MANAGING THE ABUNDANCE OF YELLOWSTONE BISON, WINTER 2013

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EXECUTIVE SUMMARY

Pursuant to the Interagency Bison Management Plan, Yellowstone bison are managed towards an end-of-the-winter guideline of 3,000 animals. Managers at Yellowstone National Park also want to progress towards equal abundance in the central and northern breeding herds, an equal proportion of males to females, and an age structure of about 70% adults and 30% juveniles. Managers want to maintain the processes of migration and dispersal by bison, while avoiding large-scale annual reductions in bison numbers due to disease, property, and safety concerns near key wintering areas in Montana. We developed a spatially explicit population model to predict the post-winter abundance of bison with and without hunter harvests and other management removals, and to explore strategies for attaining these desired conditions.

During summer 2012, the Yellowstone bison population was estimated at approximately 4,200 bison, including about 2,600 in the northern herd and 1,600 in the central herd. Predictions of the number of bison surviving winter 2013 without any harvest or other management removals averaged about 3,990. The chance of total abundance being more than 3,500 bison at the end of winter was 86%, with a 98% chance of there being more than 3,000 bison. Model simulations predicted approximately 300 bison (240 from the northern herd and 60 from the central herd) would migrate north of Mammoth and into the northern management area (Gardiner basin) during average winter conditions. Modeling predicted approximately 440 bison from the central herd would migrate west of Cougar Meadows and into the western management area (Hebgen basin) during average winter conditions. With above-average winter conditions, peak migration predictions were up to 1,400 bison in the northern area and 1,500 bison in the western area.

To progress towards the desired conditions described above, we recommend the harvest of 25 adult male bison from the central herd in the western management area (Hebgen basin) and the harvest or culling of 425 bison (400 adult females and 25 adult males) from the northern management area (Gardiner basin) during winter 2013. We do not recommend harvesting female bison from the western area because the abundance of the central herd is near the desired condition (1,500 bison) and the sex ratio is skewed towards males. Removals in the northern area should be focused on the northern herd to reduce abundance and growth potential, though it is inevitable that some bison from the central herd will be inadvertently removed. Removals from the northern area could be through harvest by public and treaty hunters and, after the general hunt ends in mid-February, through selective culling at the Stephens Creek capture facility for shipment to quarantine or research facilities, terminal pastures, or slaughter facilities. Additional bison may be removed if they resist efforts to return them from Montana to Yellowstone National Park during spring or summer. If the proposed removals are not realized this winter, then there is a 50% chance of more than 4,875 bison in population entering winter 2014.

BACKGROUND

The conservation of Yellowstone bison from near extirpation in the late 19th century to approximately 4,200 animals in summer 2012 has led to conflict regarding perceived overabundance, the potential for transmission of brucellosis from bison to cattle, and safety and property concerns when bison move into Montana. Prior to the mid-1970s, bison spent winter in Yellowstone National Park because decades of culling reduced numbers to less than 500 bison and there was a lack of tolerance for bison on winter ranges outside the park (Plumb et al. 2009). Managers ceased culling bison inside the park in 1966 and numbers were allowed to fluctuate in response to weather, predators, and resource limitations (Meagher 1973). Seasonal movements were extended as the population increased in size, with expansion of the winter range detected by the mid-1970s (Meagher 1989). Thereafter, numbers of bison migrating increased with abundance, snow pack, and experience (Geremia et al. 2011, White et al. 2011).

Approximately 60% of adult bison test positive for exposure to bovine brucellosis, a bacterial disease caused by *Brucella abortus* that may induce abortions or the birth of non-viable calves in bison, cattle, and elk (Rhyan et al. 2009). When cattle are exposed to brucellosis, there can be economic loss from slaughtering cattle, increased testing requirements, and reduced marketability. Thus, the United States government and the state of Montana agreed to an Interagency Bison Management Plan in 2000 for cooperatively managing the risk of brucellosis transmission from Yellowstone bison to cattle and conserving bison as a natural component of the ecosystem, including allowing some bison to migrate out of the park. The court-mediated settlement directs federal and state agencies to conduct a variety of management actions to minimize the risk of brucellosis transmission from bison to cattle (USDI and USDA, 2000a,b).

White et al. (2011) provided an assessment of the Interagency Bison Management Plan that indicated migrations of bison into Montana and culls to reduce the risk of brucellosis transmission exceeded expectations. Approximately 3,200 bison were removed during 2001 through 2011, with more than 20% of the bison population removed during 2006 and 2008. These removals contributed to a skewed sex ratio, gaps in the age structure, and reduced productivity, which could threaten the integrity of the population if continued. As a result, managers resolved to reduce large-scale culls of bison and their potential long-term, unintended demographic and genetic effects by implementing smaller selective culls to dampen population growth. Also, a Citizens Working Group recommended that hunting be used to regulate the abundance of bison, while minimizing capture and shipment of bison to slaughter. Harvest in Montana is the primary management tool used to limit bison abundance, but hunters remove less than 50 bison in many winters because most bison do not migrate outside Yellowstone National Park (where hunting is not authorized by Congress) until March through May when little hunting occurs due to females being late in pregnancy or calving (Geremia et al. 2011).

Biologists from Yellowstone National Park developed a spatially explicit population model for Yellowstone bison using information collected prior to (1990-2000) and after (2001-2012) the inception of the Interagency Bison Management Plan. This model supports adaptive management by making predictions about the post-winter abundance of bison with and without harvests and other management removals, and exploring strategies for managing bison numbers to maintain or progress towards the following objectives:

- Bison abundance averages 3,000 to 3,500 per decade;
- Equal sex ratio and an age structure of about 70% adults and 30% juveniles;
- Equal abundance in the central and northern breeding herds;
- Maintain the processes of migration to essential winter ranges; and
- Avoid large-scale removals (e.g., >1,000 bison).

ANNUAL MONITORING AND MANAGEMENT

During June and July, biologists from Yellowstone National Park conduct population counts and age and sex classification surveys of bison. This information is incorporated with historic climate data and long-term weather forecasts into a population model to estimate (1) historic composition and growth rates by herd (Tables 1 and 2), (2) the timing and magnitude of bison migrating beyond the park boundary during the upcoming winter, and (3) the number of bison surviving the upcoming winter under various management approaches.

Table 1. Population growth rates of Yellowstone bison in the central and northern breeding herds during 2003 through 2012, along with annual survival, birth, and emigration (to the northern herd) rates.

	Central Herd Growth Rate		Northern Herd Growth Rate	
	Average	95% range	Average	95% range
2003-04	1.15	1.08-1.22	1.19	1.11-1.27
2004-05	1.01	0.94-1.08	1.19	1.11-1.26
2005-06	0.65	0.58-0.72	0.97	0.91-1.04
2006-07	1.15	1.08-1.23	1.35	1.28-1.42
2007-08	0.28	0.21-0.36	0.88	0.82-0.93
2008-09	1.09	1.01-1.17	1.05	0.99-1.10
2009-10	1.11	1.04-1.19	1.13	1.06-1.21
2010-11	0.80	0.72-0.88	1.18	1.11-1.26
2011-12	1.14	1.06-1.22	1.12	1.04-1.19
	Population Survival, Birth, and Emigration			
adult survival	0.95	0.82-1.00	0.98	0.85-1.00
calf survival	0.77	0.65-0.93	0.78	0.63-0.94
birth	0.45	0.36-0.58	0.60	0.48-0.73
emigration	0.03	0.00-0.09	NA	NA

Table 2. Average and 95% range for age and sex structure of bison in the central and northern herd breeding herds during 2003 through 2012.

Central Herd

	Abundance	Males:100 Females	Juveniles:100 Females
2003	2,924 (2,768-3,084)	60 (53-68)	28 (26-30)
2004	3,396 (3,225-3,572)	110 (99-124)	25 (23-27)
2005	3,437 (3,281-3,595)	89 (80-99)	28 (26-30)
2006	2,422 (2,297-2,556)	112 (100-126)	26 (23-27)
2007	2,825 (2,680-2,974)	82 (73-92)	30 (28-32)
2008	1,379 (1,305-1,460)	101 (89-115)	20 (18-22)
2009	1,509 (1,428-1,592)	116 (103-132)	22 (20-24)
2010	1,690 (1,600-1,785)	126 (111-143)	24 (21-35)
2011	1,380 (1,302-1,459)	147 (129-166)	20 (19-22)
2012	1,584 (1,503-1,674)	129 (114-145)	24 (22-26)

Northern Herd

	Abundance	Males:100 Females	Juveniles:100 Females
2003	895 (847-945)	96 (85-110)	24 (23-26)
2004	1,086 (1,013-1,148)	85 (77-96)	26 (24-28)
2005	1,308 (1,244-1,371)	86 (77-96)	25 (24-27)
2006	1,275 (1,211-1,342)	75 (66-84)	31 (29-33)
2007	1,807 (1,712-1,908)	52 (46-59)	32 (29-34)
2008	1,586 (1,507-1,669)	87	32
2009	1,674 (1,590-1,765)	105 (93-118)	29 (27-31)
2010	1,910 (1,813-2,016)	63 (56-72)	33 (31-35)
2011	2,296 (2,177-2,425)	60 (54-69)	30 (28-33)
2012	2,583 (2,458-2,720)	60 (53-67)	39 (36-41)

A variety of management tools can be used to cull bison, including (1) public and treaty hunting in Montana, (2) selective culling (shipment to slaughter or terminal pastures) at boundary capture facilities to reduce the proportion of bison actively infected with brucellosis, (3) selective culling (shooting, shipment to slaughter or terminal pastures) in Montana to prevent brucellosis transmission to nearby livestock or due to human safety or property damage concerns, (4) transfer of bison to American Indian tribes or other organizations for quarantine and eventual release, and (5) transfer of bison to research facilities.

During August, biologists from Yellowstone National Park provide harvest recommendations to staff from Montana Fish, Wildlife, and Parks and American Indian tribes with recognized treaty hunting rights on unoccupied federal lands near Yellowstone National Park. As winter unfolds, biologists monitor and document actual hunter harvest, winter-kill (starvation), predation, and management culls. They also periodically update predictions for bison migration and recommendations for culling based on aerial counts, snow pack estimates, and revised weather forecasts.

POPULATION MODEL

Adaptive management provides a framework for decision-making in the face of uncertainties, and a formal process for reducing these uncertainties to improve management over time (Walters and Holling 1990). Uncertainty arises from our lack of understanding of ecological processes, measurement error, and environmental variability, as well as our lack of complete control over the effects of management actions. We attempted to account for each of these sources of uncertainty such that assessments of management alternatives were not overly optimistic (Figure 1).

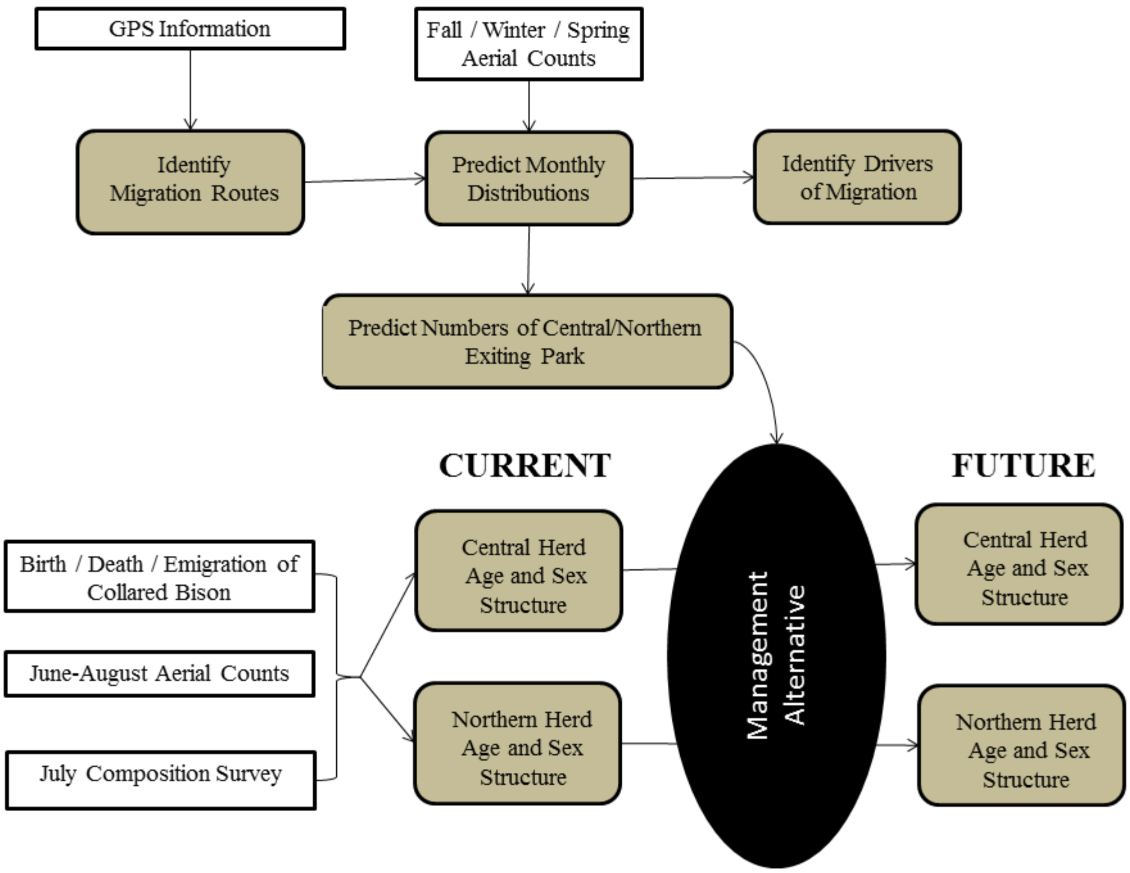

Figure 1. A conceptual diagram of the spatially explicit model used to support adaptive management of Yellowstone bison. White boxes represent information provided as inputs; gray boxes represent steps in the modeling process; and the black oval represents management treatments.

Data Collection: Sixty-six bison greater than one year of age were captured in autumn during 2004 through 2012 by immobilization with carfentanil and xylazine or at handling facilities near the boundary of Yellowstone National Park. Captured bison were fit with a store-on-board global positioning system (GPS) radio collar (Telonics, Mesa, Arizona) that collected between 2 months and 5 years of information. Radio collars were fitted on 2 to 15 adult females from the central herd during 2003 through 2012 and 6 to 23 adult females from the northern herd during 2006 through 2012. Radio collars were programmed to collect one location every 48 minutes during 2004 and 2005, and one location every 2 hours during 2006 through 2012. A total of 512,621 locations were obtained. Radio-collared bison were monitored for distribution, movements, reproduction, and survival (Table 1).

Biologists completed 136 airplane counts during 1990 through 2012 and recorded the location and size of observed bison groups ($\geq$1 animal) during systematic surveys of wintering areas (Hess 2002). Counts occurred monthly during 1990 through 1997 and 2007 through 2012, but approximately quarterly during 1998 through 2006. In addition, three replicate airplane counts were completed of breeding areas in June through August during 2003 through 2011 (Table 3).

Newborn calves were differentiated during June surveys, and ground-based age and sex classifications were completed concurrent with July surveys (Table 4). Bison were differentiated as calves, yearlings, and adults during classifications. Ages and sexes of bison removed by harvest and gather-and-slaughter were recorded during 2002 through 2012 (Table 5).

Table 3. Annual counts of Yellowstone bison in the central and northern breeding herds during June through August from 2003 through 2012.

		Central Herd			Northern Herd		
		Total	Adults	Calves	Total	Adults	Calves
2003	July 10, 2003	2,905	2,471	434	873	748	125
	August 8, 2003	2,923			888		
	August 28, 2003	2,772			994		
2004	July 21, 2004	2,811	2,310	501	1,337	1,337	
	July 28, 2004	3,027			968		
	August 4, 2004	3,339			876		
2005	July 19, 2005	3,553			1,266		
	July 26, 2005	3,394			1,353		
	August 1, 2005	3,531			1,484		
2006	July 19, 2006	2,430	2,146	284	1,283		
	July 26, 2006	2,512			1,377		
	August 2, 2006	2,496			1,279		
2007	June 14, 2007	2,734	2,385	349	1,820	1,499	321
	July 30, 2007	2,390			1,569		
	August 6, 2007	2,624			2,070		
2008	June 14, 2008	1,115	1,052	103	1,788	1,463	325
	July 8, 2008	1,540			1,341		
	July 15, 2008	1,469			1,500		
2009	June 12, 2009	1,462	1,293	169	1,839	1,520	319
	July 9, 2009	1,544			1,433		
	July 16, 2009	1,535			1,648		
2010	June 14, 2010	1,653	1,426	227	2,245	1,890	355
	July 8, 2010	1,735			1,980		
	July 22, 2010	1,713			1,850		
2011	June 21, 2011	976	880	96	2,675	2,188	487
	July 18, 2011	1,406			2,314		
	July 25, 2011	1,335			2,150		
2012	June 21, 2012	1,389	1,188	201	2,496	2,103	393
	July 8, 2012	1,640			2,531		
	July 22, 2012	1,561			2,669		

Table 4. Annual ground and aerial composition surveys of Yellowstone bison in the central and northern breeding herds during July from 2003 through 2012.

Herd	Ground Surveys	Males >1	Males 1	Females >1	Females 1	Calves	Total	Air Surveys	Mixed	Bachelor	Total
Central	July 7-8, 2003	438	150	1,426	241	498	2,753	July 10, 2003	2,521	380	2901
Northern	July 15, 2003	159	23	176	12	46	416		795	77	872
	July 18, 2003	133	11	227	15	110	496				
Central	July 14, 2004	638	179	1,082	126	497	2,522	July 21, 2004	2,594	284	2,878
	July 15, 2004	523	125	932	131	397	2,108				
Northern	July 17, 2004	247	35	331	33	164	810		1,145	125	1,270
	July 18, 2004	232	26	458	49	145	911				
Central	July 14, 2005	500	178	1,098	162	430	2,368				
	July 15, 2005	674	175	1,060	148	443	2,500				
Northern	July 6, 2005	276	63	441	51	153	984				
	July 7, 2005	205	49	324	37	97	712				
Central	July 12, 2006	368	141	654	101	258	1,522	July 19, 2006	2,078	518	2,596
	July 13, 2006	386	152	757	111	301	1,707				
Northern	July 11, 2006	102	27	202	40	103	1474				
Central	July 10, 2007	375	100	709	109	342	1,635	July 30, 2007	2,281	28	2,309
	July 11, 2007	555	119	805	106	305	1,890				
Northern	July 12, 2007	300	139	637	101	339	1,516		1,534	35	1,569
	July 17, 2007	173	28	366	28	169	764				
Central	July 9, 2008	116	36	387	50	110	699	July 8, 2008	1,101	444	1,545
Northern	July 11, 2008	198	87	433	61	232	1,011		1,158	178	1,336
Central	July 6-7, 2009	145	63	427	73	158	866	July 9, 2009	1,063	480	1,543
	July 8-11, 200	161	62	498	47	186	954				
Northern	July 13, 2009	244	84	414	53	237	1,032	July 16, 2009	1,239	191	1,430
	July 14, 2009	224	83	391	53	179	930				

Central	July 20, 2010	340	72	517	57	219	1,205	July 22, 2010	1,370	342	1,712
	July 21, 2010	369	82	537	81	228	1,297				
Northern	July 6, 2010	228	126	934	140	391	1,592	July 8, 2010	1,755	20	1,959
	July 7, 2010	298	150	679	121	344	1,592				
Central	July 7, 2011	118	58	323	37	105	641	July 18, 2011	944	413	1,407
	July 19, 2011	163	53	309	40	106	671				
Northern	July 13, 2011	303	131	915	99	361	1,809	July 12, 2011	2,103	185	2,288
Central	July 9, 2012	282	68	493	41	173	1,057	July 8, 2012	1,242	398	1,640
	July 24,2012	420	80	477	55	216	1,248	July 22,2012	1,349	212	1,561
Northern	July 9-11, 2012	375	187	876	165	466	2,069	July 8, 2012	2,451	80	2,531
	July 23-29, 2012	405	114	698	84	288	1,589	July 22, 2012	2,619	50	2,669

Table 5. Annual removal of Yellowstone bison through harvest and other management culls from the northern and western management areas in Yellowstone National Park and nearby areas of Montana during winters from 2004 through 2012.

	Northern Management Area						**Western Management Area**					
	Males		Females				Males		Females			
	Adults	Yearlings	Adults	Yearlings	Calves	Total	Adults	Yearlings	Adults	Yearlings	Calves	Total
2003-04	39	19	157	22	23	267	15	0	0	0	0	15
2004-05	0	0	1	0	0	1	20	0	53	0	23	96
2005-06	87	44	342	51	245	980	8	0	0	0	0	64
2006-07	41	0	6	0	0	47	12	0	0	0	0	16
2007-08	372	123	513	69	331	1,459	21	4	50 0		1	267
2008-09	1	0	0	0	0	1	4	0	0	0	0	4
2009-10	4	0	0	0	0	4	1	0	0	0	0	1
2010-11	29	0	58	0	1	156	14	0	27	0	8	88
2011-12	8	0	5	0	2	15	5	0	7	0	0	14

Model Development: Wintering areas and migration routes in Yellowstone National Park and nearby areas of Montana were identified using information collected from adult female bison fit with radio collars during 2003 through 2012 (Horne et al. 2007, Sawyer et al. 2009). Bison from the central breeding herd were located on six distinct wintering areas including the Hayden and Pelican valleys, Firehole River drainage, Gibbon and Madison River drainages, Hebgen basin, Blacktail Deer Plateau, and Gardiner basin (Figure 2). Bison from the northern breeding herd were located on four wintering areas including the Lamar Valley, lower Yellowstone River drainage, Blacktail Deer Plateau, and Gardiner basin (Figure 2). Generally, a single migration route connected each wintering area, and these routes occurred along rivers and roadways. Movements along migration routes were related to time since snow pack establishment, herd size, and the extent of snow pack (Geremia et al. 2011).

Ten demographic stages were used to represent the bison population, including calves, juvenile females (yearlings not capable of reproduction), adult females (2+ years of age), juvenile males, and adult males for both the central and northern breeding herds. Survival, birth, and herd emigration rates were used to determine the numbers of bison in each demographic stage among years (Table 1). Different survival rates were used for calves and adults. All reproductively mature females were assumed to have similar birth rates. Herd emigration was portrayed as occurring exclusively from the central to the northern herd. This approach allowed us to track herd abundance and age and sex structures over time, and determine the relative effectiveness of alternate management treatments for meeting desired demographic conditions.

Bison Migrations and Demography: Bison migrations followed a movement cascade, with animals moving progressively from higher to lower elevation wintering areas during autumn, winter, and spring. Most bison spent weeks or months in each wintering area before moving to another area. However, a few bison from the central herd moved directly and rapidly from their summer ranges in the Hayden and Pelican Valleys to lower elevation wintering areas in the Madison headwaters and Hebgen basin, suggesting some contribution of experience and learning on movement patterns.

Large fluctuations in abundance, from several thousands of bison during the breeding period to hundreds of bison at the conclusion of the winter migration, were observed each year in the Hayden and Pelican valleys. Similar numbers of bison remained in this summering area across years despite large differences in central herd size, which suggests a relatively constant, food-limited carrying capacity by the end-of-winter. Bison migrating from the Hayden and Pelican valleys primarily moved to the Firehole River drainage, and these movements were largely affected by time since snow pack establishment and annual snow pack severity. The Firehole River drainage served as a stop-over site for most migrating bison from the central herd, with abundance in this drainage peaking between 500 and 1,100 animals during January and February. Bison migrating from the Hayden and Pelican valleys also moved directly to the Gibbon and Madison River drainages, which also served as a stop-over site. Bison abundance in this area peaked during January and April, with most animals eventually moving either north to the Blacktail Deer Plateau in northern Yellowstone or west to the Hebgen basin in Montana. Movements of bison from the central herd to northern Yellowstone increased as their abundance increased to record levels during the early 2000s. Management removals since that time have reduced bison numbers in the central herd, but movements to northern Yellowstone continue during winter—perhaps indicating the importance of learning on bison migration patterns. Movements by bison from the central herd west into the Hebgen basin increase rapidly late in the migration period, with movement probabilities peaking during May.

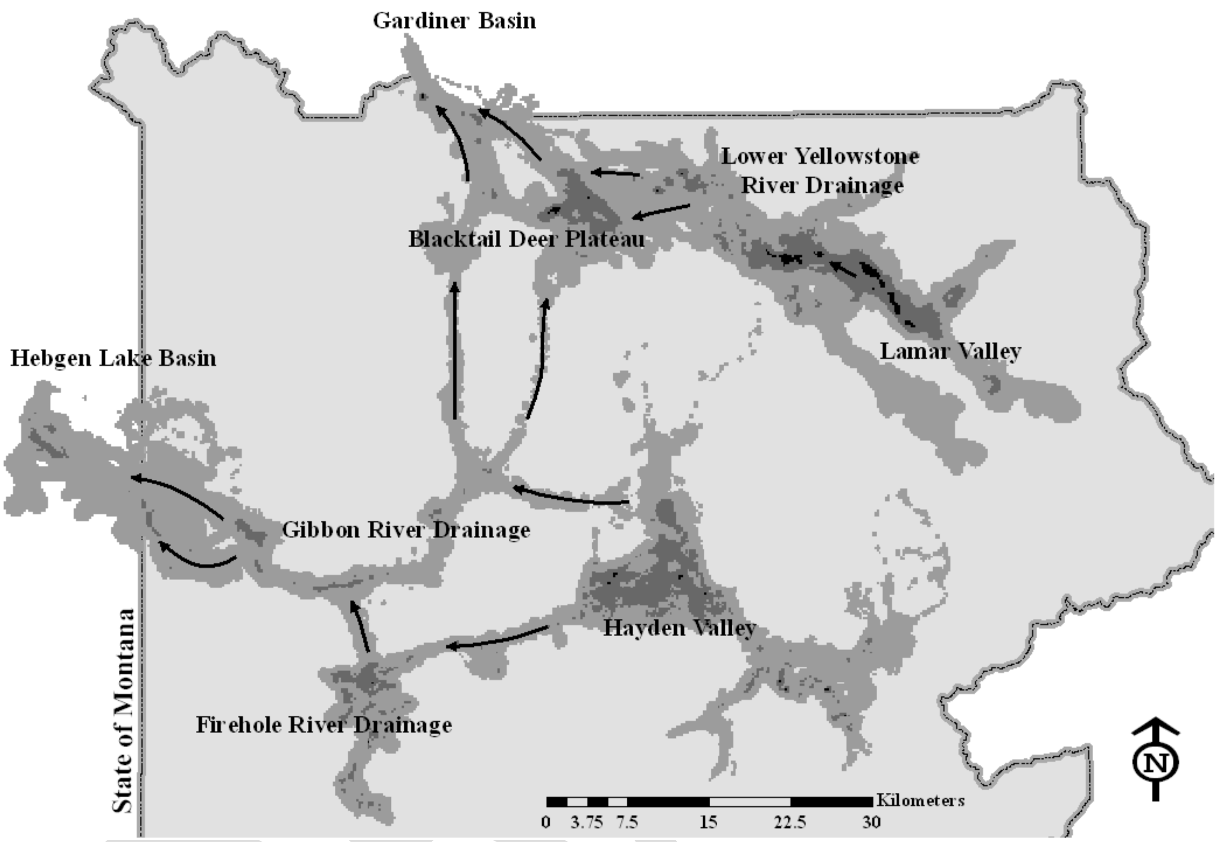

Figure 2. Wintering areas and migration routes of Yellowstone bison in Yellowstone National Park and nearby areas of Montana, with darker colors representing core use areas.

Movements of bison among wintering areas in northern Yellowstone were more variable than in central Yellowstone, likely due to greater annual fluctuations in habitat suitability. In contrast to the central portions of the park, northern areas had less severe snow pack which enabled bison better access to food during most winters. The timing and numbers of bison migrating between the Lamar Valley, lower Yellowstone River drainage, Blacktail Deer Plateau, and Gardiner basin wintering areas was affected by the interaction of snow pack establishment and herd size. Movements were exacerbated when herd size and snow pack increased. Thus, the potential exists for more than 1,000 bison to migrate beyond the northern boundary early in the year during severe winters. However, even with large herd sizes, few bison may exit the northern boundary when snow pack establishment is modest (Figure 3).

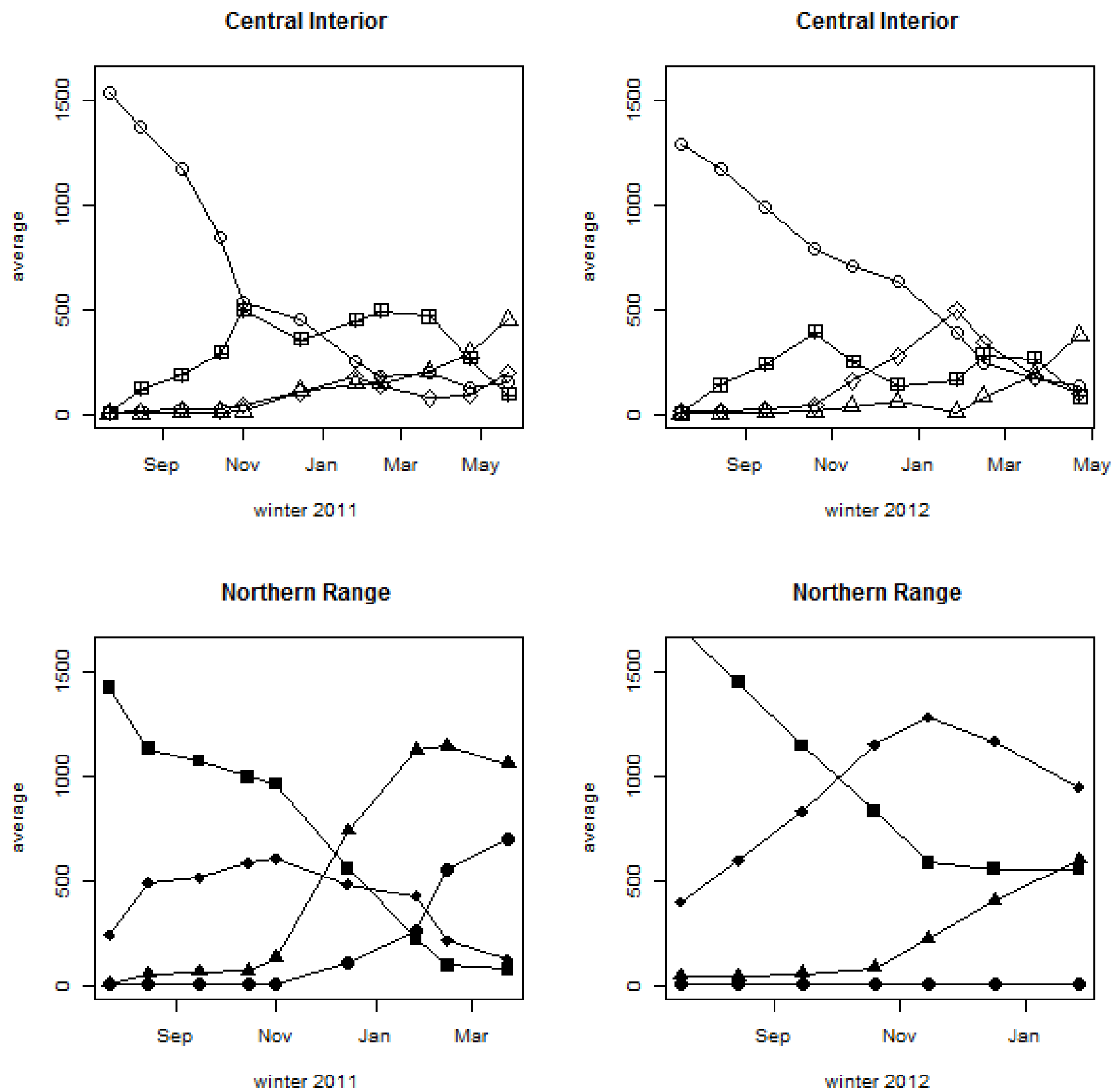

Figure 3. Estimated average numbers of bison on central and northern wintering areas in Yellowstone National Park and nearby areas of Montana during winters 2011 and 2012. Symbols are Hayden Valley (open circle), Firehole River drainage (open square), Madison River drainage (open diamond), Hebgen basin (open triangle), Lamar Valley (filled square), lower Yellowstone River drainage (filled diamond), Blacktail Deer Plateau (filled triangle), and Gardiner basin (filled circle). Distributions were illustrated through peak migration which occurred during June 2011 and May 2012 on central areas, and April 2011 and February 2012 on northern areas.

The Yellowstone bison population fluctuated between 3,000 and 5,000 bison during 2003 through 2012. The central herd decreased from approximately 3,500 bison in 2005 to less than 1,500 bison in 2012 due to large-scale, non-selective culls (primarily shipment to slaughter) during winters 2006 and 2008, as well as emigration of female and juvenile groups to the northern herd. The northern herd increased from approximately 1,250 bison in 2008 to 2,600 bison in 2012, the highest number recorded in this herd. While the sex ratio of the Yellowstone bison population is approximately equal, females outnumber males in the northern herd and males outnumber females in the central herd (Figure 4).

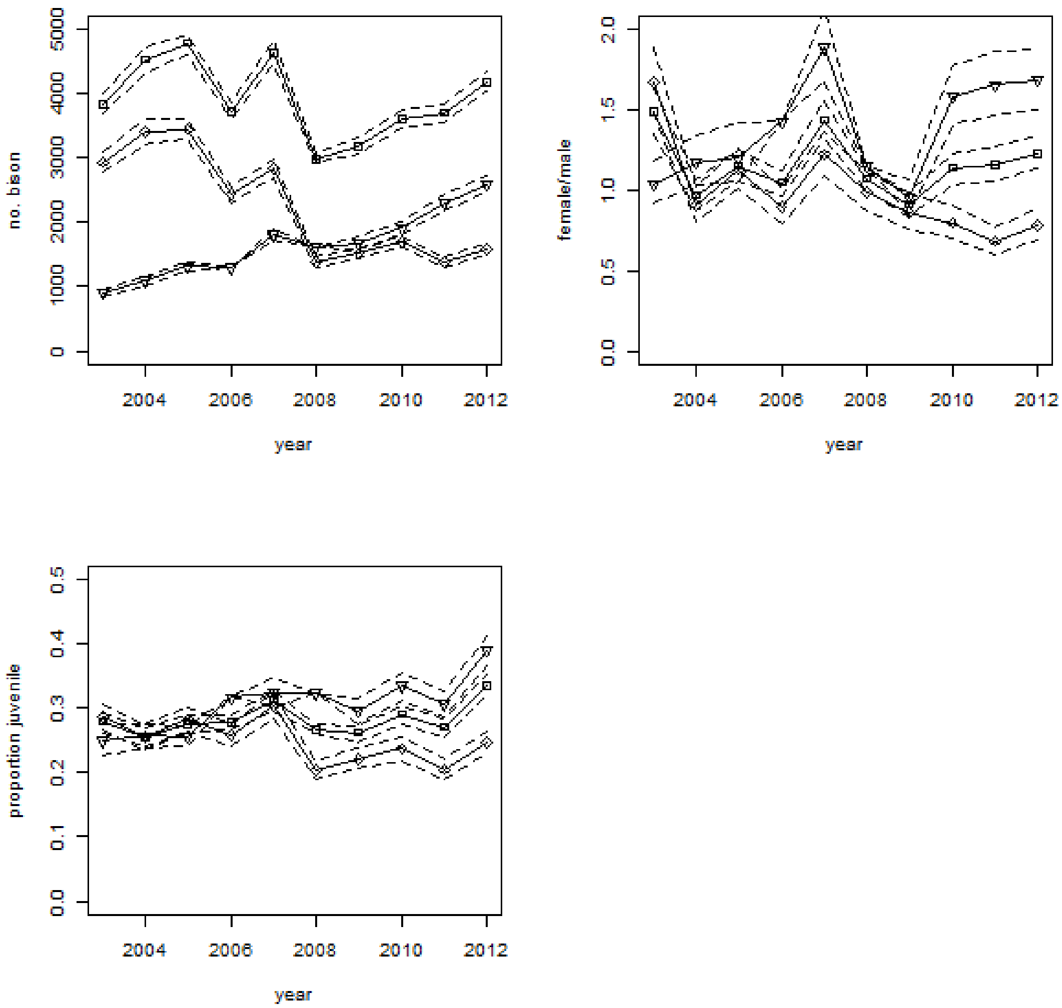

Figure 4. Median and 95% credible intervals for the abundance, sex ratio, and proportion in the juvenile stage of all Yellowstone bison (square), bison in the central breeding herd (diamond), and bison in the northern breeding herd (triangle) during 2003 through 2012.

ASSESSMENT OF LONG TERM ALTERNATIVES

We used the population model to forecast migrations and population growth during 2013 through 2017 and compared the appropriateness of different management scenarios, including:

1) Fifty either-sex licenses issued for the entire winter and split equally between hunting districts and seasons (e.g., 12 during early [November-January] and 13 during late [February-March] seasons for the northern hunting district; 12 during early and 13 during late seasons for the western hunting district).

2) Fifty either-sex licenses issued for the western hunting district for the entire winter (25 early/25 late) and 300 either-sex licenses issued for the northern hunting district during the entire winter (25 early/325 late).
3) Gather-and-consignment of up to 350 either-sex bison within the northern management area during February 16 through March 14 without any hunting in the northern and western districts.
4) Gather-and-consignment of up to 1,000 either-sex bison within the northern management areas during February 16 through March 14 without any hunting in northern and western districts.
5) Hunting as outlined in scenario 2 with gather-and-consignment of either-sex bison within the northern management area during February 16 through March 14 such that the total number of bison removed for the winter in the northern management area does not exceed 350 animals.

Supplementing increased state and treaty hunting permits with modest late winter culls (scenario number 5) provided the highest certainty of progressing towards desired conditions over the next five years (Table 6). We assumed broad uncertainty in hunter success with average probability of harvest of an individual located in hunt areas as 0.16 (SD = 0.14). This vague distribution allowed for the observed variation in annual hunter success that has occurred since 2006. With the issuance of 350 hunting permits each winter combined with extended hunting seasons, we forecast average hunter harvests of more than 100 animals during each of the next five winters. In turn, numbers of bison removed by other types of management culls were reduced by one-half compared to scenarios without hunting.

If scenario 5 can be consistently implemented, the probability of large migrations by bison outside Yellowstone National Park during winter decreases by 15 to 20% within five years. The probability of more than 500 and 1,000 bison migrating beyond the northern park boundary next winter is 68% and 48%, respectively. After five years of implementing scenario 5, we forecast a 52% and 29% chance of more than 500 or 1,000 bison, respectively, migrating beyond the northern park boundary (Table 6). Therefore, consistent hunting pressure supplemented with other types of management culls increased the chances that future migrations to the Gardiner basin would not surpass 500 bison per year. Managers could selectively remove desired age and sex classes of bison to (1) offset the potential demographic effects of selective hunting (males are selected more than females when either-sex permits are issued), or (2) reduce brucellosis infection by removing individuals likely to shed the highest doses of bacteria at their upcoming parturition event (Treanor et al. 2011, White et al. 2011).

Table 6. Predicted chance of meeting desired abundance conditions under management scenarios that incorporated: 1) culling of up to 350 migrants; 2) culling of up to 1,000 migrants; 3) issuance of 50 hunting licenses; 4) issuance of 350 hunting licenses; and 5) hunting supplemented with other management culls.

	MANAGEMENT SCENARIOS									
	CULL 350		**CULL 1,000**		**HUNTING**		**INCREASED HUNTING**		**HUNT & CULL**	
MAXIMUM MIGRATION	**Year1**	**Year5**	**Year1**	**Year5**	**Year1**	**Year5**	**Year1**	**Year5**	**Year1**	**Year5**
>500 Gardiner basin	0.68	0.51	0.43	0.02	0.81	0.86	0.75	0.74	0.68	0.52
>1000 Gardiner basin	0.47	0.27	0.26	0.00	0.61	0.72	0.52	0.50	0.48	0.29
>500 Hebgen basin	0.15	0.18	0.15	0.17	0.14	0.17	0.13	0.15	0.13	0.14
END-OF-WINTER HERD SIZE										
<1000 northern	0.12	0.28	0.24	0.61	0.07	0.02	0.09	0.11	0.12	0.24
<1500 northern	0.28	0.47	0.43	0.77	0.19	0.08	0.24	0.25	0.28	0.44
<2000 northern	0.47	0.65	0.61	0.81	0.36	0.19	0.42	0.41	0.46	0.62
1250-1750 northern	0.18	0.19	0.20	0.12	0.15	0.08	0.16	0.16	0.17	0.20
<1000 central	0.41	0.28	0.43	0.38	0.42	0.29	0.42	0.34	0.42	0.25
<1500 central	0.64	0.50	0.64	0.60	0.65	0.51	0.65	0.56	0.65	0.58
<2000 central	0.81	0.68	0.81	0.77	0.81	0.70	0.81	0.74	0.81	0.75
1250-1750 central	0.19	0.21	0.20	0.20	0.20	0.21	0.19	0.20	0.20	0.20
2500-3500 population	0.51	0.48	0.50	0.35	0.51	0.34	0.52	0.46	0.51	0.48
HUNTS/CULLS:										
Probability of Removing >500	0.00	0.00	0.78	0.23	0.00	0.00	0.00	0.00	0.00	0.00
Mean No. Culls	323	307	772	317	0	0	0	0	125	139
Mean Harvest (Gardiner basin)	0	0	0	0	24	23	198	196	199	171
Mean Harvest (Hebgen basin)	0	0	0	0	13	14	21	22	29	22

PREDICTED MIGRATIONS DURING WINTER 2013

Peak numbers of bison moving to the northern and western management areas during winter 2013 were predicted based on historical weather scenarios during the last 23 years. Thus, the range of variability in the predictions is wide. As more information becomes available, these forecasts will be refined. Predicted numbers of bison in these wintering areas by January 2013 were 155 (0-675) bison in the western area and 165 (0-825) bison in the northern area, with bison from the northern herd representing approximately 80% of the bison in the northern management area. We predicted a 76% chance of up to 500 bison, and 24% chance of >500 bison, in the northern management area by early March, suggesting a reasonably high likelihood of sufficient migrations to support management scenario 5 (Figure 5). We predicted a 64% chance of up to 500 bison, and 77% chance of up to 700 bison, in the western management area by early May (Figure 5).

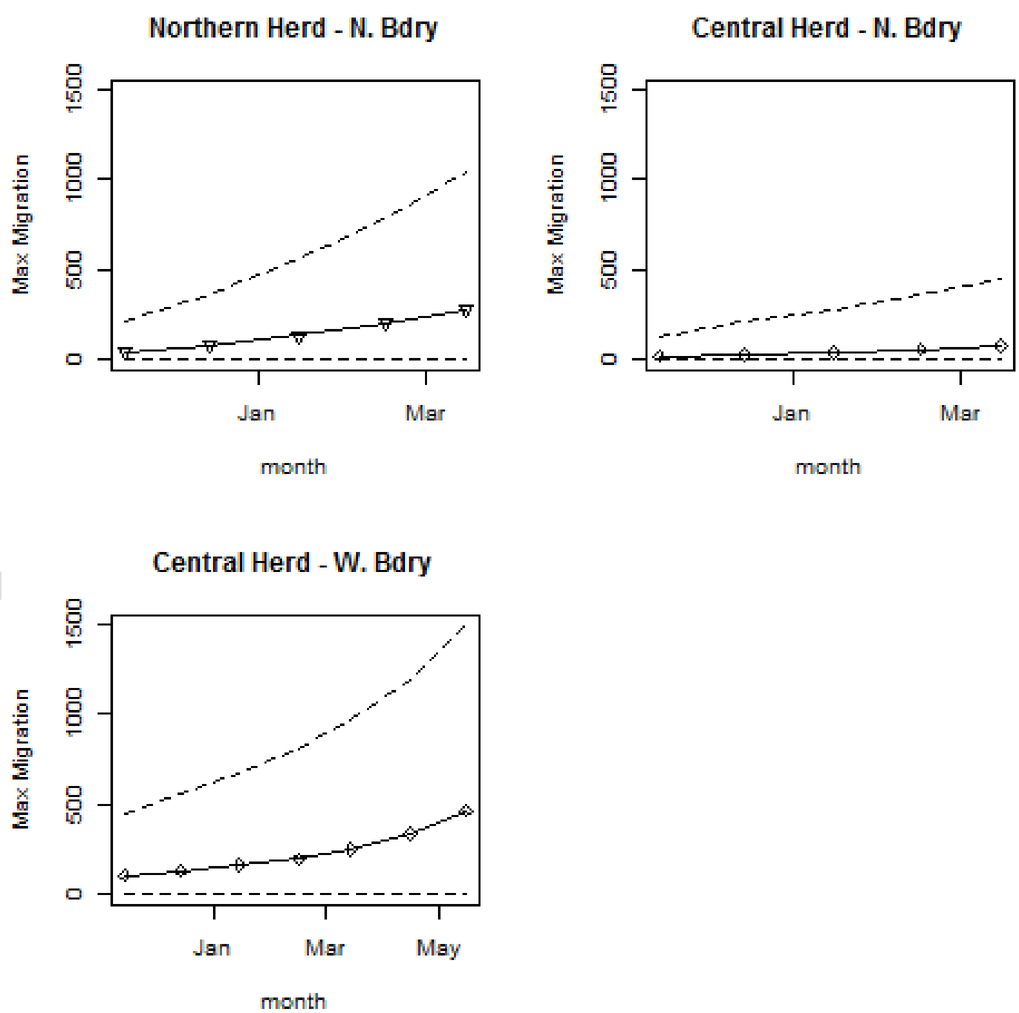

Figure 5. Median and 95% credible intervals for forecasted monthly peak migration of bison from the central and northern herds to the northern and western boundaries of Yellowstone National Park during winter 2013. Predictions were made based on all possible weather

scenarios and refined forecasts will be possible as more detailed long-term forecasts become available.

REMOVAL RECOMMENDATIONS FOR WINTER 2013

To progress towards desired conditions in terms of abundance and age, herd, and sex structure, we recommend the harvest of 25 adult male bison from the central herd in the western management area (Hebgen basin) and the harvest or culling of 425 bison (400 adult females and 25 adult males) from the northern management area (Gardiner basin) during winter 2013. We do not recommend harvesting female bison from the western management area because the abundance of the central herd is near the desired condition (1,500 bison) and the sex ratio is skewed towards males. Removals in the northern management area should be focused on the northern herd to reduce abundance and growth potential, though it is inevitable that some bison from the central herd will be inadvertently removed. Removals from the northern management area could be through harvest by public and treaty hunters and, after the general hunt ends in mid-February, through selective culling at the Stephens Creek capture facility for shipment to quarantine or research facilities, terminal pastures, or slaughter facilities. Additional bison may be removed if they resist efforts to return them from Montana to Yellowstone National Park during spring or summer. If the proposed removals are not realized this winter, then there could be more than 4,900 bison in population next winter (Figure 6).

We forecasted population growth over the next five years considering the above-outlined removal followed by four years of annual removals to the central herd ranging from 0-5 calves, 0-5 yearling females, 0-5 yearling males, 0-25 adult females, 25-50 adult males, and to the northern herd ranging from 25-50 calves, 25-50 yearling females, 25-50 yearling males, 125-175 adult females, and 125-175 adult males. Under these guidelines, annual removals will average near 400 individuals and there is high certainty of approaching all desired conditions within five years (Figure 7).

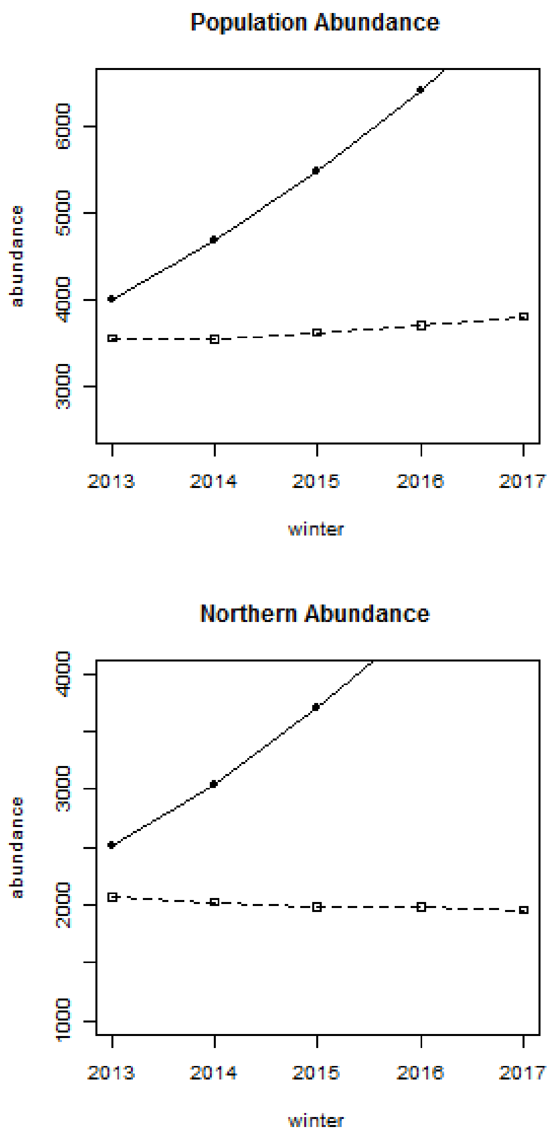

Figure 6. Forecasted average end-of-winter abundance of the Yellowstone bison population and central and northern herds during 2013 through 2017. Dotted lines indicate forecasts considering removal of 450 bison during the 2013 winter and average of approximately 400 removals during each subsequent winter. Solid lines indicate forecasts without any removals.

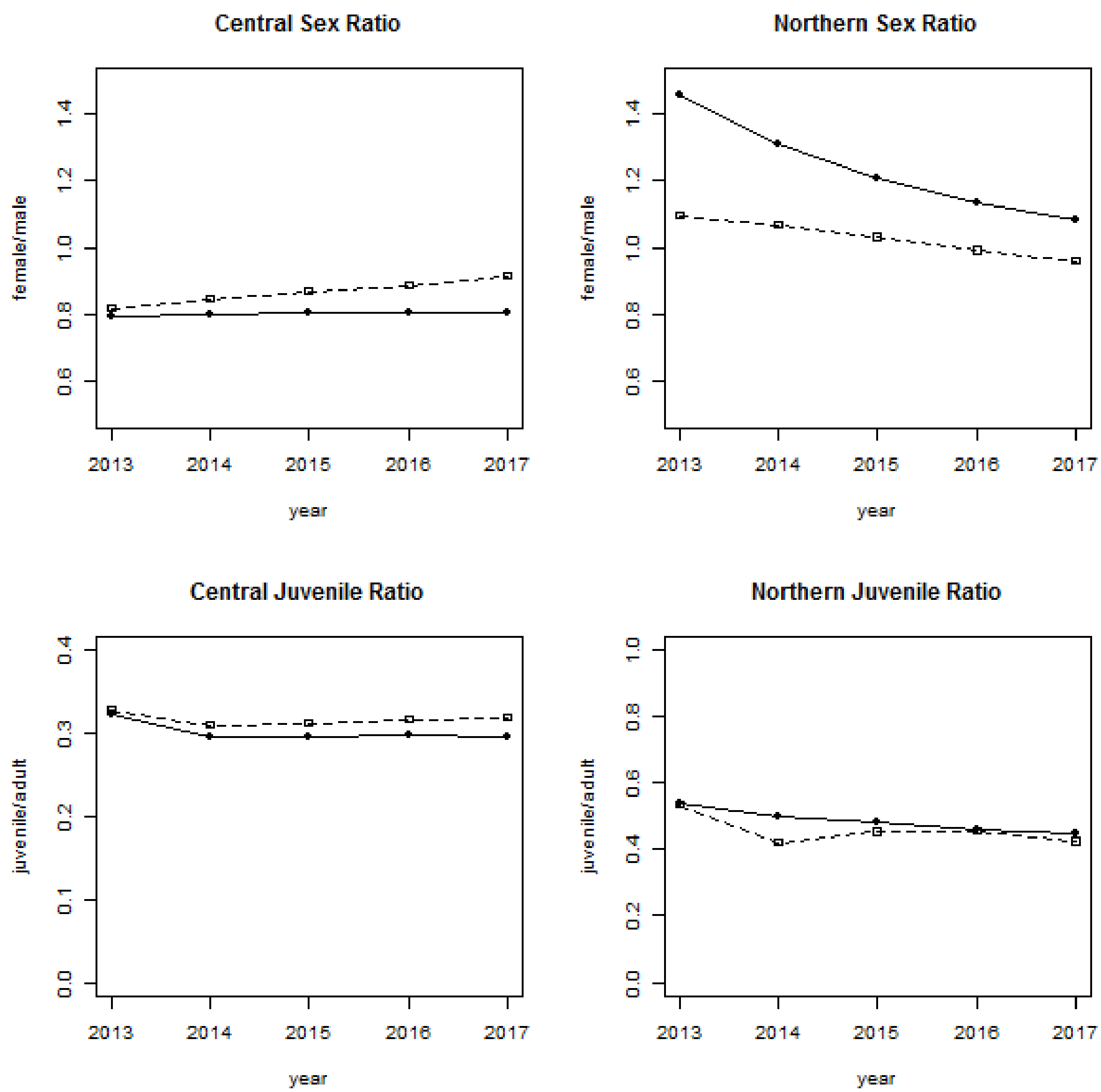

Figure 7. Forecasted breeding season central and northern herd demographics during 2013-2017. Dotted lines indicate forecasts considering removal of 450 bison during the 2013 winter and average of approximately 400 removals during each subsequent winter. Solid lines indicate forecasts without any removals.

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