote
1957				Regarding Dec. count: "Ideal counting conditions." "In February 1957, 120 antelope were removed from the herd by trapping, reducing the previously counted number to 275."	Scott (1994)[1], date and removal data; Barmore (1981:Table 105, citing Kittams 1956), count and first quote; Kittams (1958), second quote
Dec. 7, 1956	395				
Feb. 14–15			120		
?		330			
1958	158			"Seven men, poor counting conditions. ' I seriously question the completeness of the recent count, as antelope very probably were dispersed over more area than that…covered…' "	Barmore (1981:Table 105, citing Kittams 1958)
1959, ?		400			Barmore (1981:Table 105, citing Chapman 1960)
1960, ?		400[20]			Scott (1994)[1]
1961, Mar. 17	299			"Helicopter census specifically for pronghorn."	Barmore (1981:Table 105, citing Howe 1961)

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1962				"Helicopter census specifically for pronghorn; 35 min. flying time; coverage to about 1 mile north of park boundary."	Barmore (1981:Table 105, citing Howe 1962*a* for count, Howe 1962*b* for estimate, Management Assistant for YNP 1962 for coverage)
Apr. 4	278				
?		300			
1963					Barmore (1981:Table17), count; Barmore (1981:Table 105, citing Howe 1963), estimate
Apr.	124				
Spring		350			
1964					Barmore (1981:Table 17), count; Barmore (1981:Table 105, citing Howe 1964), estimate
Dec., 1963	171				
Spring		350			
1965				"Partial helicopter census in conjunction with livetrapping of pronghorn." "Livetrapping [of 25 animals] Dec. 16, 1964." "Livetrapping [of 7 animals] Jan. 6, 1965."	Barmore (1981:Table 105, citing Barmore 1965 for count, Howe 1965*b* for estimate)
Dec. 16, 1963			32		
Jan. 5	182–210				
Spring		300			
1966				"Reduction by shooting between summer 1965 and April 1966."	Barmore (1981:Table17), count; Barmore (1981:Table 105, citing Barmore 1966), estimate, removal data, and quote
Jan.	124				
Spring		200			
See comments			94		
1967				"Helicopter census; good to excellent condition; partial coverage outside park; probably included 95% of pronghorn on winter range inside the park."	Barmore (1981:Table 105, citing Barmore 1967*a* for count, Barmore 1967*b* for estimate)
Mar.	188				
Spring		200			
1968				"Reduction by shooting in October 1967." Regarding Mar. count: "Helicopter census specifically for pronghorn. Area outside of park covered to Carbella but not as intensively as inside park. Severe winter had caused many to leave the park; hard to get complete count."	Barmore (1981:Tables 17), Nov. count; Barmore (1981:Table 105, citing Barmore 1968*b*), Mar. count, estimate, removals and quotes
Oct., 1967			6		
Nov., 1967	145				
Mar.	85	200			
Spring					
1969				Regarding Dec. count: "Special pronghorn census from Piper Supercub." Regarding Mar. count: "Special antelope count by Piper Supercub. Partial coverage outside park, but not as intensive as inside."	Barmore (1981:Table 105, citing Barmore 1968*a*)
Dec., 1968	149				
Mar.	133				
Spring		200			

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1970				Special antelope count by Piper Supercub. Partial coverage outside park, but not as intensive as inside.	Barmore (1981:Table 105, citing Bucknall 1970 for estimate), Jan. count, estimate, and comments; Scott (1994)[1], Mar. count
Jan.	158				
Mar. 19	134				
Spring		170			
1971, Apr. 1	138				Scott (1994)[1]
1972, Jan. 28	134				Scott (1994)[1]
1973, Mar. 9	129				Scott (1994)[1]
1974, Apr. 22–23	103				Scott (1994)[1]
1975, Feb. 18	165				Scott (1994)[1]
1976, Apr. 8	130				Scott (1994)[1]
1977, Mar. 15	121				Scott (1994)[1]
1978, Mar. 21	146				Scott (1994)[1]
1979, Apr. 16	152				Singer (1988), Scott (1994)[1]
1980, Apr. 8	157				Singer (1988), Scott (1994)[1]
1981, Mar. 21	102				Singer (1988), Scott (1994)[1]
1982, Apr. 17	131				Singer (1988), Scott (1994)[1]
1983, Mar. 8	310				Singer (1988), Scott (1994)[1]
1984, Mar. 23	365				Singer (1988), Scott (1994)[1]
1985, Apr. 9	364				Singer (1988), Scott (1994)[1]
1986				Removals occurred during damage control hunt due to crop depredation complaints from the Church Universal and Triumphant. 15 permits issued. Numbers removed are (minimum?) estimates.	Singer (1988) and Scott (1994), count; Singer (1986, 1987) and Scott (1991), removal data
Fall, 1985			15[21,22]		
Feb. 28	363				

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1987				Removals occurred during damage control hunt due to crop depredation complaints from the Church Universal and Triumphant. 50 permits issued.	Singer (1988) and Scott (1994), count; Singer (1987, 1988) and Scott (1994, 1991) for removal data
Fall, 1986			12–15[21]		
Mar. 17	478				
1988				Removals occurred during damage control hunt due to crop depredation complaints from the Church Universal and Triumphant. 39 permits issued.	Singer (1988) and Scott (1994), count; Singer (1988) and Scott (1994, 1991), removal data
Fall, 1987			16[21]		
Apr. 14	495				
1989, Spring	411			"Not a good count"	Mack (1996)
1990, Mar. 20	472				Scott (1994)[1], Mack (1996)
1991, Apr. 2	588?			"Various file references refer to a total of 522, 588, 591, and 594 on this date. Caslick indicates observation forms total 588 counted."	Anonymous (1997)
1992				25 licenses issued. Harvest estimated, could not reliably account for take by archers.	MDFWP (1999) and Scott (1994), removal data; Scott (1994), count
Fall, 1991			23		
Mar. 24	536				
1993				25 licenses issued. Harvest estimated, could not reliably account for take by archers.	MDFWP (1999), removal data; Scott (1994) count
Fall, 1992			31		
Apr. 8	439				
1994				25 licenses issued. Harvest estimated, could not reliably account for take by archers. No count was conducted this year.	MDFWP (1999), removal data
Fall, 1993			37		
1995				25 licenses issued. Depredation hunt removed 17 does and 9 bucks. Late conditions and large decline caused Mack (1996) to assume this was merely a "Poor Count;" an assessment he later revised in light of continued low counts in subsequent years (J. Mack pers. commun., winter 2001).	MDFWP (1999) and Caslick and Caslick (1996), removal data; Mack (1996), count.
Fall, 1994			26		
Apr. 7	235				
1996				25 licenses issued. Harvest estimated, could not reliably account for take by archers. "…count was conducted under ideal conditions..."	MDFWP (1999), removal data; Mack (1996), count and quote
Fall, 1995			12		
Mar. 25	229				

Appendix A (continued).

Date	Actual Count	Estimate	Number Removed	Comments	Sources
1997				5 licenses issued but harvest estimates are not available. "Count conditions were fair to good. 92% of the pronghorn counted were inside [YNP]…some portion of the population has already migrated eastward."	MDFWP (1999), removal data; Clark (1997*a*), count and quote
Fall, 1996			?		
Apr. 21	210				
1998				5 licenses issued. Harvest estimated, could not reliably account for take by archers. "Good Count."	MDFWP (1999), removal data; Clark (1997*b*), Nov. count; Clark (1998), Mar. count and quote; Caslick and Caslick (1999), estimate
Fall, 1997			?		
Nov. 22, 1997	252				
Mar. 31	231	284			
1999				5 licenses issued. Harvest estimated, could not reliably account for take by archers. "Good Count"	MDFWP (1999), removal data; Clark (1999), count and quote
Fall, 1998			?		
Mar. 25	204				
2000				5 licenses issued. Harvest estimated, could not reliably account for take by archers. "Good Count"	Lemke (MDFWP, pers. commun.), removal data; Mack (2000, 2001), count and quote
Fall, 1999			?		
Apr. 3	205				
2001				5 licenses issued. Harvest estimated, could not reliably account for take by archers. "Fair Count"	Lemke (MDFWP, pers. commun.), removal data; Mack (2001)
Fall, 2000			?		
Apr. 3	206				

[1]Information taken from summary data sheet compiled by Dr. M. D. Scott. Although apparently based on a review of historical records, the summary did not cite the sources of information used.
[2] Scott's (1994) estimate of "~400" animals is less than that of Anonymous (1898), the only other data source located for 1898.
[3] Scott's (1994) estimate of "~600" animals is less than Skinner's (1922*a*) estimate, the only other data source located for 1899.
[4] Scott's (1994) note of a "rapidly increasing" pronghorn herd conflicts with Hofer (1902).
[5] Skinner (1922*a*) (whom Barmore [1981] cited) estimated 1,000; Scott (1994) estimated "~900," but cited no source for his information.
[6] An estimate of 1,150 is generally cited (e.g., Barmore 1981, Scott 1994), but sources suggest this actually was a rough count. Also, Anonymous (1905*a*) lists an average count of 1,100 animals, but Pitcher's (1905) figure of 1,150 is considered to be more authoritative.
[7] Although Anonymous (1905*a*) estimates the herd at 1,500–1,700, I follow previous workers (Skinner 1922*a*, Barmore 1981, Scott 1994) and use the lower figure.
[8] Scott (1994) listed an estimate of "~2000," which may have been based on the statement (Anonymous 1906*b*) that "…about 1,500 of these animals came down to the feeding grounds…and as very few of them died or were lost from any cause, the number this year should be at least 2,000." I follow Barmore (1981) and Skinner (1922*a*) in using the lower figure of 1,500.
[9] Barmore (1981) regarded this (and, more generally, other high counts of the early 1900s) as a summer count. See text for evidence that this estimate was based on animals wintering in YNP.
[10] Scott (1994) lists "~650," apparently taking the average of Skinner's (1922*a*) range of values. The Superintendent (1910) references a herd of 700. Anonymous (1910) states that, of the animals that escaped through the park fence, soldiers at YNP "succeeded in rounding up and returning…some 800 or 900 antelope."
[11] Anonymous (1911*a*,*b*) reports "about 500" pronghorns. However, the Superintendent's (1911) report is accepted here as more authoritative source.
[12] Barmore (1981) lists this as a July count, Scott (1994) describes it as a winter count. Further work to resolve this issue is needed.
[13] Scott (1994) gives the date for this count as December, 1927. Anonymous (1931) describes this as a spring count. Barmore (1981) did not record a count for this year.
[14] Barmore (1981:Table 105) lists this count in 1929, but gives only "?" rather than the month or season. Scott (1994) gives Sept. 21 as the date of this count, which I, therefore, assigned to the 1929–1930 period.
[15] Barmore's (1981:Table 105) estimate of 646 for "Spring" is probably a typographical error, in which the estimate for 1931 was carried over to 1932. Barmore lists a count of 668 for "April" and Tell (1932) lists both the count and estimate as 668.
[16] Kittams (1947) gives a slightly different figure, stating that "[d]uring January–February 1947, 235…animals were livetrapped..."
[17] Barmore (1981:Table 105) includes these 58 animals in the reductions for 1947. Because they were trapped in Dec., 1947, they are listed here with the data for 1947–1948.
[18] This removal was not reported by Barmore (1981) or Scott (1994) and, therefore, was not accounted for in Goodman's (1996) viability analysis.
[19] Counts and estimates for 1951–1952 are particularly confused. Scott (1994) lists a count of 104 (with no season or date) as the "'best' count — usually cited in literature." However, he also lists a count of 125 for Dec. 15, 1951. Barmore (1981:Table 105) does not give a count for this period, but does list an estimate of 270 for fall of 1951. It seems likely that no concerted effort to obtain a reliable count was made during this period.
[20] Barmore (1981) gives no count or estimate for 1960.
[21] Scott (1994) listed many removals during 1985–1994, including: 11 (Nov. 1985), 14 (Nov. 1986), 16 (Oct. –Nov. 1987), 2 (Dec. 1987), 1 (Jul. 1987), 2 (Feb. 1988), 1 (Apr. 1988), 2 (Aug. 1988), 1 (Oct. 1988), 51 (Oct.–Nov. 1988), 1 (Dec., 1988), 1 (Mar. 1989), 1 (Apr. 1989), 1 (Apr. 1990), 1 (May 1990), 4 (Aug. –Sep. 1990), 1 (Jan. 1991), 1 (Jun. 1991), 4 (Aug. –Dec. 1991), 23 (Oct. 1991), 3 (Jan. –Jun. 1992), 2 (Jun. –Jul. 1992), 4 (Mar. 1992), 8 (Mar. 1993), 25? (Oct. 1993; Scott's question mark, not mine), 1 (Oct. 1993), and 1 (Jan. 1994). Scott (1994) did not list causes of removals. Only removals clearly due to depredation hunts were included in the figures in Appendix A, as it was unclear whether other losses were natural or human-caused.
[22] Scott (1994) lists only 11 removals during Nov. 1985.
[23] Scott (1994) lists the maximum count for 1988–1989 as 372 animals observed on Apr. 9, 1989.

Appendix B. Average coyote pelt prices for Montana, 1972–1998, according to the Montana State Office of the USDA APHIS Wildlife Services (Larry Handegard pers. commun.). Corrected prices were adjusted for inflation using the Consumer Price Index (CPI) and the inflation calculator found at http://stats.bls.gov/cpihome.htm, and were standardized to values for the year 2000. Prices are in US dollars.

Year	Average Price	CPI Corrected Price
1972	15.31	63.07
1973	27.44	106.42
1974	31.66	110.59
1975	32.21	103.10
1976	55.43	167.75
1977	58.97	167.57
1978	56.00	147.90
1979	119.00	282.26
1980	50.57	105.68
1981	66.33	125.65
1982	62.44	111.42
1983	48.06	83.09
1984	61.17	101.38
1985	39.17	62.69
1986	43.88	68.94
1987	53.03	80.39
1988	17.60	25.62
1989	18.62	25.86
1990	12.57	16.56
1991	13.00	16.44
1992	25.00	30.68
1993	15.50	18.47
1994	25.18	29.26
1995	17.77	20.08
1996	23.59	25.89
1997	20.35	21.83
1998	17.36	18.34

Appendix C. Average coyote pelt prices, 1974–75 to 1977–78, for the region of the United States that includes Idaho, Montana, and Wyoming. Data were compiled by the International Association of Fish & Wildlife Agencies (Brian Giddings, MDFWP, pers. commun.). Corrected prices were adjusted for inflation using the Consumer Price Index (CPI) and the inflation calculator found at http://stats.bls.gov/cpihome.htm, and were standardized to values for the year 2000. Prices are given in US dollars.

Year	Average Price	CPI Corrected Price
1974–75[1]	12.42	39.55
1975–76[1]	22.12	66.59
1976–77[1]	22.27	62.95
1977–78[1]	28.51	74.90
1978–79[1]	37.22	87.82
1979–80[1]	27.45	57.07
1980–81[1]	31.56	59.47
1981–82[1]	37.94	67.35
1982–83[1]	24.32	41.83
1983–84[1]	19.96	32.91
1984–85[1]	28.61	45.55
1985–86[1]	19.69	30.77
1986–87[1]	26.14	39.42
1987–88[1]	14.79	21.42
1988–89[1]	8.13	11.23
1989–90[1]	5.85	7.67
1990–91[1]	7.68	9.66
1991–92[1]	13.20	16.12
1992–93[2]	16.74	19.84
1993–94[2]	15.76	18.22
1994–95[2]	12.62	14.19
1995–96[1]	15.34	16.75
1996–97[1]	8.42	8.99
1997–98[1]	6.65	6.99

[1]Average price for region that included Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming

[2]Average price for region that included Arizona, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Utah, and Wyomin

Bibliography

Annotated Bibliography-Vegetation

Shrublands

1. Houston, D.B. 1982. The northern Yellowstone elk: ecology and management. Macmillian Publishing Co., Inc. New York. 474 pp.

> Boundary Lands Area: The history of human use, the semiarid climate, and the very different geology and soils (Frazer et al. 1969) made the interpretation of vegetation changes in the BLA (mostly 1,500-1,800 m in elevation) very difficult. We lack photos taken before 1893 for the area, so the character of the pristine vegetation must be inferred from photos of immediately adjacent sites. Early travelers commented on the area in unflattering terms….
>
> Photos suggested that historically the upland alluvial and glacial deposits were mostly bunchgrass steppe—probably dominated by needle-and-thread and bluebunch wheatgrass, with winterfat, fringed sagebrush, and prickly pear on xeric sites. Big sagebrush occurred in more mesic swales….Sagebrush decreased in this semiarid area and perennial grasses increased following the removal of livestock—even during the drought of the 1930's….
>
> The pristine vegetation of abandoned hayfields may have been bunchgrass steppe (needle-and-thread and bluebunch wheatgrass), with sagebrush in more mesic sites. Exotic grasses (smooth brome, timothy, quackgrass, crested wheatgrass, and cheatgrass) are now the dominant vegetation in old fields, although native species are invading the periphery of some stands.
>
> Management: Conflicts and Recommendations: A number of exotic grasses and forbs have displaced native vegetation, especially in the BLA. A long-term management goal should be to reestablish native species (e.g., replace crested wheatgrass and cheatgrass with needle-and-thread and bluebunch wheatgrass). Restoration might be facilitated by using biological control agents or highly selective herbicides. The technology available to accomplish these ends is now quite primitive; here the risk is high that a "cure" could turn out to be worse than the affliction.

2. Mehus, C.A. 1995. Influences of browsing and fire on sagebrush taxa of the northern Yellowstone winter range. M.S. Thesis. Montana State University, Bozeman, MT. 70 pp.

> Abstract: Sagebrush (*Artemisia)*/grass habitat types on the Northern Yellowstone Winter Range near Gardiner, Montana provide critical winter habitat for many big game species, particularly mule deer (*Odocoileus hemonius*) and elk (*Cervus elahpus*). Because 4 sagebrush taxa are common throughout the area, often occurring in the same communities, this area also provides a unique opportunity to study relationships among these taxa.
>
> Sagebrush communities, containing Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) 4 sites, mountain big sagebrush (*A. t. vaseyana*) 4 sites, basin big sagebrush (*A.T. tridentata*) 3 sites, and black sagebrush (*A. nova*) 1 site, distributed throughout the area are described. These 12 sagebrush communities of varying levels of past browsing use were measured for canopy cover, density, and production. Canopy cover correlated most closely with browsing history, i.e., heavily used sites tended to have less canopy cover than lightly used sites. Density and production appeared to be influenced more by individual site characteristics such as elevation, topography,

precipitation, and soils. Mule deer and elk browsing of sagebrush and diet composition (where feces were available) were also measured on many of these sites. For all sites but 1, use was greater during the winter of 1992-93 than 1993-94. Big sagebrush was the most significant forage item in mule deer diets across the area during both winters, averaging 33% of the total diet across 9 sites. Common grass species comprised a large portion of elk diets at the 2 sites sampled, averaging 76%, while big sagebrush averaged 3%.

An area burned by wildfire in 1974 was studied 19 years later to compare relative reestablishment of big sagebrush and rabbitbrush (*Chrysothamnus*) taxa. Recovery was minimal for subspecies of big sagebrush, while rabbitbrush abundance was much greater than that of unburned areas. Wyoming big sagebrush recovered to a lesser extent than mountain big sagebrush or basin big sagebrush ($p < 0.05$). Mountain and basin big sagebrush recovered to the same extent. These relationships were consistent for canopy cover, density, and production.

Rabbitbrush canopy cover and density were not consistent. Threadleaf rubber rabbitbrush (*Chrysothamnus nauseosus consimilis*), mountain low rabbitbrush (*C. viscidiflorus lanceolatus*), and narrowleaf low rabbitbrush (*C.v. viscidiflorus*) recovery as expressed by canopy cover were not different ($p>0.05$). However, mountain low rabbitbrush established to a greater density than threadleaf rubber and narrowleaf low rabbitbrush ($p<0.05$). The differences are a result of the large number of seedling and small rabbitbrush plants not expressed by canopy cover. Because a large proportion of seedlings may not reach maturity, canopy cover is probably a better indicator of long-term establishment than density.

This study should help natural resource managers to make habitat management decisions. Because big sagebrush is a critical cover and browse species for wintering ungulates in the study area, habitat management should focus on protection of these habitat types. Fire negatively influences non-sprouting browse species like big sagebrush that are already declining under intense browse pressure.

3. Singer, F.J. and R.A. Renkin. 1995. Effects of browsing by native ungulates on the shrubs in big sagebrush communities in Yellowstone National Park. Great Basin Naturalist 55(3): 201-212.

Abstract: The effects of elk (*Cervus elaphus*), pronghorn (*Antilocapra Americana*), and mule deer (*Odocoileus hemonius*) browsing on shrubs in big sagebrush (*Artemisia* tridentata) communities were monitored over a 31-yr period in Yellowstone National Park. Ungulates were restricting Wyoming big sagebrush (spp. *Wyomingensis*) heights, size, and recruitment on the lower-elevation stratum only, while no such suppression was observed on the high-elevation stratum. Parallel increases in mountain big sagebrush (spp. *Vaseyana*) densities and cover occurred over the study period on both browsed and unbrowsed sites at the higher-elevation stratum, although big sagebrush, green rabbitbrush (*Chrysothamnus viscidiflorus*), and horsebrush (*Tetradymia canescens*) were slightly taller and crown sizes were slightly larger on unbrowsed than browsed sites. Wyoming big sagebrush utilization (percent leader use) was eight times higher (= 87 ± 7.2% by pronghorns, mule deer, and elk) on the low-elevation winter stratum (Boundary Line Area [BLA] portion of the winter range), while mostly mountain big sagebrush with leader use averaged 11 ± 4.1% (nearly all by elk) on the high-elevation range stratum. In addition, annual aboveground biomass production of big sagebrush did not differ between browsed and unbrowsed study sites on the high-elevation stratum of the winter range. Population turnover was higher on browsed big sagebrush at the high-elevation plots; seedling germination and survival rates were higher on browsed plots versus unbrowsed plots. No difference was observed in percent dieback of big sagebrush adult plants between browsed and unbrowsed plants at the higher stratum. Browsing did not influence the number of leaves or seedstalks per plant ($p > 0.05$), but leaves averaged 45% longer and seedstalks 42 longer on browsed big sagebrush. Ungulate

browsing, however, apparently suppressed production, germination, and survival of Wyoming big sagebrush on the low-elevation stratum. Numbers of Wyoming big sagebrush declined 43% and cover declined 29%, 1957-1990, on browsed sites on the BLA. Annual biomass production on browsed sites at the low-elevation stratum was only 6-35% that of unbrowsed sites, and big sagebrush recruitment was less on browsed sites. Percent leader use of big sagebrush did not differ between the period of ungulate reductions, 1962-69, and the 1980's on the lower stratum (= 87% leader use), but utilization was less on higher portions of the winter range during the period of elk reductions (= 2%) than during the 1980s following cessation of elk controls (= 11%).

4. Wambolt, C.L. 1998. Sagebrush and ungulate relationships on Yellowstone's northern range. Wildlife Society Bulletin 26(3): 429-437.

<u>*Abstract*</u>: Sagebrush (*Artemisia* spp.) ecology and forage relationships with ungulates are related to the Northern Yellowstone Winter Range (NYWR). The NYWR in northern Yellowstone National Park (YNP) and adjacent Montana is an important area for ungulates. I synthesized research published in peer-refereed and peer-edited literature related to the historical and present associations between ungulates and sagebrush on the NYWR. The NYWR habitats preferred by elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) were dominated by sagebrush, and these ungulates preferently foraged on 4 sagebrush taxa. There were significant differences in development between protected and browsed sagebrush at 19 locations across the NYWR. Elk foraging on sagebrush significantly increased sagebrush utilization and held sagebrush populations below their potential in the absence of other browsing ungulates. Sagebrush had not recovered from burning 10-19 years earlier. Knowledge of sagebrush taxa should provide resource managers important information for management of the extensive NYWR habitats.

5. Wambolt, C.L. and H.W. Sherwood. 1999. Sagebrush response to ungulate browsing in Yellowstone. Journal of Range Management 52(4): 363-369.

<u>*Abstract:*</u> Big sagebrush (*Artemisia tridentata* Nutt.) declined from ungulate browsing during the first half of the twentieth century on the Northern Yellowstone Winter Range. It was our objective to compare shrub parameters of Northern Yellowstone Winter Range sagebrush habitat types continually browsed or protected for 32 to 37 years. Measurements were taken in and out of exclosures for 19 environmentally paired, protected, and browsed sites. We found significant differences in development between protected and browsed shrubs. Big sagebrush canopy cover at the 19 sites averaged 19.7% with protection and 6.5% where browsed ($P<0.0027$), and plants were twice as numerous ($P<0.0027$) under protection. Winter forage production of individual sagebrush plants was also greater under protection at 16 of the 19 paired sites ($P<0.0027$). Subdominant sprouting shrubs generally responded the same as big sagebrush. This ungulate induced decline of shrubs has implications for many Northern Yellowstone Winter Range values. Ultimately many organisms are sacrificed with the loss of quality big sagebrush habitat.

6. National Research Council. 2002. Ecological Dynamics on Yellowstone's Northern Range. National Academy Press, Washington, D.C. 180 pp.

<u>PRESENT CONDITIONS:VEGETATION.</u> CONCLUSIONS:

Sagebrush- Big sagebrush at higher elevations in the northern range appears to be at relatively high abundance and vigor. These areas are important for ungulates during the nonwinter portions of the year. Because snow is usually deep and plants are relatively protected from elk browsing, these areas do not show sagebrush decline and may even show increases. They are not obviously of immediate management concern. Lower-elevation big sagebrush stands, which have been very heavily used by elk, are decreasing in density and productivity, especially near the northern park boundary. Those sites are critical winter range for a variety of other ungulates, especially pronghorn. It appears that, without extensive and intensive management to offset the damage done by elk browsing and grazing, the sites will continue to be degraded as resources for pronghorns and other ungulates, especially near the northern boundary of the park.

Grasslands

1. Houston, D.B. 1982. The northern Yellowstone elk: ecology and management. Macmillian Publishing Co., Inc. New York. 474 pp.

Boundary Lands Area: The history of human use, the semiarid climate, and the very different geology and soils (Frazer et al. 1969) made the interpretation of vegetation changes in the BLA (mostly 1,500-1,800 m in elevation) very difficult. We lack photos taken before 1893 for the area, so the character of the pristine vegetation must be inferred from photos of immediately adjacent sites. Early travelers commented on the area in unflattering terms….

Photos suggested that historically the upland alluvial and glacial deposits were mostly bunchgrass steppe—probably dominated by needle-and-thread and bluebunch wheatgrass, with winterfat, fringed sagebrush, and prickly pear on xeric sites. Big sagebrush occurred in more mesic swales….Sagebrush decreased in this semiarid area and perennial grasses increased following the removal of livestock—even during the drought of the 1930's….

The pristine vegetation of abandoned hayfields may have been bunchgrass steppe (needle-and-thread and bluebunch wheatgrass), with sagebrush in more mesic sites. Exotic grasses (smooth brome, timothy, quackgrass, crested wheatgrass, and cheatgrass) are now the dominant vegetation in old fields, although native species are invading the periphery of some stands.

Management: Conflicts and Recommendations: A number of exotic grasses and forbs have displaced native vegetation, especially in the BLA. A long-term management goal should be to reestablish native species (e.g., replace crested wheatgrass and cheatgrass with needle-and-thread and bluebunch wheatgrass). Restoration might be facilitated by using biological control agents or highly selective herbicides. The technology available to accomplish these ends is now quite primitive; here the risk is high that a "cure" could turn out to be worse than the affliction.

2. Coughenour, M.B. 1991. Biomass and nitrogen responses to grazing of upland steppe on Yellowstone's northern winter range. Journal of Applied Ecology 28:71-82.

SUMMARY

1. The responses of herbaceous vegetation on upland steppe of Yellowstone National Park's northern winter range to grazing by elk were investigated during 1987-88 using exclosures erected at four sites in 1958-62.

2. Elk winter-grazing on plants reduced standing dead material and litter biomass at most but not all sites and dates. Plant productivity was not reduced.

3. Live above-ground grass biomass was reduced by winter grazing at one of four sites in 1987 and three sites in 1988. Live grass was more abundant in grazed areas at two sites in 1987.

4. Live forb biomass was *c.* 33% of grass biomass, and was not affected by grazing in 1987, but increased slightly outside exclosures in 1988, perhaps because of the dry summer.

5. Root biomass was not affected by grazing at any site.

6. Nitrogen concentration of live grass, dead grass, and *Artemisia frigida* were increased by winter grazing. Total N flow to herbivores in 1987 would consequently have been stimulated by herbivory, and in 1988 would have been depressed by herbivory only one-third as much as biomass.

7. The net effects of winter grazing appeared to be a reduction of biomass flow from decomposers into elk, accompanied by an enhanced rate of N recycling back to elk. The fact that perennial root biomass has persisted best indicated the net consequences of winter grazing for these plants.

3. Singer, F.J. 1995. Effects of grazing by ungulates on upland bunchgrass communities of the northern winter range of Yellowstone National Park. Northwest Science 69(3):191-203.

Abstract: Herbivory by native ungulates, primarily elk (*Cervus elaphus*), was studied on xeric, bunchgrass-dominated slopes on the northern ungulate winter range of Yellowstone National Park. Plant cover, standing green biomass, and nutrient concentrations were compared between grassland sites protected from grazing for 24-27 years and adjacent plots grazed mostly during winter by elk, and to some extent by bison (*Bison bison*). Accumulated litter and standing dead vegetation were four times more abundant on the ungrazed plots. However, few consistent differences were observed in grass or forb biomass from elk herbivory. There was no overall effect of grazing treatment on forbs or other nongrasses ($P<0.05$). Total grass biomass was less on grazed than ungrazed sites in 1986, after a dry, warm spring, but there was no difference in 1987 ($P<0.05$). Biomass of junegrass (*Koeleria macrantha*) and thick-spiked wheatgrass (*Agropyron dasystachyum*) was greater on grazed than ungrazed sites. Three nongrasses (*Artemisia frigida, Phlox hoodii, Antennaria microphylla*) were more abundant on ungrazed sites although the effect on grazing treatment was not significant ($P>0.05$). The number of grasses (= 4.5), forb (17.5), and shrub (= 3.5) species did not differ between grazed and ungrazed plots ($P<0.05$). Vegetative culms of bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), bluegrass (*Poa* spp.), needle-and-thread grass (*Stipa comata*), junegrass, and thick-spiked wheatgrass were shorter on winter grazed plots ($P<0.05$), but grazing did not affect the numbers of vegetative culms or the height or numbers of reproductive culms of grasses ($P>0.05$), with the single exception that more vegetative culms of junegrass occurred on grazed sites. Protein content averaged 16% higher in bluebunch wheatgrass, 36% higher in Idaho fescue, and 10% higher in junegrass ($P<0.05$) on grazed sites. Bare ground averaged 38% more on grazed sites than on ungrazed sites ($P<0.05$), but pebble cover was 50% less on grazed sites (probably because of hoof compaction); as a result all bare surfaces (bare ground plus pebble cover) averaged

only 18% greater on grazed sites. Dead clumps of the grazing sensitive bluebunch wheatgrass and Idaho fescue can be expected on an overgrazed range, but dead bunchgrass clumps did not vary between grazed and ungrazed sites (*P<0.05*). The effects of herbivory by native ungulates was observed in swale sites that had been disturbed by agricultural activities until the 1930's. Three grasses (*Stipa viridula, Poa pratensis, Poa compressa)* possessed greater cover on grazed swales, but one forb, field pennycress (*Thlaspi arvense*), was less abundant on grazed sites. Herbivory by ungulates greatly stimulated grass but not forb cover on these productive swale sites (grass cover was double that of ungrazed sites) (*P<0.05*), and grazing mostly by elk contributed to the continued dominance of these sites by the exotic, grazing resistant *Poa pratensis* even 54 years following cessation of agricultural activities.

4. Coughenour, M.B., F.J. Singer, and J.J. Reardon. 1996. The Parker transects revisited- long-term herbaceous vegetation trends on Yellowstone's northern winter range. Pp. 13-27 *in* F.J. Singer (ed.). Effects of grazing by wild ungulates in Yellowstone National Park. USDI NPS Tech. Rept. NPS/NRYELL/NRTR/96-01. Natural Resource Information Division. Denver, CO. 375. pp.

Abstract: A method to rapidly assess range condition and trend from line transect measurements of basal area and species composition was first applied in Yellowstone in 1958 in association with 2-ha grazing exclosures established on the northern winter range. Transects in and out of the exclosures were resampled in 1962, 1967, 1974, 1981, 1986, and 1989. Total live plant frequencies increased significantly both in and out of exclosures between 1967 and 1981 and decreased from 1981 to 1986. Changes in plant frequencies between 1958 and 1989 were much more significant than changes because of exclosure from grazing. Precipitation variability was the most probable cause of these temporal changes, as suggested by correlations between precipitation and plant frequencies. Exclosure had no effect total live plant frequencies. The increase in total plant frequency until 1981 implied a converse decrease in bare ground. The decrease in plant frequency after 1981 was climatically driven, as evidenced by parallel changes outside and within exclosures. Dominant perennial grasses either maintained their relative abundance or increased until 1986. Forbs decreased in relative abundance until 1986 and increased after 1986 in response to drought. On the basis of these trends obtained by application of Parker transects, we conclude that elk grazing has not degraded the herbaceous component of the Yellowstone northern winter range. We recommend, however, that the Parker data be converted to basal area using a recent algorithm and that the technique be dropped in favor of less problematic methodologies.

5. Despain, D.G. 1996. The coincidence of elk migration and flowering of bluebunch wheatgrass. *Pp.* 139-143 *in* F.J. Singer (ed.). Effects of grazing by wild ungulates in Yellowstone National Park. USDI NPS Tech. Rept. NPS/NRYELL/NRTR/96-01. Natural Resource Information Division. Denver, CO. 375 pp.

Abstract: Bluebunch wheatgrass (*Agropyron spicatum*) is a major species of the lower elevations and foothills of the Rocky Mountains. It is highly palatable and strongly affected by grazing during its flowering period. Bluebunch wheatgrass serves as a major food on winter ranges for elk (*Cervus elaphus*) and other ungulates migrating from higher elevations. Elk move off bluebunch wheatgrass ranges before the onset of flowering, thus allowing adequate time for regrowth of the grass before the next season of intensive grazing.

6. National Research Council. 2002. Ecological Dynamics on Yellowstone's Northern Range. National Academy Press, Washington, D.C. 180 pp.

> PRESENT CONDITIONS:VEGETATION. CONCLUSIONS:
> *Grasslands*- Grasslands do not appear to have been altered as much by grazing as low-elevation shrublands have been by browsing. However, the few comprehensive reviews of the literature do not factor in the amount of biomass or other integrated measures of ecosystem characteristics contributed by nonnative species. The few studies available do not indicate that biodiversity is declining or that these systems are near a threshold value for some characteristic that is critical to any ecosystem process that currently appears to be within normal, long-term variations of the system. However, the committee would have more confidence if there were more data and analyses available.

Soils

1. Lane, J.R. and C. Montagne. 1996. Characterization of soils from grazing exclosures and adjacent areas in northern Yellowstone National Park. Pp. 65-71 *in* F.J. Singer (ed.). Effects of grazing by wild ungulates in Yellowstone National Park. USDI NPS Tech. Rept. NPS/NRYELL/NRTR/96-01. Natural Resource Information Division. Denver, CO. 375 pp.

Abstract: Paired plots in Yellowstone National Park's northern winter range were studied in 1986 and 1987 to determine if differences in soil chemical and physical properties occurred between areas inside and outside of eight ungulate grazing exclosure sites. Sampling for soil surface bulk density, double ring infiltration, and nutrient analysis was conducted inside and outside of all exclosures. Simulated rainfall was applied inside and outside of five exclosures under three separate treatments: vegetation undisturbed, vegetation clipped, and clipped vegetation and litter removed. Some differences ($P = 0.10$) were identified in soil chemical properties, but no consistency was identified between inside and outside of exclosures. Soil surface (0-5cm) fine earth bulk density was significantly higher outside of exclosures at four (Junction Butte, Mammoth, Gardiner east, and Lamar Valley east) of eight sites. One site (Lamar Valley west) had significantly higher infiltration inside the exclosure. For the simulated rainfall study, no differences in runoff were significant for treatment 1 (vegetation undisturbed). Runoff was higher outside at three sites (Gardiner east, Blacktail east, Lamar Valley east) for treatment 2 (vegetation clipped), and at two sites (Blacktail east, Blacktail west) for treatment 3 (vegetation and litter removed). Because baseline soils data were not collected when the exclosures were established, no conclusions can be made concerning changes over time due to grazing or protection from grazing.

2. Shovic, H.F. 1996. Soil quality, erosion potential, and site productivity on landscapes in northwestern Yellowstone National Park, Wyoming. Pp. 245-263 *in* F.J. Singer (ed.). Effects of grazing by wild ungulates in Yellowstone National Park. USDI NPS Tech. Rept. NPS/NRYELL/NRTR/96-01. Natural Resource Information Division. Denver, CO. 375 pp.

Abstract: The grasslands and shrublands north of Mammoth Hot Springs, Wyoming, are a critical part of the northern range. Though small in extent (4,065 ha), the area

provides important winter range for a variety of species. The objective of this paper is to report on grass and shrub site productivity and erosion parameters for landscapes in the study area and their relation to inherent landform, soil, and vegetation characteristics. About 33% of the study area has clayey, salt affected soils. These soils are poor plant growth media, with low water holding capacity, high root resistance, poor aeration, and possible sodium toxicity. They have many surficial rock fragments, further reducing productivity. Almost half of the study area has moderate or high erosion potential. It is probable that steep slopes, high clay content, salt concentration, and other inherent properties of the landscape are primarily responsible for that potential. About 6% of the area has been highly disturbed through intensive agriculture and habituation. This contributes to the unnatural look of some part of the study area, as well as reducing productivity and influencing erosion. The study area has been observed to have high winter use by ungulates and also appears to have these landscape characteristics. High wildlife usage has undoubtedly contributed to average coverage, vegetative species dominance, and erosion status. However, its importance is compounded by inherent ecosystem properties and past disturbances described above. The ecosystems in the survey area are combinations of parameters: landforms (unstable landslides, steep slopes, erodible mudstones), soils (salt and clay concentration, large numbers of rock fragments), and vegetation (salt tolerant, or otherwise unproductive habitat types with inherently low cover, exotic or introduced species) all influenced by the relatively dry climate. These factors (and past disturbance) significantly influence soil productivity, site productivity, and erosion potential. Given the character of these environmental variables, the intensity of their effects may confound a cursory analysis of the apparent effects of present wildlife usage. Therefore, assessments of the reasons for the area's appearance should be based on examination of all relevant ecological parameters as well as that usage.

Revegetation efforts in the Boundary Lands Area

1. McClure C. and D. Despain. 1991. Stevens Creek reveg plot update. Unpublished report on file in the Yellowstone Center for Resources. 1pp.

Synopsis: Six species of plants were planted in the spring of 1988 in two exclosures at Stevens Creek and their germination and survival monitored through September 4, 1988. On July 2, 1991, Don Despain and Craig McClure re-evaluated plant survival at the two experimental revegetation plots.

The plots in the crested wheatgrass field were recolonized by crested wheatgrass and none of the six planted species had survived in the plots, however, several volunteer fringed sage plants were growing inside the enclosure.

The plots in the mustard field, although colonized by various "weeds", did have plants surviving from 1988. In addition, western wheatgrass was noted to be spreading from one of the plots via runners, while bluebunch wheatgrass appeared to have spread by seed as possible did needle and thread and green needle. However, the additional plants in the needle and thread and green needle plots may have resulted from delayed germination occurring after the 1988 planting or be bluebunch wheatgrass plants which germinated from seed. Also, winter fat survived in only one of the two plots.

The following account, by species, lists the number of plants counted following germination in 1988, the number of surviving plants encountered in 1991, the additional number of plants counted in 1991, and the percentage of surviving plants from 1988-91 for planted plots in the mustard field:

Bluebunch wheatgrass: 55-53-11, 96%

Western wheatgrass: 21-11-24, 52%
Green needle: 58-16-1, 28%
Needle and thread: 41-10-3, 24%
Winter fat: 50-12-0, 24%
Fringed sage: 0-0-0, 0%

2. Scott, S.A. 1994. Boundary Line Area reclamation in Yellowstone National Park, Progress Report. Unpublished report on file in the Yellowstone Center for Resources. 5 pp.

Synopsis: The purpose of this research and demonstration project is to determine the best ways to reestablish native vegetation in those parts of the BLA that were extensively modified by human activity. Specific objectives were to test the effects of plant species, fertilization, irrigation, season of planting, seeding technique, exclosures, and exotic plant competition on germination and survival of native plants.

Two areas were selected: one was the *Alyssum spp.* infested area near the horse corrals, and the other was in a crested wheatgrass field near the county road. Two sites within each area were further selected for exclosure construction. Three of the 4 exclosure sites (two *Alyssum* and 1 crested wheatgrass site) were treated with Roundup in June of 1992 to kill off the existing exotic plant community, and were tilled 14 days after herbicide treatment. Fenced exclosures (24.0m x 22.5 m) were constructed in July of 1992. Five native plant species (2 grasses- bluebunch wheatgrass [*Agropyron spicatum*] and needle and thread [*Stipa comata*]; 1 forb- wild flax [*Linum perenne*]; 2 shrubs- big sagebrush [*Artemisia tridentata*] and fringed sage [*Atremisia frigida*]), whose seeds were collected locally in the park and showed tested viability from 87%-95%, were used. Seed of each species was randomly assigned to 110 one meter squared plots at each of the 3 experimental exclosures, and seeds (200-500 per plot) were planted from 1-15 November 1992. For the grass species (47 plots at each site), seeds were either drilled 1 inch deep in 5 evenly spaced rows per plot , or hand broadcast and lightly raked for each plot. The wild flax seed was hand broadcast and lightly raked (30 plots), while the shrub seeds were hand broadcast and not raked (33 plots). On 11 May, 1993, the remaining crested wheatgrass exclosure site and an additional 10m x 10m unfenced area in the field were also sprayed with Roundup and tilled 7 days later. On 25-27 May, 1993 these areas were also seeded as described above. A subset of plots (bluebunch wheatgrass and fringed sage only) were fertilized with phosphate during the spring of 1993 because of the relatively high nitrogen content in the sampled soils; no additional potassium was required. A pump irrigation system with overhead sprinklers was established in one of the *Alyssum* exclosure sites in June of 1993. The site was irrigated once per week only if total precipitation for the preceding week did not exceed 0.1 inches. The site was subsequently irrigated on 12 occasions over a 20-week period with 0.2 inches of water each time, totaling 2.4 inches of additional moisture above the ambient precipitation for the season.

Results:

1. No native seed germination was observed in the spring plowed and seeded, unfenced crested wheatgrass plots. Very poor native seed germination (0-2.1%) was observed in the spring seeded crested wheatgrass exclosure.
2. Control of crested wheatgrass with Roundup application was best accomplished in the fall. Fall treatment did not experience crested wheatgrass re-invasion, while considerable re-invasion occurred in the spring treated areas.
3. Fall grass seed drilling produced slightly better germination percentages (6.2-16.0% for bluebunch wheatrgrass; 2.1-13.0% for needle and thread) than broadcast seeding (5.8-12.0% for bluebunch wheatgrass; 2.1-7.9% for needle and thread). No

difference in germination was observed between phosphate-fertilized and unfertilized plots.
4. Grass germination was better in the fall-planted *Alyssum* sites (5.8-16.0%) than the fall-planted crested wheatgrass site (2.1-9.8%), possibly due to differences in soil nitrogen concentrations inherent to each site (35 mg/kg at the *Alyssum* site compared to 8.6 mg/kg at the crested wheatgrass site) or allelopathy of crested wheatgrass.
5. Irrigation more than doubled the number of grass/forb plants producing seed (12.0-17.0% vs 3.2-7.2%) after one growing season at the *Alyssum* site.
6. The percentage of germinating shrub seeds (*Artemisia spp.*) was low across all sites (0-0.4%), but was encouraging.

3. Scott, S.A. 1995. Boundary Line Area reclamation in Yellowstone National Park- second annual progress report. Unpublished report on file in the Yellowstone Center for Resources. 12 pp.

Synopsis: The primary objectives of the second year of experimentation in the BLA were: 1) continue measurement from existing plots to determine seed germination and plant growth rate; 2) determine the relative effect of continued irrigation of the *Alyssum* exclosure site; 3) assess whether germination of spring broadcast seeding (using bluebunch wheatgrass and western wheatgrass [*Agropyron smithii*]) in herbicide treated areas without tilling is comparable to areas both treated with herbicide and tilled; 4) till, seed with a native grass seed mixture of bluebunch wheatgrass and needle and thread, and harrow an unfenced, 5-acres area dominated by crested wheatgrass for future seed production; 5) spring-transplant 11 big sagebrush seedlings each into the irrigated *Alyssum* exclosure and a crested wheatgrass exclosure to assess transplanting vs seeding; and 5) reseed plots in the failed spring-seeded crested wheatgrass exclosure in the fall of as well as 10 failed plots in both the *Alyssum* exclosures in the fall of 1994 with 3 new grass species: Sandberg's bluegrass (*Poa sandbergii*), Indian ricegrass (*Oryzopsis hymeniodes*), and a variable seeding rate (200 vs 400 seeds per square meter) of junegrass (*Koelaria cristata*).

The northern *Alyssum* exclosure was irrigated twice weekly beginning on 1 May 1994. The average amount of water applied was 0.2 inches during only those weeks when less than 0.2 inches of rainfall were received. Irrigation was discontinued by 1 September, and the total amount of irrigated water received above ambient rainfall was 5.37 inches. Spring broadcast seeding of a new 40m x 40m unfenced area subjected to herbicide (Roundup) control of *Alyssum* was completed on 12 May, and was further sprinkler-irrigated in accordance with the schedule of the exclosure throughout the month of June. The 5-acre site for growing native bluebunch wheatgrass and needle and thread was tilled with a tractor on 31 October 1994, seeded over the next 2 days, then harrowed on 4 November 1994.

Results:
1. Germination in the new spring-seeded, herbicide-applied *Alyssum* field did not occur, and irrigation was discontinued at the end of June. Continued irrigation in the established *Alyssum* exclosure made a considerable difference in the number of grass plants producing seed (38.5-50.0% vs 22.5-35.3%), grass height (= 52.2 cm vs 35.4 cm for bluebunch wheatgrass, 27.9 cm vs 16.2 cm for needle and thread), and grass cover (= 42.3% vs 20.1% for bluebunch wheatgrass, 46.4% vs 16.1% for needle and thread) compared to the non-irrigated *Alyssum* exclosure. When compared with the established non-irrigated crested wheatgrass exclosure, grasses in the non-irrigated *Alyssum* exclosure produced a comparable percentage of bluebunch wheatgrass plants producing seed (26.9% vs 29.1%), but about one-half the proportion of needle and thread plants producing seed (35.3% vs 71.2%). Plant heights were similarly comparable (= 35.4 cm for bluebunch wheatgrass in the

non-irrigated *Alyssum* exclosure compared to 30.3 cm in the crested wheatgrass exclosure; = 16.2 cm vs 17.8 cm for needle and thread). Plant cover, however, was generally lower for the crested wheatgrass exclosure (11.2% vs 20.1% for bluebunch wheatgrass, 13.4% vs 16.1% for needle and thread).
2. Irrigation of transplanted big sagebrush seedlings in the *Alyssum* exclosure positively affected their survival compared to the non-irrigated transplants in the crested wheatgrass exclosure. After 4 months, 8 of 11 (72.7%) big sagebrush transplants were surviving with irrigation, while no surviving transplants were found in the crested wheatgrass exclosure.
3. Fall reseeding of the previously unsuccessful germination plots in both areas, as well as the fall seeding of the 5-acre tilled site, will not be known until 1995.
(Renkin's note: Crested wheatgrass quickly recolonized the tilled field, and within 1-2 years equaled or exceeded the pre-tilled density. No germination of native seed was observed.)

4. Renkin, R., C. Hendrix, and R. Gray. 1999. Experimental revegetation trials in the Gardiner triangle area: first year progress report. Unpublished report on file in the Yellowstone Center for Resources. 16 pp.

Synopsis: Experimental revegetation plots were installed in 1999 to simultaneously assess native seed germination and establishment with efforts to control non-native plants inside the park boundary near Gardiner, MT. Prior to the onset of seed germination in March, 1999, 3 sites within an 11-acre field dominated by the exotic annuals Russian thistle (*Salsola* kali) and annual wheatgrass (*Agropyron triticeum*) were randomly selected for native seeding/experimentation. The factorial experimental design consisted of seed drilling (with a Brillion seeder to a depth of 0.25-0.5 inches) each of 3 areas (23m x 11 m each) with a native seed mix collected locally (9 parts bluebunch wheatgrass [*Agropyron spicatum*]: 4 parts Indian ricegrass [*Oryzopsis hymenoides*]: 54 parts needle and thread [*Stipa comata*]: 32 parts green needlegrass [*Stipa viridula*]: trace of western wheatgrass [*Agropyron smithii*]: 1 part common rabbitbrush [*Chrysothamnus nauseosus*] for a total of 1.38 lbs. live seed at a rate of 10-11 lbs per acre); a fenced exclosure (5m x 17m with four- $3m^2$ subplots) for paired comparisons with supplemental water, herbicide (1% Roundup), water/herbicide, and control (no treatment); and a mulch and mulch/water treatment outside the exclosures only. Following planting on 31 March 1999, a handful of the seed mix was successfully germinated under greenhouse conditions to validate viability of the seed mix, and the exclosures were constructed.

The first germinating species to appear on site were annual wheatgrass (12 April) and Russian thistle (20 April). From 6 May through 11 May, the experimental herbicide and herbicide/water treatment plots were sampled prior to the first herbicide application that occurred on 19 May. A second wave of seed germination occurred by 10 June, all experimental plots were sampled from 21-28 June, and a second herbicide application followed on 1 July.

The supplemental water treatment (measured at 10 gal per application per plot and delivered via garden hose from a portable truck) was not intended to emulate irrigation, but was intended to prolong or increase soil moisture conditions through precipitation-free periods lasting greater than 5 days. From March through June, the site received 4.05 inches (121%) of seasonal precipitation, with 2.05 inches falling during May. In an attempt to germinate the planted seed, however, the supplemental watering treatment was carried into September. The water application resulted in an additional 2.65 inches of moisture (38% increase) above ambient precipitation levels received from March through September.

Results: None of the drilled native seed mix was observed to have germinated during the study. Twenty different plant species were encountered, yet only 9 occurred with a frequency > 5%. Six of these species were exotic annuals, 1 (*Poa* *pratensis*) an exotic perennial, and 2 were native perennials (*S. comata* and *A. smithii*) sprouting from established root stock but at low densities. Because Russian thistle and annual wheatgrass dominated the site, the experimental results related to those species only were carried forward.

Regarding pre-herbicide application, significant site differences (P=0.00) were observed in the number of germinating annual wheatgrass and Russian thistle plants. Herbicide application effectively killed all germinating plants and significantly reduced the post-spray germination of annual wheatgrass (= 176±116 standard deviation per m^2 prespray vs 12±27 postspray, P = 0.00). Even though herbicide application significantly reduced the number of germinating Russian thistle (= 912±856 per m^2 prespray vs 768±567, P=0.015), sufficient densities remained to prolong the weed problem.

Other than site and herbicide application, no other significant treatment effects were observed on the postspray density of annual wheatgrass. Water only (= 130±91 per m^2) and control (no treatment) (= 146±65 per m^2) densities did not differ, but were significantly greater (P=0.00) than either the herbicide only (= 14±30 per m^2) and herbicide/water treatments (= 10±23 per m^2). No difference in seedling density (P=0.14) was observed inside (= 82±101) or outside (= 68±70) of the exclosures,

Postspray densities of Russian thistle, on the other hand, experienced other significant treatment effects in addition to the site effect, in spite of herbicide control. Significantly higher (P=0.00) seedling densities occurred in the water only treatment (= 1074±497 per m^2) compared to the herbicide/water treatment (= 653±337), but neither treatment differed from the control (= 777±465) or herbicide only treatment (= 884±716). Significantly higher seedling densities likewise occurred outside (= 954±642) than inside (= 739±385) the exclosures. No consistent within-site differences could be attributed to the mulch and mulch/water treatment except at site #3, where collectively Russian thistle densities were significantly lower (= 234±174, P<0.05) than other treatments outside the exclosure.

The most obvious trends following the first year of experimentation in the triangle were: 1) the failure of any planted native seed to germinate, and 2) the reproductive ecology and differential response of the two primary exotic species under control. The lack of planted seed germination, despite successful greenhouse germination, suggests environmental of mechanistic influences rather than some other cause. Insufficient cold storage or seed moisture content, seed dormancy, spring planting, the timing and amount of spring precipitation, residual herbicide effect, unfavorable soil structure/microbial activity, competition with the existing exotic seed bank, or any combination thereof may have contributed to the lack of germination. All of the trends reported here demonstrate the overwhelming influence of the robust and prolific soil seed bank of Russian thistle as being perhaps the major impediment to revegetation of the triangle to native plant communities. Because of the cascading effect beginning with seed germination and continuing through to a desired vegetation community, exhausting or eliminating the exotic soil seed bank remains fundamental and complimentary to any revegetation effort.

5. Reid, S. 2002. Gardiner triangle seed mixes and seed germination tests: spring 2002. Unpublished data on file with the Planning, Compliance, and Landscape Architect Division, Yellowstone National Park. 5 pp.

Synopsis: The seed mix for planting in the Gardiner triangle totaled 117.5 lbs of grass and 21.78 lbs of forb/shrub and included: Great Basin wildrye *(Leymus cinereus)*- 82.1 lbs; needle and thread grass *(Stipa comata)*- 12.95 lbs; Idaho fescue *(Festuca idahoensis)*- 1.39 lbs; Indian ricegrass *(Oryzopsis hymenoides)*- 2.27 lbs; bluebunch wheatgrass *(Pseudorogneria spicata)*- 0.48 lbs; western wheatgrass

(Pascopyrum smithii)- 0.11 lbs; prairie junegrass *(Koelaria macrantha*)- 0.04 lbs; slender wheatgrass (*Elymus trachycaulum)*- 15.35 lbs; Nelson's wheatgrass *(Stipa nelsonii)*- 0.54 lbs; western needlegrass *(Stipa occidentalis)*- 0.50 lbs; green needlegrass *(Stipa viridula)*- 7.0 lbs; yarrow *(Achillea millefolium)*- 1.0 lbs; silver sage *(Artemisia frigida)*- 6.5 lbs; big sagebrush *(Artemisia tridentata)*- 0.19 lbs; rabbitbrush *(Chrysothamnus nauseosus)*- 8.69 lbs; wooly yellow daisy *(Eriophyllum lanatum)*- 0.02 lbs; and greasewood *(Sarcobatus vermiculatus)*-5.37 lbs. In addition 8 bales of needle and thread grass with seed and grass stalk all combined, totaling about 16 lbs of pure seed, were used. Seeds were obtained from the Bridger (MT) Plant Materials Center or collected locally and stored over a period ranging from 1 to 12 years. Seeds were planted over the 11-acre area on 28 and 29 of March 2002 at an average rate of 13.77 lbs per acre. The plantings were watered overhead throughout the season via an irrigation piping system drafting from the local fire hydrant. Germination of all seeds by source and age were attempted under greenhouse conditions. Germination rates were highly variable under greenhouse conditions, but only 1 sample of rubber rabbitbrush collected in 1989 showed no germination.

<u>OTHER</u>

1. Despain, Don G. 1990. Yellowstone Vegetation, Consequences of Environment and History in a Natural Setting.Roberts Reinhart Publishers., Boulder, CO. 239 pp.

Describes the vegetation habitat and cover types in the park, their distribution, the physical environment, and the natural forces that influence plant succession. Shrub and grassland types in the Gardiner Basin include a bluebunch wheatgrass/Sandberg's bluegrass habitat type, with the Sandberg's bluegrass phase on the better soils of the mudflows, and the needle-and-thread phase mainly on the river deposited sands and gravels. Despain describes a big sagebrush/bluebunch wheatgrass habitat type in the Gardiner Basin.

2. Whittlesey, L.H. *In prep.* They're going to build a railroad: Cinnabar, Stevens Creek, and the Game Ranch addition to Yellowstone National Park.

A manuscript in preparation that details land settlements and ownerships in the Boundary Lands Area, the life, times, and people of the town of Cinnabar, and the complex interactions involved in the government acquisition of those lands. This was a wealthy source of information in describing the land use history of the area. Not yet available for public use.

Annotated Bibliography-Wildlife

Pronghorn

1. Barmore, W.J., Jr. 2003. Ecology of Ungulates and their Winter Range in Northern Yellowstone National Park, Research and Synthesis 1962-1970. Yellowstone Center for Resources, Yellowstone National Park, Wyoming.

Abstract: This study was conducted from 1962-1967 on winter ranges for elk, mule deer, pronghorn, Rocky Mountain bighorn sheep, bison, and moose in the northern one-third of the park. Ungulate population characteristics, distribution, and density were determined from aerial and ground surveys. Habitat selection by 14,270 elk, 6,203 mule deer; 3,198 pronghorn; 2,655 bighorn sheep; 953 bison; and 329 moose was determined during 1967-70 from ground observations along standard routes and was described in terms of 8 vegetation types, 10 slope-exposure classes, and snow depth. Changes in selected plant communities and species from 1949-1970 were evaluated from periodic re-measurements and photographs of permanent plots inside and outside exclosures (62 Parker 3-step transects, 56 chart quadrats, 33 belt transects, 25 condition and trend transects for shrubs and trees) and from annual estimates of overwinter and spring forage utilization by ungulates. Regulation is accomplished annually by a complex of dynamically interacting variables in which stochastic events are important in determining the regulatory contribution of the variables and the nature of the dynamic equilibrium between ungulates and their environment. Regulation is primarily accomplished by the annual effect on reproduction and mortality of susceptible adults to winter weather—primarily the highly variable and unpredictable snow regime—as it influences food availability, habitat selection and, thus, nutritional condition. Morphological characteristics of the ungulates relative to their ability to cope with snow, their food and feeding habits, and learned behavior also are important factors contributing to regulation and ecological separation of species. The ungulates attempt to increase to the highly variable and annually unpredictable carrying capacity of their winter environment by reproducing maximally for their physiological condition, and often excessively relative to the environment's capacity to support them. Characteristics of the regulating mechanism include (1) disproportionately heavy mortality of young annually, (2) periodically heavy mortality of young and susceptible adults due to food shortage during winter, and (3) heavy utilization by ungulates most winters of palatable plants on the most available winter range sites. Predation smoothes out food-imposed fluctuations of ungulate populations but does not prevent them from periodically exceeding the variable carrying capacity of their winter range. Vegetation on the winter range has either changed little since primeval times or measured changes primarily reflect factors other than unnatural impacts of native ungulates. Factors which maintain a dynamic equilibrium between ungulates and vegetation without its progressive deterioration are discussed. Greatest benefits can probably be derived from the park by allowing full expression of natural forces, by replacing missing ecosystem components where possible, and by not attempting to stimulate missing components or processes by artificial manipulation. The new dynamic equilibrium thus established will differ somewhat from the primeval, but will probably be more acceptable and valuable ecologically than alternative management schemes.

2. Boccadori, S.J. 2002. Effects of winter range on a pronghorn population in Yellowstone National Park, Wyoming. M.S. Thesis, Montana State University, Bozeman.

Abstract: The only population of pronghorn antelope (*Antilocapra americana*) in Yellowstone National Park (YNP) has showed a recent drop in numbers from over 500 animals in the early 1990's to <240 animals since 1995. Concern for the long-term sustainability of this herd led to an examination of the effects that the winter range has on the habitat use and demographics of this population. Radiotelemetry data were collected on instrumented adult does from June 1999 through August 2001. While all pronghorn congregated on the winter range from December through March, there were 2 distinct segments to this population based on migratory strategy: a resident herd that remained on the winter range year-round and a herd that migrated to higher valleys within the Park during the summer. There was evidence of migration north of YNP as well. The current winter range is located within the northern range of YNP, just west of

Gardiner, Montana. A portion of it lies outside the Park on private, Forest Service, and conservation easement lands. Results from logistic regression showed that pronghorn selected for cover and elevation on the winter range and selected among cover types. Rabbitbrush (*Chrysothamnus* spp.) and greasewood (*Sarcobatus* spp.) cover types were used more than grassland, while big sagebrush (*Artemisia tridentata* spp.) types were avoided. Observational data did not show one cover type being used more for feeding and bedding than other cover types. Microhistological analysis of fecal pellets showed that the majority of pronghorn winter diet was comprised of browse, with rabbitbrush being the most prevalent woody species. Due to heavy browsing by ungulates over the past century, seral species such as rabbitbrush have dominated on the winter range while the vigor of the sagebrush community has declined. Adult doe survival probabilities and fawn: doe ratios for non-migratory pronghorn were lower than those for migratory pronghorn. An evaluation of the relationship between adult mortality and recruitment showed that during this study the resident herd was draining the population while the migratory herd was the source of the limited recruitment that occurred.

3. Byers, J.A. 2002. Fecundity and fawn mortality of northern Yellowstone pronghorn. Final report dated December 4, 2002, and submitted to the National Park Service by the University of Idaho. Cooperative agreement #1443CA157099002.

Abstract: Based on a comparison of body masses and on the relationship of body mass to skeletal size during 1999-2001, pronghorn females in Yellowstone were in slightly poorer condition than females on National Bison Range. The slightly poor condition of Yellowstone females was reflected by shorter gestations, lighter fawns, and fawns in slightly poorer condition compared to those on the Bison Range. However, Yellowstone females produced litters that were 13% of their own body mass, the same level of reproductive expenditure that existed on the Bison Range. Though Yellowstone fawns were somewhat lighter than Bison Range fawns, all captured fawns were vigorous and appeared healthy. The frequency distribution of fawn age at death was bimodal, with a peak shortly after birth and another smaller peak at about 18 days, the age when fawns began to make the transition out of pure hiding and were up and visible for increasing amounts of time. Fawn mortality was not attributable to condition. All pronghorn females spent the winter in the grassland west of Gardiner, and did not migrate into the higher grasslands until just before giving birth. A female that gave birth in the Lamar had the same winter diet as a female that gave birth on winter range, yet the fawns of these two females had greatly different chances of survival. The data implicated coyote predation as the major source of fawn mortality and a key factor that currently limits the Yellowstone pronghorn population. Though the poor condition of the ungulate winter range is reflected in slightly poor condition of pronghorn females, the effect is not large enough to influence fecundity, litter size, or fawn health. Whether the high level of reproductive effort coupled with poor winter range shortens longevity of females remains an important question to answer in the future.

4. Houston, D.B. 1982. The Northern Yellowstone Elk. MacMillan Publishing Co., New York.

Abstract: This study examines the nature of existing vegetation-ungulate relationships on the northern winter range of Yellowstone National Park to determine if population reductions are necessary in the park. Field work was conducted from June 1970 to February 1979. Aspects of the ungulate-vegetation equilibria have changed over the past century, mainly as a result of fire suppression. With one exception, however, the data available do not indicate that reductions of elk or any other ungulate are necessary in the park to alter the present equilibria with the vegetation, alter interspecific relationships among herbivores, or for other reasons. Bison are the exception. A program to prevent contact between bison and cattle will require the sporadic removal of limited numbers of bison at the park boundary. The objective of maintaining representative natural ecosystems must be modified for northern Yellowstone elk because the park is not a complete ecological unit for one segment of the population that migrates outside the park. Hunting alters the dynamics of the elk herd and otherwise conflicts with park objectives. However, it may be possible, through sensitive management, to minimize these effects. The precariously low numbers of pronghorn on the northern range resulted primarily from human predation and consideration should be given to reestablishing pronghorn on the range outside the park. Not only would this expanded distribution more closely resemble historic conditions, but chances for perpetuating the pronghorn would be greatly enhanced. Maintaining populations of large native carnivores is an especially important and challenging management objective on the northern range. The gray wolf should be restored to the park because its absence represents perhaps the single greatest departure from the objective of maintaining natural ecosystems. Human conflicts with the management of elk and other large mammals outside the park will accelerate as land is further subdivided and developed. Opportunities should not be missed for purchasing lands on the winter range and adding them to the public domain for wildlife. Within the park, the goal should be to reduce the size and number of developments.

5. Keating, K. 2002. History of pronghorn population monitoring, research, and management in Yellowstone National Park. Final report dated January 28, 2002, and submitted to the National Park Service by the USGS Northern Rocky Mountain Science Center, Bozeman, Montana. NPS Agreement #1443-IA-1248-01-006.

Abstract: Pronghorn antelope in Yellowstone National Park (YNP) persist in a small population that historically has experienced recurrent, sometimes dramatic declines. They apparently are isolated from other pronghorns, depend partly on private lands for winter range, experience heavy predation of fawns, and concentrate during winter in a relatively small area, thereby increasing their vulnerability to factors like disease or locally extreme weather. Overall, the situation raises serious concerns about the long-term viability of this population. Although such concerns are not new, evidence of a dramatic population decline since 1991 and continued poor recruitment has created a renewed sense of urgency. Recent efforts to revitalize pronghorn research in YNP began with fawn recruitment and habitat use studies, initiated in 1999 and 2000. With those studies drawing to a close, YNP is reviewing the status and direction of its pronghorn program. The Yellowstone Pronghorn Conservation Assessment Workshop was convened in YNP in January, 2002, to appraise the current state of knowledge about this pronghorn population and make recommendations about future management and research needs. This review of pronghorn population change, management, and research in YNP was commissioned in May, 2001, to provide historical background for workshop participants.

6. National Park Service. 2002. Yellowstone Pronghorn Conservation Assessment Workshop, Mammoth Hot Springs, Yellowstone National Park, January 28-31, 2002. Final report dated August 5, 2002, Yellowstone Center for Resources, Yellowstone National Park, Mammoth, Wyoming.

Abstract: Yellowstone National Park convened an expert panel on pronghorn consisting of members from academia and federal and state agencies during January 28-31, 2002, to appraise the current state of knowledge about the status of the Yellowstone pronghorn population and make recommendations regarding future management and research needs. The panel recommended that the park also consider implementing the following high-priority management actions: 1) implement a rigorous monitoring program to estimate vital rates and identify and monitor migration routes, fawning areas, the proportion of the herd in each summer sub-group, and differential fawn mortality among groups; 2) develop at least 2 independent aerial and/or ground survey methods for reliably estimating the abundance of the pronghorn population; 3) develop a contingency plan of management alternatives that could be implemented if the abundance of the herd continues to decrease; 4) **develop and implement a habitat restoration plan for former agricultural lands on the winter range within the park boundary**; 5) collect fecal samples from summer and winter ranges on a monthly or weekly basis and assess percent fecal nitrogen and DAPA; and 7) conduct necropsies of mortalities and opportunistically sample (e.g., during capture operations) blood and feces for chemical serology, trace elements, and parasites. In addition, the panel recommended that the park initiate the following high-priority research actions: 1) conduct an integrated study of the ecological interactions between wolves, coyotes, and pronghorn that evaluates the apparent differential mortality/recruitment among pronghorn fawning areas in relation to wolf and coyote densities and use; 2) conduct comparative genetics analyses to measure heterozygosity, allele frequencies, and genetic distances (mitochondrial DNA, microsatellite (nuclear) DNA) to evaluate inbreeding, genetic uniqueness, and genetically similar potential source populations for possible future translocation; and 3) conduct a study that integrates weather patterns, forage production, pronghorn nutritional condition, and recruitment.

7. National Research Council. 2002. Ecological dynamics on Yellowstone's northern range. National Academy Press, Washington, D.C.

Abstract: On March 26, 2002, the Committee on Ungulate Management in Yellowstone National Park, Board on Environmental Studies and Toxicology, Division on Earth and Life Studies, National Research Council (NRC), issued their 3-year evaluation of Yellowstone National Park's management of the northern range entitled "Ecological Dynamics on Yellowstone's Northern Range" (National Research Council 2002). The NRC committee concluded that the Yellowstone "pronghorn herd faces a serious risk of extinction." As a result, the committee recommended that "[a] thorough study of current and likely future trajectories of the pronghorn population and the role of human effects on this population is needed …"

8. O'Gara, B.W. 1968. A study of the reproductive cycle of the female pronghorn (*Antilocapra americana* Ord.). Dissertation, University of Montana, Missoula.

Abstract: One hundred and thirty-seven pronghorn were collected from the National Bison Range and Yellowstone National Park, Montana. The reproductive tracts of females were examined and unique aspects described. Weights, measurements, and fat indices were compared to determine the cause of low fawn survival in Yellowstone. The fetal sex ratio was 110 males:100 females, while the viable conceptus:doe ratio was 195:100. One fawn was pregnant and carrying twins; 10 yearlings were collected and each carried twins. The ovulation rate increased to age 7 and then decreased slightly. Twelve does >9 years old were collected and all carried twins. The kidney fat index was the best indicator of condition. The physical condition of adult females was poorest in May and best in December. Lactating does were in poor condition during the late summer when other animals were regaining fat. According to all the indices used, the Yellowstone animals were in better condition than those on the National Bison Range. The low fawn counts in Yellowstone are due to some type of post-partum mortality factor. It appeared highly possible that coyote predation on young fawns in the factor.

9. Scott, M.D. 1992. Buck-and-pole fence crossings by 4 ungulate species. Wildlife Society Bulletin 20:204-210.

Abstract: In 1988 and 1989, I studied the abilities of mule deer, pronghorns, bison, and elk to cross a 3.8-km buck-and-pole fence that was built on part of the northern border of Yellowstone National Park (USA). No animal jumped the fence. Mule deer were most successful at crossing through intact fence, followed by pronghorns, bison, and elk. Rate of gate use by ungulate species was nearly the reverse of intact-fence crossing success rate. Except for bison, the overall total successful fence-crossing rate was about 87-91%. Closure of all gates in a fence of the size studied would virtually stop all crossings by elk and bison. If gates cannot be left open, elk may jump buck-and-pole fences if the top 1 or 2 rails are removed (leaving a maximum height of about 1 m), or if barbed wire meeting wildlife passage guidelines is substituted. Mule deer commonly fed inside the fence and may have benefited from exclusive use of this forage. Pronghorns, bison, and elk had difficulty entering the fence from the 4-rail side. Elk and pronghorns sometimes seemed to become trapped inside the fence.

10. Singer, F.J., and J.E. Norland. 1994. Niche relationships within a guild of ungulate species in Yellowstone National Park, Wyoming, following release from artificial controls. Canadian Journal of Zoology 72:1383-1394.

Abstract: Niche relationships and diet overlaps were compared among elk (*Cervus elaphus*), bison (*Bison bison*), bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) between 1967-1970 and 1986-1988, a period when total ungulate numbers nearly tripled on Yellowstone's northern range. Ungulate species ratios on Yellowstone's northern winter range during the latter period were 100 elk: 10 mule deer: 3 bison: 2 pronghorns: 1 bighorns. Elk numbers were positively correlated to bison, mule deer, and pronghorn numbers (r-2 = 0.76, 0.97, and 0.48, respectively, $P < 0.01$). Few other changes in habitat use or habitat overlap occurred, and diets for only 2 of the 10 species pairs, elk-bighorn (Spearman's rank order coefficient (RHO) = 0.55, $P < 0.05$) and mule deer - pronghorn (RHO = 0.64, $P < 0.05$), were significantly associated with each other. Bison consumed more grass and fewer sedges, mule deer more fringed sage (*Artemisia frigida*) and more rabbit-brush (*Chrysothamnus spp*.), and bighorn sheep more grasses and fewer sedges, while pronghorns ate less saltsage (*Atriplex nuttalli*) but more big sagebrush (*Artemisia tridentata*) during 1986-1988 than during 1967-1970. Bison expanded their range and bison and bighorn sheep used a wider variety of habitats. We found little evidence of change in competitive interactions between ungulate species. A few diet and habitat overlaps increased, the opposite of the prediction from the competitive exclusion principle amongst species, suggesting that intraspecific competition was more important. Several explanations are proposed for the lack of changes in niche relationships during a period of near tripling in density of the ungulate guild.

Elk

1. Barmore, W.J., Jr. 2003. Ecology of Ungulates and their Winter Range in Northern Yellowstone National Park, Research and Synthesis 1962-1970. Yellowstone Center for Resources, Yellowstone National Park, Wyoming.

Abstract: This study was conducted from 1962-1967 on winter ranges for elk, mule deer, pronghorn, Rocky Mountain bighorn sheep, bison, and moose in the northern one-third of the park. Ungulate population characteristics, distribution, and density were determined from aerial and ground surveys. Habitat selection by 14,270 elk, 6,203 mule deer; 3,198 pronghorn; 2,655 bighorn sheep; 953 bison; and 329 moose was determined during 1967-70 from ground observations along standard routes and was described in terms of 8 vegetation types, 10 slope-exposure classes, and snow depth. Changes in selected plant communities and species from 1949-1970 were evaluated from periodic re-measurements and photographs of permanent plots inside and outside exclosures (62 Parker 3-step transects, 56 chart quadrats, 33 belt transects, 25 condition and trend transects for shrubs and trees) and from annual estimates of overwinter and spring forage utilization by ungulates. Regulation is accomplished annually by a complex of dynamically interacting variables in which stochastic events are important in determining the regulatory contribution of the variables and the nature of the dynamic equilibrium between ungulates and their environment. Regulation is primarily accomplished by the annual effect on reproduction and mortality of susceptible adults to winter weather—primarily the highly variable and unpredictable snow regime—as it influences food availability, habitat selection and, thus, nutritional condition. Morphological characteristics of the ungulates relative to their ability to cope with snow, their food and feeding habits, and learned behavior also are important factors contributing to regulation and ecological separation of species. The ungulates attempt to increase to the highly variable and annually unpredictable carrying capacity of their winter environment by reproducing maximally for their physiological condition, and often excessively relative to the environment's capacity to support them. Characteristics of the regulating mechanism include (1) disproportionately heavy mortality of young annually, (2) periodically heavy mortality of young and susceptible adults due to food shortage during winter, and (3) heavy utilization by ungulates most winters of palatable plants on the most available winter range sites. Predation smoothes out food-imposed fluctuations of ungulate populations but does not prevent them from periodically exceeding the variable carrying capacity of their winter range. Vegetation on the winter range has either changed little since primeval times or measured changes primarily reflect factors other than unnatural impacts of native ungulates. Factors which maintain a dynamic equilibrium between ungulates and vegetation without its progressive deterioration are discussed. Greatest benefits can probably be derived from the park by allowing full expression of natural forces, by replacing missing ecosystem components where possible, and by not attempting to stimulate missing components or processes by artificial manipulation. The new dynamic equilibrium thus established will differ somewhat from the primeval, but will probably be more acceptable and valuable ecologically than alternative management schemes.

2. Boyce, M.S., M.G. Turner, J. Fryxell, and P. Turchin. 2003. Scale and heterogeneity in habitat selection by elk in Yellowstone National Park. Ecoscience 10:421-431.

Abstract: Resource selection functions (RSF) can be used to explore the role of scale in determining patterns of habitat use. We estimated RSFs for 93 radiocollared adult-female elk (*Cervus canadensis)* with resource availability defined at 4 spatial scales and 2 seasons in Yellowstone National Park. Habitat selection was differed markedly among scales and seasonal ranges. During winter elk moved to ranges at lower elevations where snow water equivalents were low and selected landscapes with a mix of forest and open vegetation at all spatial scales. Areas of high vegetation diversity were selected at large spatial scales during summer, whereas elk selected less diverse areas on winter range. During summer elk selected forests that burned 12–14 years ealier but used these burns less than expected by chance during winter. Habitat selection by elk occurred at multiple spatial scales, thus we cannot prescribe a single scale as being best for modeling habitat use by elk. Instead selection of an appropriate scale will vary depending on the research question or management issue at hand.

3. Cook, R.C., J.G. Cook, and L.D. Mech. 2004. Nutritional condition of northern Yellowstone elk. Journal of Mammalogy 85:714-722.

Abstract: We estimated nutritional condition for 96 female northern Yellowstone elk (*Cervus elaphus nelsonii*) during mid- to late winter 2000, 2001, and 2002. Neither year nor capture location significantly influenced any measure of condition (body fat, body mass, and longissimus dorsi thickness; $P \geq 0.14$). Overall, age = 8.9 ± 0.4 SE, body fat = 9.5% ± 0.4, body mass = 235.1 kg ± 2.2, and loin muscle thickness = 5.6 cm ± 0.1. Despite an age segregation pattern across the winter range ($P = 0.016$), we found no evidence of bias in our estimates of nutritional condition due to this pattern because condition was unrelated to age. Yearly pregnancy and lactation rates of all cows ranged from 78 to 84% and 8 to 16%, respectively, at the time of capture. Lactational status significantly influenced body condition ($P = 0.003$), with lactating cows having 50% less fat than non-lactating cows. Probability of pregnancy observed for elk that we captured followed a logistic curve as a function of body fat levels. Based on mid- to late winter body fat levels, we would predict low mortality of adult cows during mild to normal winters. We suggest the possibility of nutritional limitation acting on this herd through summer-autumn forage conditions, in association with limitations during harsh winters.

4. Coughenour, M.B., and F.J. Singer. 1996. Elk population processes in Yellowstone National Park under the policy of natural regulation. Ecological Applications 6:573-593.

Abstract: The interrelations of weather, plant production and abundance, and elk population dynamics on Yellowstone's northern winter range were examined for a 23-year period when there was minimal human offtake from the herd. Significant correlations between precipitation and plant production, between elk population responses and precipitation, and between elk population responses and elk population density strongly suggested that forage limited elk population growth. Although population responses to density have been documented previously in Yellowstone, responses to precipitation have not. Correlations between elk population responses and annual precipitation were presumably consequences of plant growth responses to precipitation and subsequent effects on elk nutritional status. Population regulation was most consistently achieved through the responses of juveniles rather than adults. Winter mortality of juveniles was primarily correlated with elk numbers, whereas recruitment was primarily correlated with precipitation. Adult mortality rates were not significantly correlated with elk numbers, but were correlated with precipitation. Per capita rate of increase was negatively correlated with elk number, but 55% of the variance was density-independent. There was evidence that winter weather affected the elk, but season-long weather indices had poor predictive power. A stage-structured population model using regression equations of mortality and recruitment rate responses to precipitation and elk numbers, predicted that the population could vary within a range of apprxeq 16400 +- 2500 sighted elk (mean +- 1 SD).

5. Fortin, D., H.L. Beyer, M.S. Boyce, D.W. Smith, T. Duchesne, and J.S. Mao. 2005. Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology, *in press*.

Abstract: A trophic cascade has recently been reported among wolves, elk and aspen on the northern winter range of Yellowstone National Park, but the mechanisms of indirect interactions within this food chain have yet to be established. We investigated whether the observed trophic cascade might have a behavioral basis by exploring environmental factors influencing the winter movements of 13 elk equipped with GPS-radiocollars. Paths of traveling elk were broken down into steps, which correspond to the straight-line segment between successive locations at 5-hour intervals. Each observed step was paired with 200 random steps having the same starting point, but differing in length and/or direction. Comparison between environmental characteristics of observed and random steps revealed that elk movements were influenced by multiple environmental features, such as the distance from roads, the presence of a cliff along the step, and the energy required to make that step. After accounting for the influence of these environmental factors, we additionally found that elk selected steps on the basis of the habitat type in which they ended. This influence of habitat locations on elk movements depended on the spatial distribution of wolves in the northern winter range of the park. In low wolf-use areas, the relative preference for step end point locations followed: aspen stands > open areas > conifer forest areas. As the risks of wolf encounter increased, elk's preference for aspen stands gradually decreased, and selection became strongest for steps ending in conifer forest areas under high risks of encountering wolves. Our study supports the hypothesis that the Yellowstone's trophic cascade in the wolf-elk-aspen system has a behavioral basis, where elk respond to wolf spatial distribution on their winter range by shifting their habitat selection.

6. Houston, D.B. 1982. The Northern Yellowstone Elk. MacMillan Publishing Co., New York.

Abstract: This study examines the nature of existing vegetation-ungulate relationships on the northern winter range of Yellowstone National Park to determine if population reductions are necessary in the park. Field work was conducted from June 1970 to February 1979. Aspects of the ungulate-vegetation equilibria have changed over the past century, mainly as a result of fire suppression. With one exception, however, the data available do not indicate that reductions of elk or any other ungulate are necessary in the park to alter the present equilibria with the vegetation, alter interspecific relationships among herbivores, or for other reasons. Bison are the exception. A program to prevent contact between bison and cattle will require the sporadic removal of limited numbers of bison at the park boundary. The objective of maintaining representative natural ecosystems must be modified for northern Yellowstone elk because the park is not a complete ecological unit for one segment of the population that migrates outside the park. Hunting alters the dynamics of the elk herd and otherwise conflicts with park objectives. However, it may be possible, through sensitive management, to minimize these effects. The precariously low numbers of pronghorn on the northern range resulted primarily from human predation and consideration should be given to reestablishing pronghorn on the range outside the park. Not only would this expanded distribution more closely resemble historic conditions, but chances for perpetuating the pronghorn would be greatly enhanced. Maintaining populations of large native carnivores is an especially important and challenging management objective on the northern range. The gray wolf should be restored to the park because its absence represents perhaps the single greatest departure from the objective of maintaining natural ecosystems. Human conflicts with the management of elk and other large mammals outside the park will accelerate as land is further subdivided and developed. Opportunities should not be missed for purchasing lands on the winter range and adding them to the public domain for wildlife. Within the park, the goal should be to reduce the size and number of developments.

7. Kay, C.E. 1990. Yellowstone's northern elk herd: a critical evaluation of the "natural-regulation paradigm. Dissertation, Utah State University, Logan.

Abstract: Prior to 1968, the National Park Service maintained that an unnaturally large population of elk had severely damaged Yellowstone Park's northern winter range, including aspen and willow communities. However, under "natural regulation" management adopted in the early 1970s the agency now believes that vegetation changes in the park are due to normal plant succession, climatic change, or fire suppression, not ungulates. The agency also believes that large numbers of elk (12,000-15,000) have wintered on the park's northern range for the last several thousand years. This study tested several of the major assumptions or predictions of the Park Service's "natural regulation" paradigm by collecting vegetation data, reviewing historical source materials, and analyzing archaeological reports. The available evidence suggests that observed changes in Yellowstone's tall willow and aspen communities are due primarily to ungulate browsing, not other factors. The future of sexually reproducing willow and aspen communities on the park's northern range appears to be in jeopardy. Under current management, their extinction is only a matter of time. Moreover, entire plant and animal communities have been affected, not just aspen and willows. Historical accounts and archaeological data indicate that few elk inhabited Yellowstone prior to creation of that national park in 1872. These results do not support the "natural regulation" paradigm. Prior to European influence, predation by Native Americans and carnivores limited elk, as well as other ungulate numbers throughout the Greater Yellowstone area.

8. Lemke, T.O., J.A. Mack, and D.B. Houston. 1998. Winter range expansion by the northern Yellowstone elk herd. Intermountain Journal of Sciences 4:1-9.

Abstract: We examine and describe changes in northern Yellowstone elk (*Cervus elaphus*) winter distribution, population size and harvests from 1975-1997. Since the late 1970s, northern Yellowstone elk have expanded their winter range by 41 percent to about 152,663 ha. During this period, elk winter range north of Yellowstone National Park (YNP) has more than doubled from 22,179 ha. to 53,269 ha. Since 1988-89 the number of elk wintering north of YNP has averaged 5460 elk/year (1,533-8,626) with 2,000-4,500 elk wintering north of Dome Mountain where few Yellowstone elk wintered prior to 1988-89. Minimum fall elk population estimated increased form 11,149-12,941 animals in the late 1970s to a mean of 17,409 $\pm$ 1,377 (SD) elk based on nine annual counts conducted between 1981-82 and 1994-95. Minimum winter (post-hunting) numbers averaged 15,520 $\pm$ 2324 (SD) for the same period. With more elk migrating out of YNP, late season elk harvests 64 percent form 892 $\pm$ 506 (SD) elk/year from 1979-80 to 1987-88 to 1,459 $\pm$ 815 (SD) elk/year from 1988-89 to 1996-97. Winter range expansion, elk migration behavior and increased winter harvests dispelled earlier concern that winter hunts would prevent elk form using all available winter range. Challenges facing the management of Yellowstone elk north of YNP include harvesting enough elk to maintain the long-term diversity and productivity of winter range vegetation, resolving land use conflicts with elk expanding into Paradise Valley, and addressing growing concerns about the possible transmission of the disease brucellosis from elk to domestic livestock.

9. Mao, J. 2003. Habitat selection by elk before and after wolf reintroduction in Yellowstone National Park, Wyoming. Unpublished Master of Science thesis, University of Alberta, Edmonton, Alberta, Canada.

Abstract: Prey species select habitat in an attempt to obtain necessary resources (food, mates, shelter, etc.) while also avoiding predation. I examined whether habitat selection by elk (*Cervus elaphus*) changed following the reintroduction of wolves (*Canis lupus*) into Yellowstone National Park in 1995. Using conditional fixed-effects logistic regression to build habitat selection models, I compared seasonal habitat selection by elk before versus after wolf reintroduction based on weekly elk radiolocations taken in 1985-1990 and 2000-2002. In summer, when wolf activity was centered around dens and rendezvous sites, elk avoided wolves by selecting higher elevations, less open habitat, more burned forest, and, in high wolf density areas, steep slopes. In winter, elk could not spatially separate themselves from wolves and, compared to prewolf times, they selected for more open habitats after wolf recovery. Elk appear to use habitat selection to avoid wolves in summer, but must rely on behavioral anti-predator strategies (*e.g.,* grouping) in winter.

10. National Research Council. 2002. Ecological dynamics on Yellowstone's northern range. National Academy Press, Washington, D.C.

Abstract: Factors whose influences are related to population density interact with factors whose influences are not to regulate elk and bison populations in the northern range. There is a strong density-dependent signal in northern range elk and bison population dynamics, but their responses differ: bison tend to expand their range to areas outside Yellowstone National Park when their population exceeds roughly 2,500, whereas reproductive rates in elk decline when their populations exceed roughly 15,000 (page 7). In addition to density-dependent factors, elk and bison populations also are affected by density-independent factors such as weather and because ungulates and their food do not always vary in a synchronous way. Thus, some ungulate populations tend to fluctuate regardless of human management intervention. The best available scientific evidence does not indicate that ungulate populations are irreversibly damaging the northern range (page 102). In addition, several significant changes have been made in the northern range in recent years, including the reintroduction of wolves and expansion of the winter range outside the park; the long-term influence of these changes cannot yet be determined. Thus, resource managers in Yellowstone National Park could continue to manage the northern range as they are now. That is , managers would continue to let the populations of elk, bison, and other ungulates fluctuate without any direct (inside Yellowstone) controls, letting a combination of weather, wolves, range conditions, and external controls (e.g., outside-the-park hunting, land uses, and population reduction by state agencies, such as the Montana Department of Livestock's program for bison) influence the population numbers.

11. Smith, D.W., T.D. Drummer, K.M. Murphy, D.S. Guernsey, and S.B. Evans. 2004. Winter prey selection and estimation of wolf kill rates in Yellowstone National Park, 1995-2000.

Abstract: Wolf (*Canis lupus*) impacts on prey are a central post-wolf-reintroduction issue in the greater Yellowstone ecosystem (GYE) of the western United States. Further, estimates of wolf kill rates, used to understand these impacts, can be biased due to unrecovered kills. In Yellowstone National Park (YNP), visibility of wolves allowed us to combine independent aerial and ground observations and use a double-count method to estimate the probability of recovering kills. We consequently used this data to adjust estimates of wolf kill rates. We conducted monitoring annually from 1995 to 2000 during 2 30-day periods in early (15 Nov–14 Dec) and late winter (Mar). Estimated recovery rates of wolf kills for ground and aerial crews were 50% and 45%, respectively, although we determined that this varied by location (distance from road) and possibly age (calf or adult) of the kill. The estimated combined recovery rate was 73%. Estimated wolf kill rates were higher in late winter (2.2 kills/wolf/month) compared to early winter (1.6 kills/wolf/month), with an overall estimated rate of 1.9 kills/wolf/month. The primary prey of wolves in winter was elk (*Cervus elaphus*; 90%). During our study, 43% of the elk killed were calves, 28% were adult females (cows), 21% were adult males (bulls), and 9% were of unknown age/sex. Comparing prey selection to prey availability, wolf packs residing on the northern range (NR) of the GYE selected for calves, against cows, and approximately proportional to availability for bulls. Prey use was different for wolf packs occupying the NR compared to packs residing in other areas (non-northern range [NNR]) and varied seasonally for NR packs. Variation in wolf kill rates by season, and the relative stability of the northern Yellowstone elk herd during a series of mild winters despite increases in wolf density, suggest that kill rates and ultimately elk population size are influenced by winter weather. Management of ungulates should reflect the addition of wolves combined with the unpredictability of winter weather in the mountainous terrain of the western United States.

12. Singer, F.J., A. Harting, K.K. Symonds, and M.B. Coughenour. 1997. Density dependence, compensation, and environmental effects on elk calf mortality in Yellowstone National Park. Journal of Wildlife Management 61:12-25.

Abstract: We studied survival of radiocollared elk (*Cervus elaphus*) calves in Yellowstone National Park from 1987 to 1990, and survival of calves computed from population estimates from 1968 to 1992. We hypothesized that summer and winter survival of elk calves and mass of neonates were inversely related to population size, measures of environmental severity, and timing of births. Herd-wide survival estimates based on winter counts, reported harvests, and herd classifications, suggested that winter survival of elk calves was radiocollared calves averaged 0.65 (n = 127 marked calves) from 1987 to 1990, the losses mostly due to predation (22%). Winter survival of calves averaged 0.72 (n = 88 marked calves entered the winter period), with losses due mostly to malnutrition (58%). Summer survival of radiocollared calves was positively correlated with estimated birth weight (P = 0.001). Survival of radiocollared calves during winters 1987-90 was correlated positively with early calving and mildness of the winter (in contrast to herd-wide survival estimates), and was inversely correlated with estimated elk population size that winter (P = 0.006). Winter survival of radiocollared calves was lower during 1988-89 following the drought and large fires than the other 3 winters (P < 0.001). Predation on elk calves during summer doubled after the drought and fires of 1988 (13% calf losses to predation before the fires vs. 29% after the fires). Potential compensation existed between components of calf mortality: predators killed more light (P = 0.041) and more late born calves (P = 0.146); calves were born later and lighter (P = 0.048) following severe weather conditions; and heavier born calves survived at a higher rate (P = 0.006). Our results are consistent with the hypothesis that density-dependent mortality of calves during winter due to malnutrition, and summer mortality of calves due to predation were partially compensatory but severe environmental conditions produced largely additive components to both summer (increased predation) and winter (increased malnutrition) mortality.

13. Singer, F.J., and J.E. Norland. 1994. Niche relationships within a guild of ungulate species in Yellowstone National Park, Wyoming, following release from artificial controls. Canadian Journal of Zoology 72:1383-1394.

Abstract: Niche relationships and diet overlaps were compared among elk (*Cervus elaphus*), bison (*Bison bison*), bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) between 1967-1970 and 1986-1988, a period when total ungulate numbers nearly tripled on Yellowstone's northern range. Ungulate species ratios on Yellowstone's northern winter range during the latter period were 100 elk: 10 mule deer: 3 bison: 2 pronghorns: 1 bighorns. Elk numbers were positively correlated to bison, mule deer, and pronghorn numbers (r^2= 0.76, 0.97, and 0.48, respectively, P < 0.01). Few other changes in habitat use or habitat overlap occurred, and diets for only 2 of the 10 species pairs, elk-bighorn (Spearman's rank order coefficient (RHO) = 0.55, P <0.05) and mule deer -pronghorn (RHO = 0.64, P <0.05), were significantly associated with each other. Bison consumed more grass and fewer sedges, mule deer more fringed sage (*Artemisia frigida*) and more rabbit-brush (*Chrysothamnus spp*.), and bighorn sheep more grasses and fewer sedges, while pronghorns ate less saltsage (*Atriplex, nuttalli)* but more big sagebrush (*Artemisia tridentata*) during 1986-1988 than during 1967-1970. Bison expanded their range and bison and bighorn sheep used a wider variety of habitats. We found little evidence of change in competitive interactions between ungulate species. A few diet and habitat overlaps increased, the opposite of the prediction from the competitive exclusion principle amongst species, suggesting that intraspecific competition was more important. Several explanations are proposed for the lack of changes in niche relationships during a period of near tripling in density of the ungulate guild.

14. Taper, M.L., and P.J.P. Gogan. 2002. The northern Yellowstone elk: density dependence and climatic conditions. Journal of Wildlife Management 66:106-122.

Abstract: We analyzed a time series of estimates of elk numbers on the northern Yellowstone winter range from 1964 to 1979 and 1986-1995 using a variety of discrete time stochastic population dynamic models.

These models included adjustments for density, an increase in the area of winter range used by elk, lagged effects of the weather covariates of spring precipitation, snow depth and winter temperature, and the impacts of the 1988 drought and fires. An information-criteria-based model-selection process strongly supported evidence of density dependence. The best model, a Ricker model, distinguished between the 2 time periods. The bulk of the difference between the 2 periods is attributed to an increase in the amount of winter range used by elk. Inclusion of the covariates spring precipitation and spring precipitation squared greatly improved the model fit. We detected a short-lived increase in elk population growth following the 1988 drought and fires. Fertility and survivorship of adults appeared to have different density dependent forms that together result in a biphasic relationship between population growth and density. This study confirms the presence of density-dependent regulations in the northern Yellowstone elk herd, and enhances our understanding of population dynamics of these ungulates.

15. White, P.J., and R.A. Garrott. 2005. Yellowstone's ungulates after wolves – expectations, realizations, and predictions. Biological Conservation, *in press*.

Abstract: We evaluated the initial implications of wolf (*Canis lupus*) recovery on ungulates in Yellowstone National Park and compared expectations prior to wolf restoration with observed impacts since restoration. The numerical and functional responses of colonizing wolves in Yellowstone's prey-rich environment were higher than expected and close to the maximum rates predicted prior to wolf restoration. Counts of northern Yellowstone elk (*Cervus elaphus*) decreased more (50%) than predicted (5-30%), and will likely continue to decrease given the strong preference of wolves for elk and continued high kill rates despite this substantial reduction in elk abundance. Contrary to expectations, human harvests were not reduced appreciably concurrent with wolf restoration, but instead remained similar to pre-wolf restoration years. However, antler-less permits were gradually reduced by 51% during 2000-2004 and additional reductions may be necessary while wolf densities remain high. There have been no substantial effects of wolf recovery on other ungulate species (bighorn sheep (*Ovis canadensis*), bison (*Bison bison*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*)). However, wolf recovery may eventually contribute to increased bison and pronghorn abundance by decreasing elk and coyote abundance, respectively. Wolf recovery may also contribute to more-pronounced spatial structuring of sex/age classes of northern Yellowstone elk through changes in their distribution, migration, and age structure. The initial consequences of wolf recovery support the premise that wolves may naturally achieve densities above their threshold for ecological effectiveness and contribute to significant changes in ecosystems, including the amelioration of ungulate-caused landscape simplification.

16. White, P.J., and R.A. Garrott. 2005. Northern Yellowstone elk after wolves. Wildlife Society Bulletin, *in press*.

Abstract: We analyzed counts, vital rates, and limiting factors for northern Yellowstone elk (*Cervus elaphus*) before and after wolf (*Canis lupus*) restoration in 1995-1996 to evaluate predictions that elk numbers would move to a lower equilibrium point with corresponding density-related changes in vital rates. Elk counts decreased from approximately 17,000 in 1995 to 8,335 in 2004. Pregnancy rates for prime-age females (3-15 years) during 2000-2003 were high (0.90) and similar to those during 1950-1967 when elk density was 30% lower (5-9 elk/km^2). The survival rate for prime-aged females was 0.85 (95% CI = 0.81 to 0.87) compared to 0.99 when harvests were low and wolves absent. The proportions of elk harvested each year increased as elk numbers decreased during 1990-2002, but departed from this anti-regulatory trend as permit levels were reduced in 2003-2004. Snow pack strongly influenced elk vulnerability to hunting by increasing migration to lower elevations. Thus, harvests removed a relatively constant proportion (27 $\pm$ 5%) of animals that migrated out of the park each year, primarily prime-aged females with high reproductive value. Conservative estimates of wolf off-take (>1,000 elk) exceeded harvests by 2003 with wolves primarily selecting calves and older elk with lower reproductive value. Recruitment decreased as the ratio of wolves to elk increased and wolves maintained high kill rates and rapid population growth despite a 50% decrease in elk counts. Elk numbers will likely continue to decrease until: 1) levels of harvest and/or predation decrease sufficiently; 2) there is sufficient time for recruitment of calves to prime breeding age; and 3) there is a numerical response of wolves to fewer elk. We

recommend managers quickly adjust antler-less permit quotas to population size in a density-dependent manner so that harvests do not accelerate the decrease in elk numbers.

Bighorn Sheep

1. Lemke, T.O. 2003. Northern Yellowstone Cooperative Bighorn Sheep Survey, 2003. Report dated May 8, 2003, Montana Fish, Wildlife, and Parks, Bozeman, Montana.

Abstract: Aerial surveys during April 28-May 2, 2003, by Montana Fish, Wildlife, and Parks (MFWP) detected 185 sheep (90 ewes, 29 lambs, and 66 rams) on the northern range (inside and outside Yellowstone National Park (YNP)). Sheep were detected in the following areas: Point of Rocks; Tom Miner basin; Yankee Jim Canyon/Corwin Springs/LaDuke; Travertine/Bear Creek/Deckard Flats; Beattie Gulch/Devil's Slide/Cinnabar Mountain; Mount Everts to Mammoth in YNP; Mount Norris to Tower Junction in YNP; and Black Canyon to Barronette Peak in YNP. A ratio of 32 lambs per 100 ewes was observed, which compares to an average spring recruitment estimate of 22 lambs per 100 ewes (range = 7-32) during 1995-2003. The growth rate of the northern Yellowstone population is relatively stable to slightly decreasing with an average count of 183 (range = 134-229) sheep since 1995. These counts remain well below the record high count of 487 sheep prior to the outbreak of infectious keratoconjunctivitis (i.e., "pinkeye") during the winter of 1981-82 that resulted in the direct and indirect mortality of at least 60 percent of the population.

2. Meagher, M. 1992. *Chlamydial*-caused infectious keratoconjunctivitis in bighorn sheep of Yellowstone National Park. Journal of Wildlife Disease 28:171-176.

Abstract: An outbreak of infectious keratoconjunctivitis occurred in bighorn sheep (*Ovis canadensis*) in Yellowstone National Park during the winter of 1981-82. The causative organism was identified as *Chlamydia* sp., origin unknown. Direct and indirect mortality totaled approximately 60% of at least 500 bighorn sheep in the northern range population. The infection probably affected all sex and age classes, but field surveys of live animals and recorded mortality suggested that mature rams died disproportionately. Field observations made the following winter of individuals having both normal and cloudy appearing eyes suggested that perhaps half of the bighorns then present on the core units of winter range had contracted the disease and survived. By 1988, there appeared to be about 300 bighorn sheep in the population.

3. Ostovar, K. 1998. Impacts of human activity on bighorn sheep in Yellowstone National Park. M.S. Thesis, Montana State University, Bozeman.

Abstract: Seventeen years have passed since bighorn sheep (*Ovis canadensis canadensis*) in Yellowstone National Park (YNP) experienced a massive *Chamydial*-caused die-off. Currently, no sigh of *Chlamydia* or pneumonia is evident, thus other factors are considered to be limiting the population. The proposed changes to the Gardiner-Mammoth highway and the highway through Dunraven Pass could increase or decrease human disturbances to the core population of bighorn sheep. Approximately 65% of all observations on the Everts winter range occurred on the top of McMinn Bench (along the proposed road route). One ewe group currently must cross the Gardiner-Mammoth highway to reach spring lambing grounds. The placement of the road onto McMinn Bench would impact at least 2 other populations of ewe groups and 2-3 populations of ram groups, which seek shelter, security, water, and minerals in the cliffs. Use of the Dunraven Pass road corridor was low and potential displacement from road changes would be minor. Disturbance events wee recorded during behavioral observations. Human presence was recorded for 26% of all observations, with 25% of these resulting in disturbances. The percentage of overall human disturbances for all observations in each group was: McMinn Bench ewes 7.5%, McMinn Bench rams 4.6%, Mount Washburn 4.3%, Deckard Flats 5.4%, Rattlesnake Butte 2.9%. The most disturbing human activity (based on overt reactions) was helicopter aircraft. To evaluate the effects of these human disturbances I used 3 non-invasive techniques that may be indicators of stress in bighorn sheep: behavioral activity levels, lungworm larvae shedding levels (LPG), and levels of the hormone corticosterone. Most

groups were not significantly different in degree of activity except for McMinn Bench, which had higher levels of activity than Rattlesnake Butte. Significant differences were found in LPG between sexes (rams < ewes) ($F = 4.76$, $P = .0299$) and between two groups (McMinn Bench < Rattlesnake Butte) ($F = 7.24$, $P = .0075$). LPG did not correspond to levels of disturbance or degree of activity. Corticosterone levels did not correlate with LPG levels, suggesting that LPG may not be a good indicator or disturbances. Corticosterone differences in radio-collared and uncollared individuals were insignificant. Rams had significantly lower corticosterone levels than females ($F = 4.56$, $P = .0334$). Levels dropped during winter and increased dramatically for both rams and ewes during the month of May, suggesting that measures of corticosterone may be more indicative of social stress than climatic or nutritional stress during the winter. McMinn Bench ewes had significantly higher levels of corticosterone than Rattlesnake Butte ewes ($F = 6.31$, $P = .0125$) corresponding with distance to road, activity levels, human disturbance rates and possibly reproductive success.

4. Singer, F.J., and J.E. Norland. 1994. Niche relationships within a guild of ungulate species in Yellowstone National Park, Wyoming, following release from artificial controls. Canadian Journal of Zoology 72:1383-1394.

Abstract: Niche relationships and diet overlaps were compared among elk (*Cervus elaphus*), bison (*Bison bison*), bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) between 1967-1970 and 1986-1988, a period when total ungulate numbers nearly tripled on Yellowstone's northern range. Ungulate species ratios on Yellowstone's northern winter range during the latter period were 100 elk: 10 mule deer: 3 bison: 2 pronghorns: 1 bighorns. Elk numbers were positively correlated to bison, mule deer, and pronghorn numbers (r^2= 0.76, 0.97, and 0.48, respectively, $P < 0.01$). Few other changes in habitat use or habitat overlap occurred, and diets for only 2 of the 10 species pairs, elk-bighorn (Spearman's rank order coefficient (RHO) = 0.55, $P < 0.05$) and mule deer -pronghorn (RHO = 0.64, $P < 0.05$), were significantly associated with each other. Bison consumed more grass and fewer sedges, mule deer more fringed sage (*Artemisia frigida*) and more rabbit-brush (*Chrysothamnus spp.*), and bighorn sheep more grasses and fewer sedges, while pronghorns ate less saltsage (*Atriplex, nuttalli)* but more big sagebrush (*Artemisia tridentata*) during 1986-1988 than during 1967-1970. Bison expanded their range and bison and bighorn sheep used a wider variety of habitats. We found little evidence of change in competitive interactions between ungulate species. A few diet and habitat overlaps increased, the opposite of the prediction from the competitive exclusion principle amongst species, suggesting that intraspecific competition was more important. Several explanations are proposed for the lack of changes in niche relationships during a period of near tripling in density of the ungulate guild.

Mule Deer

1. Lemke, T.O. 2003. Northern Yellowstone Cooperative Spring Mule Deer Survey, 2003. Report dated May 7, 2003, Montana Fish, Wildlife, and Parks, Bozeman, Montana.

Abstract: Aerial surveys during April 28-May 2, 2003, by MFWP detected 2,023 mule deer on the northern range (inside and outside YNP). A ratio of 44 fawns per 100 adults was observed, which compares to an average spring recruitment estimate of 40 fawns per 100 adults (range = 14-57) during 1986-2003. The growth rate of the population is relatively stable with an average count of 2,014 (range = 1,616–2,544) mule deer during 1986-2003.

2. Singer, F.J., and J.E. Norland. 1994. Niche relationships within a guild of ungulate species in Yellowstone National Park, Wyoming, following release from artificial controls. Canadian Journal of Zoology 72:1383-1394.

Abstract: Niche relationships and diet overlaps were compared among elk (*Cervus elaphus*), bison (*Bison bison*), bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*) between 1967-1970 and 1986-1988, a period when total ungulate numbers nearly tripled on Yellowstone's northern range. Ungulate species ratios on Yellowstone's northern winter range during the latter period were 100 elk: 10 mule deer: 3 bison: 2 pronghorns: 1 bighorns. Elk numbers were positively correlated to bison, mule deer, and pronghorn numbers (r^2= 0.76, 0.97, and 0.48, respectively, P < 0.01). Few other changes in habitat use or habitat overlap occurred, and diets for only 2 of the 10 species pairs, elk-bighorn (Spearman's rank order coefficient (RHO) = 0.55, P <0.05) and mule deer -pronghorn (RHO = 0.64, P <0.05), were significantly associated with each other. Bison consumed more grass and fewer sedges, mule deer more fringed sage (*Artemisia frigida*) and more rabbit-brush (*Chrysothamnus spp*.), and bighorn sheep more grasses and fewer sedges, while pronghorns ate less saltsage (*Atriplex, nuttalli)* but more big sagebrush (*Artemisia tridentata*) during 1986-1988 than during 1967-1970. Bison expanded their range and bison and bighorn sheep used a wider variety of habitats. We found little evidence of change in competitive interactions between ungulate species. A few diet and habitat overlaps increased, the opposite of the prediction from the competitive exclusion principle amongst species, suggesting that intraspecific competition was more important. Several explanations are proposed for the lack of changes in niche relationships during a period of near tripling in density of the ungulate guild.

Moose

1. Tyers, D.B. 2003. Winter ecology of moose on the northern Yellowstone winter range. Dissertation, Montana State University, Bozeman.

Abstract: Shiras moose (Alces alces shirasi) invaded the Northern Yellowstone Winter Range (NYWR) in the 1800's. Management of this species has been handicapped by limited population data and reliance on habitat use paradigms from other areas in North America. For example, although moose in most regions forage in recently disturbed forests with abundant deciduous shrubs, I did not find this to be true on the NYWR. I used multiple methods to determine population status, including aerial surveys, horseback surveys, road surveys, and ground counts in willow habitats. Moose were most easily seen when they foraged in willow (*Salix* spp.) stands in November-December and May-June. Attempts to count moose at other times resulted in marked under-sampling. Fires in 1988 removed mature forests at a landscape level resulting in a loss of preferred winter habitat and a sustained population reduction. I also investigated moose winter foraging activities among burned (1988), logged, forested, and forest edge environments. Logged areas and recent burns were rarely used, but forest interiors were important habitat. The edge effect did not benefit moose in winter. NYWR moose coped with winter by seeking concentrations of food to maximize feeding and minimize movement. They optimized foraging by using 2 taxa that grow in patches, willow and subalpine fir (*Abies lasiocarpa*). Moose fed in willow until snow forced them to nearby forested hillsides where they browsed supalpine fir <5 m in height. Subalpine fir, a shade tolerant tree, grows more rapidly under a forest canopy. It can reproduce through layering, creating an expanding patch of small trees around the parent. Patches are largest and most numerous in the oldest lodgepole pine (*Pinus contorta*) forests. Moose used other characteristics of lodgepole forests to reduce energy output by finding routes with less than average snow depth to reach subalpine fir patches. Moose also browsed goosebearry (*Ribes* spp.) and buffaloberry (*Shepherdia canadensis*), nutrient rich shrubs that are scattered and energetically expensive to obtain. Exclosure studies showed willow was suppressed before 1988, and fires and drought increased negative effects. Higher willow utilization rates in 1989 probably reflected a response by moose to a loss of winter habitat due to the 1988 fires, a foraging strategy that may have contributed to observed willow mortality. From 1989 to 1997, some willow showed signs of recovery. Replacement of older forests where moose foraged before 1988 could take several hundred years. Maintaining remaining populations should concentrate on minimizing loss of mature forests and adjacent willow and careful hunting management.

<u>Mountain Goats</u>

1. Lemke, T.O. 2004. Origin, expansion, and status of mountain goats in Yellowstone National Park. Wildlife Society Bulletin 32:532-541.

Abstract: In the 1980s scientists determined that an introduced mountain goat (*Oreamnos americanus*) population caused negative impacts to subalpine plant communities in Olympic National Park (ONP). These findings resulted in a controversial and costly mountain goat reduction program from 1981-1989. Since 1990 introduced nonnative mountain goats from Montana have successfully colonized Yellowstone National Park (YNP) via the Absaroka and Gallatin mountain ranges. Using systematic aerial surveys from 1997-2001, I documented a breeding goat population inside or within 1 km of YNP that increased from 24 to 96 mountain goats observed (mean observed rate of increase r = 0.35). Because of increasing goat populations immediately adjacent to YNP, Montana Fish, Wildlife, and Parks (MFWP) established 2 new hunting districts and 44 mountain goats were harvested near YNP from 1996-2001. The mountain goat is a socially popular "charismatic" species with high watchable-wildlife values. However within YNP they also are viewed with concern as an exotic species, potentially capable of exploiting fragile subalpine landscapes where, by policy, nonnative ungulates are not welcomed. Based on habitat availability and goat densities to the north, YNP potentially may support 200-300 mountain goats. Important ecological differences between YNP and ONP may reduce the likelihood of negative resource impacts of mountain goats in YNP. However, the speed at which mountain goat numbers and distribution are increasing warrants further habitat and population monitoring to better understand and predict the ecological effects of this new species. Future mountain goat management decisions in YNP should be based on documented impacts of goats on their habitat and other species in YNP and not what has occurred in ONP. Mountain goat management efforts in YNP should acknowledge MFWP's management objective of maintaining viable goat populations in suitable habitats and recognize that goats from Montana will continue to be a source population for future dispersal into and colonization of YNP.

2. Schullery, P., and L. Whittlesey. 2001. Mountain goats in the greater Yellowstone ecosystem: a prehistoric and historical context. Western North American Naturalist 61:289-307.

Abstract: Because the relatively recent colonization of portions of Yellowstone National Park by introduced mountain goats (*Oreamnos americanus*) from public game lands in Montana raises important policy and management questions for the park, it is necessary to understand the prehistoric and early historical record of mountain goats in the Greater Yellowstone Ecosystem. We reviewed previous paleontological, archeological, and historical studies of goat presence and examined a large body of historical material for evidence of goats. Native mountain goat range most closely approached the Greater Yellowstone Ecosystem to the west, but no modern authority claims goats were resident in the ecosystem in recent centuries. Historical accounts of goat presence in the region prior to 1882 (and thus prior to any known introduction of goats by Euro-Americans) are limited to one possible sighting by unreliable observers and a few casual mentions of goat presence by people of limited or unknown familiarity with the ecosystem. Other early observers in the region specifically stated that goats were not native. Between 1882 and 1926 other observers and residents agreed that mountain goats were not native to the park, or to the larger area around it. It is impossible to prove absolutely that there were no goats in the ecosystem prior to modern introductions, but historical evidence demonstrates that it present, such goats must have been exceedingly rare and uncharacteristically unsightable. National Park Service policy relating to exotic species developed gradually after the creation of Yellowstone National Park in 1872, moving from a general receptivity to introduction of at least some favored nonnative species to a general prohibition on all such introductions. Current policy, while disapproving of all nonnative species, seems to reserve special efforts at removal of nonnatives for those species that pose the greatest threat to native species and ecosystems. Current policy is not helpful in defining the minimum amount of evidence needed to prove a

species was present or absent, or whether or not an introduced nonnative species is causing sufficient harm to justify its removal.

Bison

1. United States Department of the Interior and United States Department of Agriculture. 2000. Bison Management for the state of Montana and Yellowstone National Park: Final Environmental Impact Statement. Washington, D. C. three volumes, 2147 pp.

Bison are an essential component of Yellowstone National Park because they contribute to the biological, ecological, cultural, and aesthetic purposes of the park. However, Yellowstone National Park is not a self-contained ecosystem for bison, and periodic migrations into Montana are natural events. Some bison have brucellosis and biologically can transmit it to cattle outside the park boundaries in Montana. Left unchecked, the migration of brucellosis-infected bison from Yellowstone National Park into Montana could have not only direct effects on local livestock operators, but also on the cattle industry statewide. The cooperation of several agencies is required to fully manage the herd and the risk of transmission of brucellosis from bison to Montana domestic cattle.

The purpose of the proposed interagency action is to maintain a wild, free-ranging population of bison and address the risk of brucellosis transmission to protect the economic interest and viability of the livestock industry in the state of Montana. The final environmental impact statement examines eight alternative means of minimizing the risk of transmitting the disease brucellosis from bison to domestic cattle on public and private lands adjacent to Yellowstone National Park.

Implementing the modified preferred alternative would result in no moderate or major adverse impacts. The long-term bison population size would fluctuate between 2300 and 4000 and sero-prevalence would slowly be reduced Bison would be allowed into management zones outside the park under certain conditions. In the later stages of the management plan, bison would not be tested or marked before they exit the park, leading to major benefits to those groups and individuals who regard free-ranging, wild bison as culturally important, including positive impacts on those seeking to view bison. A special management area is identified roughly as the area from Park headquarters at Mammoth to the head of Yankee Jim Canyon. The management zone outside the National Park boundary is limited to lands west of Old Yellowstone Trail. Use of this area by bison will not occur until cattle no longer occupy the management zone during winter and an area specific bison management strategy is developed between the Gallatin National Forest and the private land owners in the vicinity. Positive impacts from the acquisition and use of about 6,000 acres outside the north boundary of park for winter range would benefit ungulates. A reduction in the use of the Stephens Creek capture facility during later stages of implementation would also benefit wildlife in the area. Slight benefits to livestock operators from measures to mitigate the perception of risk, including additional testing of cattle, possible vaccination of adult cattle, and many other risk management measures at no cost to livestock operators were expected. Non-market benefits associated with the use of acquired winter range north of the park by bison were also predicted.

2. Demarais, S. and P. Krausman. 2000. Ecology and management of large mammals in North America. Prentice Hall, Inc. Upper Saddle River, New Jersey. 778p.

The concepts of ecosystem management, biodiversity and conservation biology are important to effective wildlife management in a modern world full of complexity. However, there is still much to be learned from studies of individual animals. This book systematically describes the details important to management of large carnivores and ungulates. There are also chapters to discuss individual species management issues. The bison management chapter has a distinct focus on Yellowstone bison partly because of the coauthors experience and partly because of the wild free ranging nature of our population. There are very good short descriptions of bison diet selection and fencing options for managing bison.

3. Barmore, W. J., Jr. 2003. Ecology of ungulates and their winter range in northern Yellowstone National Park, Research and Synthesis 1962-1970. National Park Service, Mammoth, Wyoming. 524pp.

Inadequate scientific understanding about the ecology of ungulates and their habitats in the park and how they have been influenced by modern humans has resulted in controversy among scientists and the public about how park ungulate populations and their habitats should be managed. This publication is a compilation of work done by the author during his nine years of employment as a biologist at Yellowstone. He has drawn from the writings of his predecessors to draw comparisons over time, especially in evaluating population responses to changing management strategies. The authors description of habitat in the NBLA and single photo provide limited info about conditions during his tenure at Yellowstone. The author describes bison movement patterns during a time when bison abundance was very low and probably not forced by environmental conditions to expand their range toward the Gardiner basin. This work reinforces the influence that snow conditions have on bison distribution and readers can likely surmise the potential for bison use of the NBLA now that the population has increased.

4. Singer, F. J. and J. E. Norland. 1994. Niche relationships within a guild of ungulate species in Yellowstone National Park, Wyoming, following release from artificial controls. Canadian Journal of Zoology 72:1383-1394.

This paper compares niche overlaps between five ungulate species that use the northern range of Yellowstone National Park. The study used the work conducted by Barmore in the late 1960's as an early study period and replicated field studies to describe habitat use patterns and diet selection by these ungulates. While bison increased in abundance by about 700% between the two study periods, the area of use by bison in the later period was only about 300% greater than then used in the 1960's. These authors note greater intraspecific competition for both habitat and food by bison. This study showed that grasses constitute about 53% of the diet for bison while sedges and rushes combined to make up about 44% of the diet. These data represent a significant increase in use of grasses and reduction in use of sedges ($p<0.05$). Bison increased their habitat overlap with all the other ungulates. Bison and elk exhibit a high degree of habitat overlap, especially during winter, but a low to moderate overlap in diet selection. This was not unexpected relative to other studies.

5. Meagher, M. 1989. Range expansion by bison of Yellowstone National Park. J. Mammology 70:670-675.

This paper presents evidence that due to learned behavior about the larger landscape and the unusually heavy snowfall of the winter 1975/1976 the bison of the northern range in Yellowstone National Park began to enlarge their distribution. While previous reports have cited that bison have inhabitated deep snow habitats in Yellowstone National Park and a population has persisted, this paper suggested that bison may increase their survival probability by moving to lower elevation winter range where snow pack is less deep.