MANAGING THE ABUNDANCE OF YELLOWSTONE BISON, WINTER 2014

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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 maintain more than 1,000 bison in the central and northern breeding herds, similar proportions of males to females (range = 40-60%), and an age structure of about 70% adults and 30% juveniles (range = 22-33% juveniles). Managers want to allow bison to seasonally migrate, while avoiding annual reductions in bison numbers of more than 1,000 due to brucellosis, property, and safety concerns near wintering areas in Montana. It is important to consider that bison from central Yellowstone migrate to both the northern and western management areas during winter. Thus, some unknown proportion of the harvest or culls in the northern management area consists of bison from the central herd, which likely averages more than 10% under current population conditions.

Current Population Conditions: During June 2013, there were about 4,600 bison in the Yellowstone population following calving, including about 3,200 bison in northern Yellowstone and 1,400 in central Yellowstone. Harvests and culls during winter 2013 (October 2012-April 2013) totaled approximately 237 bison, including 83 from the western management area and 154 from the northern management area. Harvests were biased towards males (57%) and did not reflect the recommended guidelines of removing 400 females and 25 males from the northern management area and 25 males from the western management area. As a result, herd abundance and age and sex structure did not progress towards desired conditions.

Removal Recommendations: Without harvests or culls, we predict an end-of-winter population of approximately 4,335 bison in 2014 that increases to nearly 6,000 bison by the end of winter in 2016. The removal of 600 bison, including 300 females (45 yearlings, 255 adults), 165 males (25 yearlings, 140 adults), and 135 calves, from the northern management area during each of the next three winters would improve the chances of meeting the desired population and herd conditions. We do not recommend any removals of bison from the western management area. However, if managers decide to harvest bison in this area then harvests should be limited (e.g., less than 50) and focused on bulls. These management recommendations increase the chances of an end-of-winter population of 3,000-3,500 bison more than 13 times over a no harvest/cull alternative within three years.

Movements and Implementation: Under average snow and standing vegetation conditions, we predict approximately 600 bison will move to the northern management area by late winter, and 100-200 bison will occupy the western management area from December 2013 through March 2014, with numbers increasing in April and May 2014. Current migration predictions are highly uncertain (e.g., maximum migrations may exceed 2,000 bison in the northern and 1,000 bison in the western management area), but the precision of estimates will increase as

information becomes available on snow conditions and bison distribution during early next winter. Removals could be implemented through public and treaty hunting in Montana (300-400 bison) and capture at the northern boundary capture facility followed by shipment to slaughter, terminal pastures, or research facilities (200-300 bison). Gather-and-consignment could be implemented weekly before March through non-selective removals of small groups (e.g., 25-50) of bison. If necessary to reach removal objectives for a given year, larger groups of bison could be gathered into the northern capture facility and consigned after the majority of public and treaty hunting is completed in late February or early March.

BACKGROUND

The conservation of Yellowstone bison from near extirpation in the late 19th century to approximately 4,600 animals in summer 2013 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 possibly, 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 annual harvests and smaller 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 have removed less than 250 bison in most 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 (2001-2013) 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:

1. End-of-winter bison abundance averages 3,000 to 3,500 per decade;
2. Equal sex ratio and an age structure of about 70% adults and 30% juveniles;
3. More than 1,000 bison in each of the central and northern breeding herds;
4. Maintain the process of migration to essential winter ranges; and
5. Avoid removing more than 1,000 bison from the population in any winter.

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 into a population model with demographic rates from long-term studies, reported removals during the previous winter, historic climate data, and long-term weather forecasts 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 (Table 7), and (3) the number of bison surviving the upcoming winter under various management approaches (Tables 8 and 9).

A variety of management tools could be used to limit the abundance of Yellowstone bison, including (1) public and treaty hunting in Montana, (2) culling via shooting or shipment to slaughter or terminal pastures, (3) transfer of bison to research facilities, and (4) transfer of bison to American Indian tribes or other organizations for quarantine and eventual release. Currently, no terminal pastures or quarantine facilities are operational.

During summer, biologists from Yellowstone National Park develop harvest recommendations that they share with harvest managers from Montana Fish, Wildlife & Parks and American Indian tribes with recognized treaty hunting rights on some federal lands in southwestern Montana. As winter unfolds, biologists from the agencies and tribes monitor and document actual hunter harvest, winter-kill (starvation), predation, and management culls. Biologists from the park also periodically update predictions for bison migration based on aerial surveys of bison distribution, snow pack estimates, and revised weather forecasts.

Table 1. Estimated[1] population growth rates of Yellowstone bison in the central and northern breeding herds during 2003 through 2013, along with estimated 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
2012-13	0.86	0.78-0.93	1.20	1.13-1.26
	Population Survival, Birth, and Emigration			
Adult survival	0.95	0.84-1.00	0.99	0.87-1.00
Calf survival	0.72	0.61-0.84	0.75	0.62-0.86
Birth[2]	0.45	0.36-0.55	0.59	0.49-0.72
Emigration	0.02	0.00-0.10	NA	NA

[1] Throughout this document the words 'estimated' or 'predicted' refer to model generated quantities. These quantities, such as the values in this table, are determined by identifying the most reasonable value based on several (rather than a single) sources including: birth, death, and emigration records of individually collared adult female bison; monthly aerial counts of bison on wintering areas; repeated aerial counting and ground classification of bison on breeding areas during summer; agency reported removals; and weather and vegetation conditions.

2 These birth rate estimates include neonatal mortality between parturition in May and June and counts and classification surveys in June, July, and August.

Table 2. Estimated average and 95% range for age and sex structure of Yellowstone bison in the central and northern breeding herds during 2003 through 2013.

Central Herd

	Abundance	Males:100 Females	Juveniles:100 Adults
2003	2,924 (2,768-3,084)	60 (53-68)	40 (36-44)
2004	3,396 (3,225-3,572)	110 (99-124)	34 (31-37)
2005	3,437 (3,281-3,595)	89 (80-99)	40 (36-43)
2006	2,422 (2,297-2,556)	112 (100-126)	35 (32-38)
2007	2,825 (2,680-2,974)	82 (73-92)	43 (39-47)
2008	1,379 (1,305-1,460)	101 (89-115)	26 (23-28)
2009	1,509 (1,428-1,592)	116 (103-132)	30 (27-33)
2010	1,690 (1,600-1,785)	126 (111-143)	31 (28-34)
2011	1,380 (1,302-1,459)	147 (129-166)	26 (24-29)
2012	1,584 (1,503-1,674)	129 (114-145)	28 (26-31)
2013	1,367 (1,296-1,443)	127 (113-145)	29 (26-32)

Northern Herd

	Abundance	Males:100 Females	Juveniles:100 Adults
2003	895 (847-945)	96 (85-110)	33 (29-35)
2004	1,086 (1,013-1,148)	85 (77-96)	36 (32-39)
2005	1,308 (1,244-1,371)	86 (77-96)	34 (30-37)
2006	1,275 (1,211-1,342)	75 (66-84)	45 (41-50)
2007	1,807 (1,712-1,908)	52 (46-59)	47 (42-53)
2008	1,586 (1,507-1,669)	87	47
2009	1,674 (1,590-1,765)	101 (93-118)	42 (38-46)
2010	1,910 (1,813-2,016)	60 (54-68)	53 (47-60)
2011	2,296 (2,177-2,425)	61 (54-68)	45 (40-49)
2012	2,583 (2,458-2,720)	66 (58-75)	60 (53-68)
2013	3,204 (3,040-3,371)	63 (57-71)	56 (50-62)

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).

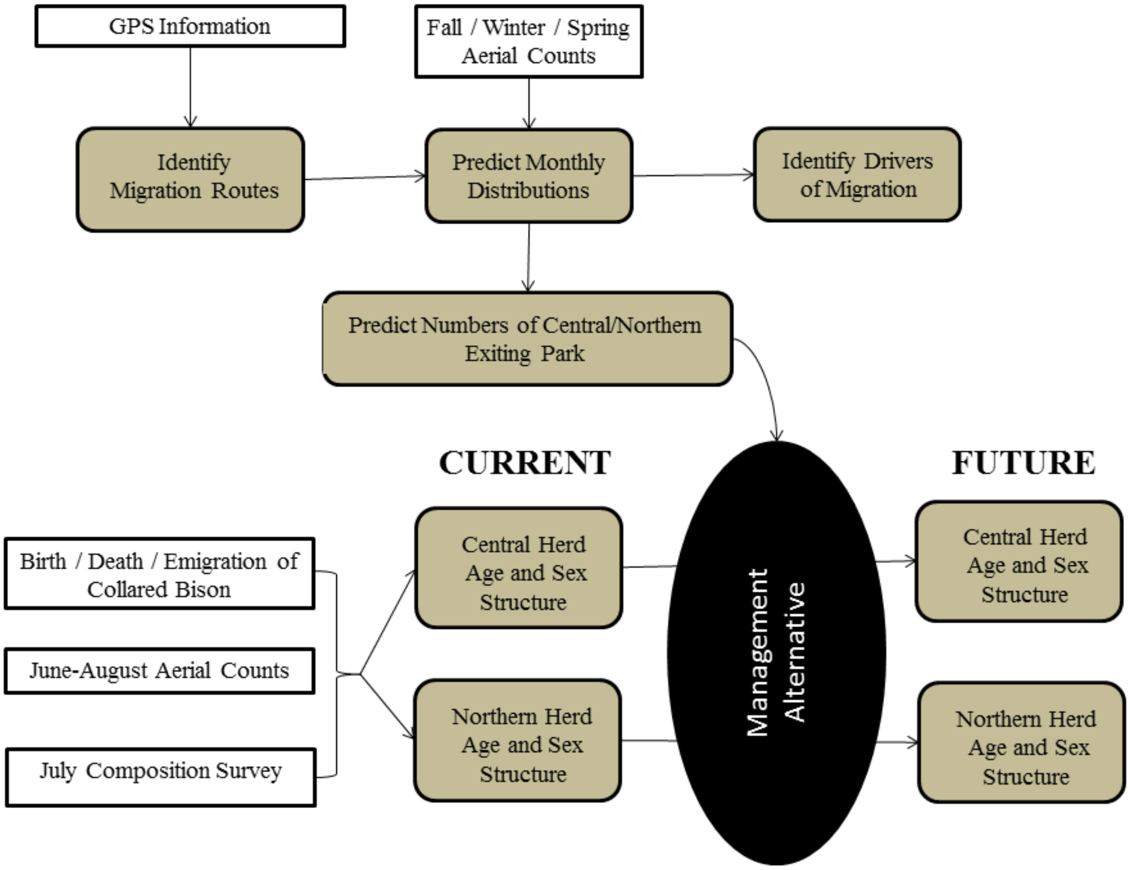

Figure 1. A conceptual diagram of the spatially explicit model used to support adaptive management of Yellowstone bison. White boxes represent information provided as inputs; gray boxes represent steps in the modeling process; and the black oval represents management treatments.

Data Collection: Sixty-seven bison greater than one year of age were captured in autumn during 2004 through 2013 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 6 years of information. Radio collars were fitted on 2 to 15 adult females from the central herd during 2003 through 2013 and 6 to 23 adult females from the northern herd during 2006 through 2013. 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. Reproduction, survival, and herd interchange information was combined with previous research on these quantities extending back to 1996 for survival and reproduction (Fuller et al. 2007) and 2002 for herd interchange.

Biologists completed 146 airplane counts during 1990 through 2013 and recorded the location and size of observed bison groups (1 or more animals) during systematic surveys of wintering areas (Hess 2002). Counts occurred monthly during 1990 through 1997 and 2007 through 2013, 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 2013 (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-consignment were recorded during 2002 through 2013 (Table 5).

Model Description: A hierarchical Bayesian state-space model (implemented in program R, R Core Development Team 2013) was developed. In this approach, unobserved quantities and parameters are 'estimated' or 'predicted.' Unobserved quantities include true numbers of bison in wintering areas, and removal and population herd, age, and sex classes. These quantities are unobserved, because it is impossible to perfectly count them in Yellowstone. Parameters allow unobserved quantities to change over time, for example, annual adult female survival is a parameter that allows the number of females to change from year to year. Unobserved quantities and parameters are estimated by identifying the most reasonable values based on several, rather than a single, data source including: birth, death, and emigration records of individually collared adult female bison (1996-2013); monthly aerial counts of bison on wintering areas (1990-2013); repeated aerial counting and ground classification of bison on breeding areas during summer (2003-2013); agency reported removals (2003-2013); and weather and vegetation conditions (1990-2013). Unobserved quantities and parameters are not single values, but are described by probability distributions. In other words, model generated estimates of all unobserved quantities and parameters have average values and ranges.

Model Implementation: Wintering areas and migration routes were identified using information collected from adult female bison fit with radio collars during 2003 through 2013 (Horne et al. 2007, Sawyer et al. 2009). Bison from the central breeding herd were assumed to use 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 assumed to use four wintering areas including the Lamar Valley, lower Yellowstone River drainage, Blacktail Deer Plateau, and Gardiner basin (Figure 2).

Unobserved central and northern herd sizes were estimated each July during 1990-2002. Counts were assumed to under- or over-count true herd sizes. Counting accuracy was assumed to be similar throughout the year and between areas, and was determined by comparing counts and predicted numbers of bison in wintering areas from all 146 aerial surveys during 1990-2013. Unobserved numbers of central and northern herd bison in each wintering area were estimated each month from July through peak numbers of bison in northern (February through April) and western management areas (April through June) during 1990-2002. Estimates were made on the day of aerial counting or the 15th of the month when a count did not occur. Counts in management areas were adjusted by removals occurring prior to counting. Unobserved numbers of bison in areas were based on numbers of bison present during the previous month, movement probabilities between areas, survival, and aerial counts of wintering areas. Movement probabilities were related to time since snow cover, snow pack magnitude, standing vegetation, herd size, and year of study.

Population dynamics were incorporated into the model starting in 2003. Bison were portrayed in 10 demographic stages 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. Unobserved numbers of bison in each demographic stage were estimated during June each year (2003-2013), which is after the annual calving period. Estimates were based on numbers of bison in each stage during the previous year; estimated winter removals; survival, birth, and emigration probabilities; aerial counts; and ground composition surveys. Survival, birth, and emigration probabilities were, in turn, estimated from aerial counts, ground composition surveys, and mark recapture histories of individually marked adult females. Survival for age and sex classes was assumed to be constant, meaning that it was not influenced by winter or herd size conditions. Therefore, our model portrayed exponential growth in the absence of removals. Separate birth and survival probabilities were estimated for each herd. Males and females at least 1 year of age were assumed to have the same survival. Calves were assumed to have lower survival than older animals. Unobserved numbers of removals to each demographic stage were estimated based on the age and sex composition of reported removals, predicted numbers of central and northern herd animals moving beyond each park boundary, and estimated numbers of bison in demographic stages between years.

The age and sex composition of monthly numbers of bison in wintering areas was estimated beginning in 2003. Age and sex composition of bison in wintering areas was assumed to be proportional to the entire herd age and sex composition estimated in June. In addition to the procedure described above for estimating monthly distributions, unobserved numbers of bison were also based on numbers of GPS collared bison in each wintering area.

Future herd sizes and composition, and spatial distributions were also unobserved. These quantities were predicted based on estimated parameters for movements, demography, and model uncertainty (e.g., a model is not a perfect representation of reality) determined during 1990-2013. We evaluated several scenarios because of unknowns in the numbers of bison that needed to be removed to offset population growth, our ability to identify central and northern herd animals in the northern management area, and total numbers of migrants moving into management areas by late winter.

- <u>Scenario 1 (No Action):</u> Herd conditions were predicted during 2014-2016 without removals to identify the chance of meeting desired population and herd conditions under a no action alternative. Chance was defined as the magnitude of the probability distribution for each unknown quantity (e.g., population size) that was within desired conditions (e.g., 3,000-3,500 bison).
- <u>Scenario 2 (Absolute Control):</u> We assumed that it was possible to remove exact numbers of central and northern animals, and numbers of removals were not limited by movements to management areas. We completed this analysis to identify the minimum number of removals necessary to move closer to desired population and herd conditions.

- <u>Scenario 3 (Partial Control):</u> We assumed that removals were not limited by movements to management areas and we could remove exact numbers of bison in age and sex stages. This scenario differed from absolute control because herd membership of removals was treated as unknown and estimated using the predicted ratio of central and northern herd members within the northern management area. This ratio was estimated using herd abundance in 2013 and a broad range of winter conditions.
- <u>Scenario 4 (Uncontrolled):</u> A removal objective for total bison in each age and sex class was specified for each management area. Numbers of bison in management areas were predicted through March 15th based on predicted herd sizes and average winter conditions. Bison within management areas were removed up to the objective. We assumed that up to 100% of bison in management areas could be either harvested by hunters or gathered into capture facilities. Herd membership of removals in the northern management area was estimated using the predicted ratio of central and northern herd members within the area.

These scenarios represent different levels of certainty over management control, and each was valuable in predicting the effectiveness of management over no action. Assessments of model fit suggested that model uncertainty was overestimated, which was unsurprising given the number of unobserved quantities and parameters that were estimated. Therefore, understanding management effectiveness across different scenarios of uncertainty was important for identifying a preferred alternative.

Table 3. Annual counts of Yellowstone bison in the central and northern breeding herds during June through August from 2003 through 2013.

		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		
2013	June 6, 2013	1,338	1,170	168	3,154	2,620	534
	July 14, 2013	1,504			3,420		
	July 22, 2013	1,337			3,228		

Table 4. Annual ground and aerial composition surveys of Yellowstone bison in the central and northern breeding herds during July from 2003 through 2012. Ground composition columns represent total numbers of animals observed in mixed age and sex groups.

		Males		Females							
Herd	Ground Surveys	More than 1	1	More than 1	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
Central	July 17, 2013	287	101	415	82	197	1,082	July 15, 2013	1,162	342	1,504
	July 25,2013	372	102	401	77	191	1,143	July 22, 2013	1,148	189	1,337
Northern	July 16, 2013	457	231	1,061	191	528	2,468	July 15, 2013	3,275	145	3,420
	July 23, 2013	608	249	1,149	198	538	2,742	July 22, 2013	3,151	77	3,228

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 2013.

	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
2012-13	88	3	45	5	9	154	39	0	44	0	0	83

Table 6. Average and 95% range for age and sex structure of removals to bison in the central and northern herd breeding herds during 2003 through 2013. Removals were estimated because age and sex composition were sometimes unrecorded and unknown numbers of central herd animals were removed in the northern management area.

	Central Herd					**Northern Herd**				
	Males		Females			Males		Females		
	Adults	Yearlings	Adults	Yearlings	Calves	Adults	Yearlings	Adults	Yearlings	Calves
2003-04	60 (32-98)	30 (9-68)	92 (54-134)	33 (13-68)	37 (14-71)	3 (0-10)	2 (0-8)	6 (1-19)	2 (0-8)	2 (0-9)
2004-05	24 (11-47)	0 (0-6)	41 (22-59)	0 (0-1)	27 (12-48)	0 (0-0)	0 (0-0)	1 (0-1)	0 (0-0)	0 (0-0)
2005-06	188 (113-275)	110 (47-185)	265 (169-374)	98 (42-182)	219 (136-328)	22 (5-60)	17 (4-44)	46 (13-106)	15 (4-42)	38 (11-90)
2006-07	38 (23-49)	0 (0-6)	9 (2-20)	0 (0-10)	2 (0-10)	6 (2-16)	0 (0-0)	2 (0-6)	0 (0-0)	0 (0-0)
2007-08	242 (139-371)	125 (60-227)	329 (204-482)	67 (23-145)	168 (83-297)	138 (76-224)	95 (38-130)	237 (126-368)	80 (29-160)	183 (91-302)
2008-09	4 (2-4)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	1 (0-1)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
2009-10	3 (1-4)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	2 (0-3)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
2010-11	47 (24-76)	0 (0-12)	66 (37-95)	0 (0-4)	23 (6-45)	41 (18-73)	0 (0-1)	51 (24-81)	0 (0-4)	5 (0-23)
2011-12	11 (2-7)	0 (0-1)	7 (2-12)	0 (0-2)	0 (0-2)	5 (1-10)	0 (0-1)	4 (0-8)	0 (0-1)	2 (0-2)
2012-13	56 (28-77)	3 (0-9)	54 (28-77)	3 (0-5)	5 (1-15)	43 (21-69)	8 (1-9)	29 (12-55)	9 (2-11)	13 (3-15)

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.

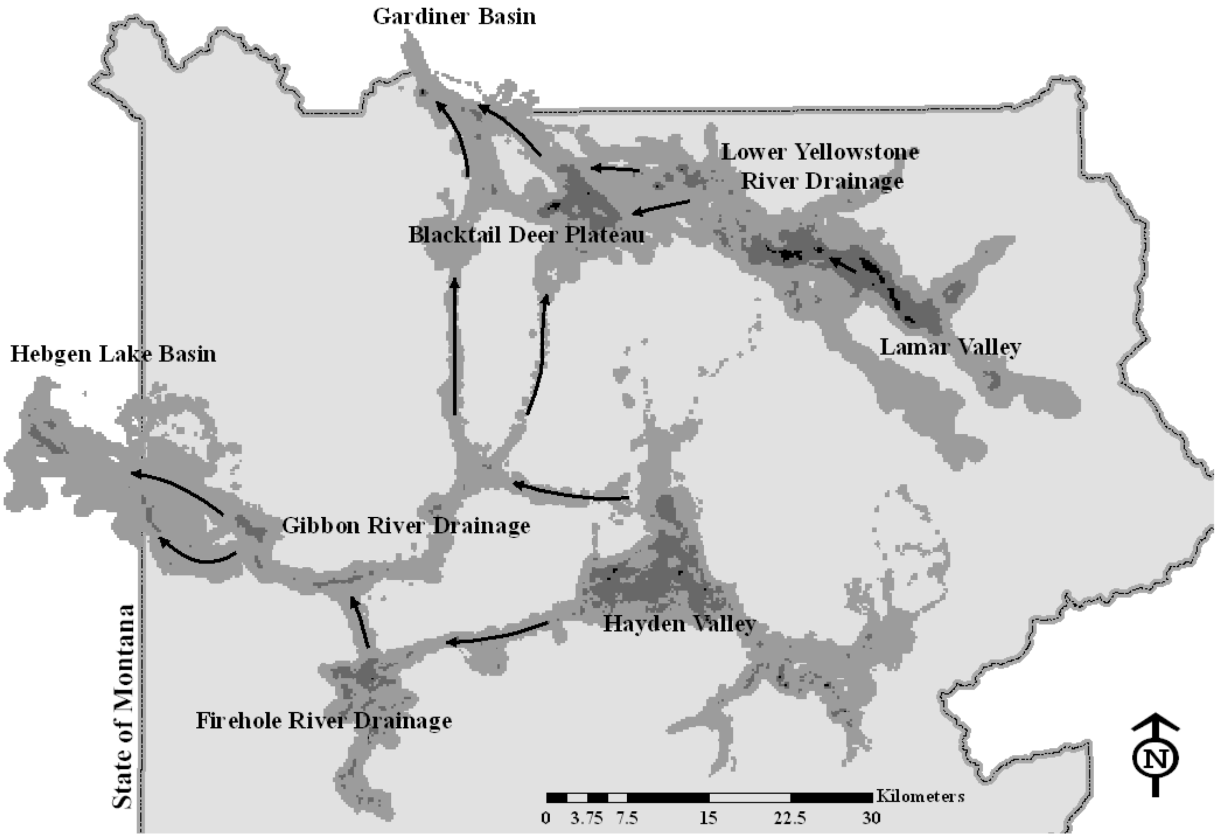

Figure 2. Wintering areas and migration routes of Yellowstone bison in Yellowstone National Park and nearby areas of Montana, with darker colors representing core use areas.

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.

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 and 4).

The Yellowstone bison population fluctuated between 3,000 and 5,000 bison during 2003 through 2013. The central herd decreased from approximately 3,500 bison in 2005 to 1,367 bison in 2013 (1,296-1,443; 95% credible interval) due to large-scale, non-selective culls (primarily shipment to slaughter) during winters 2006 and 2008 (Table 6), as well as emigration of female and juvenile groups to the northern herd. Despite this decrease in numbers, about 2% (0-10%) of bison from the central herd have emigrated into the northern herd each year (Table 1). The northern herd increased from approximately 1,250 bison in 2008 to 3,162 (3,002-3,326) bison in 2013, the highest number recorded in this herd. Adult annual survival (95% average chance central; 99% northern) and births (45% central; 59% northern) is higher in the northern herd, perhaps due to less severe winters (Table 1). Reported birth values represent chances of calves surviving through early June and likely include some neonate mortality. Higher herd densities have not influenced births or survival and the bison population has experienced exponential growth in the absence of human removals.

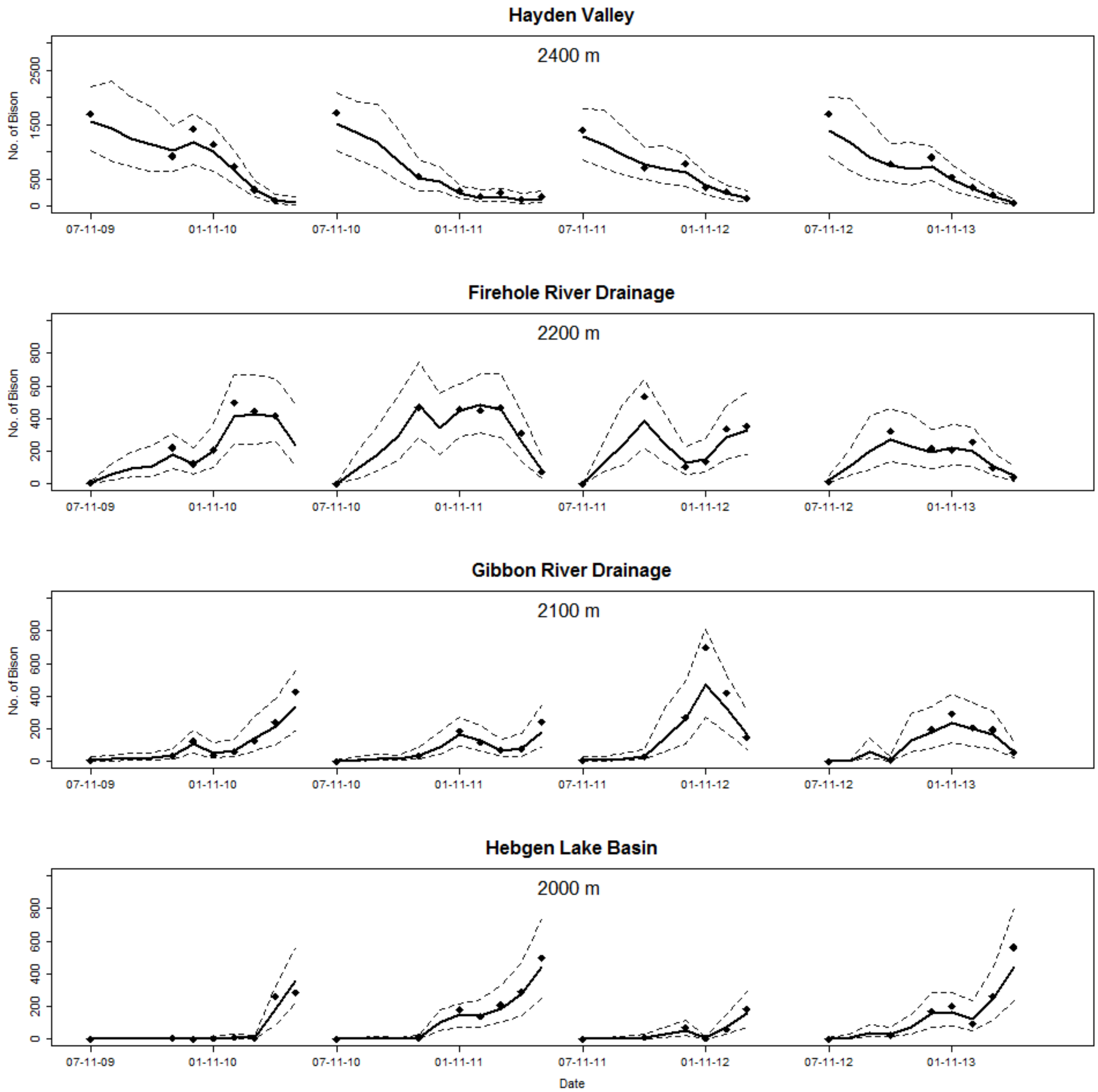

Figure 3. Counts (diamonds) of bison in the central portion of Yellowstone National Park and nearby areas of Montana during winter. Solid lines represent the average, while dashed lines represent the 95% range. Each year, bison progressively moved from the highest elevation (Hayden Valley) in summer to the lowest elevation (Hebgen Lake basin) in spring. Trend curves begin in July each year and continue until peak migration or the month of the last aerial count.

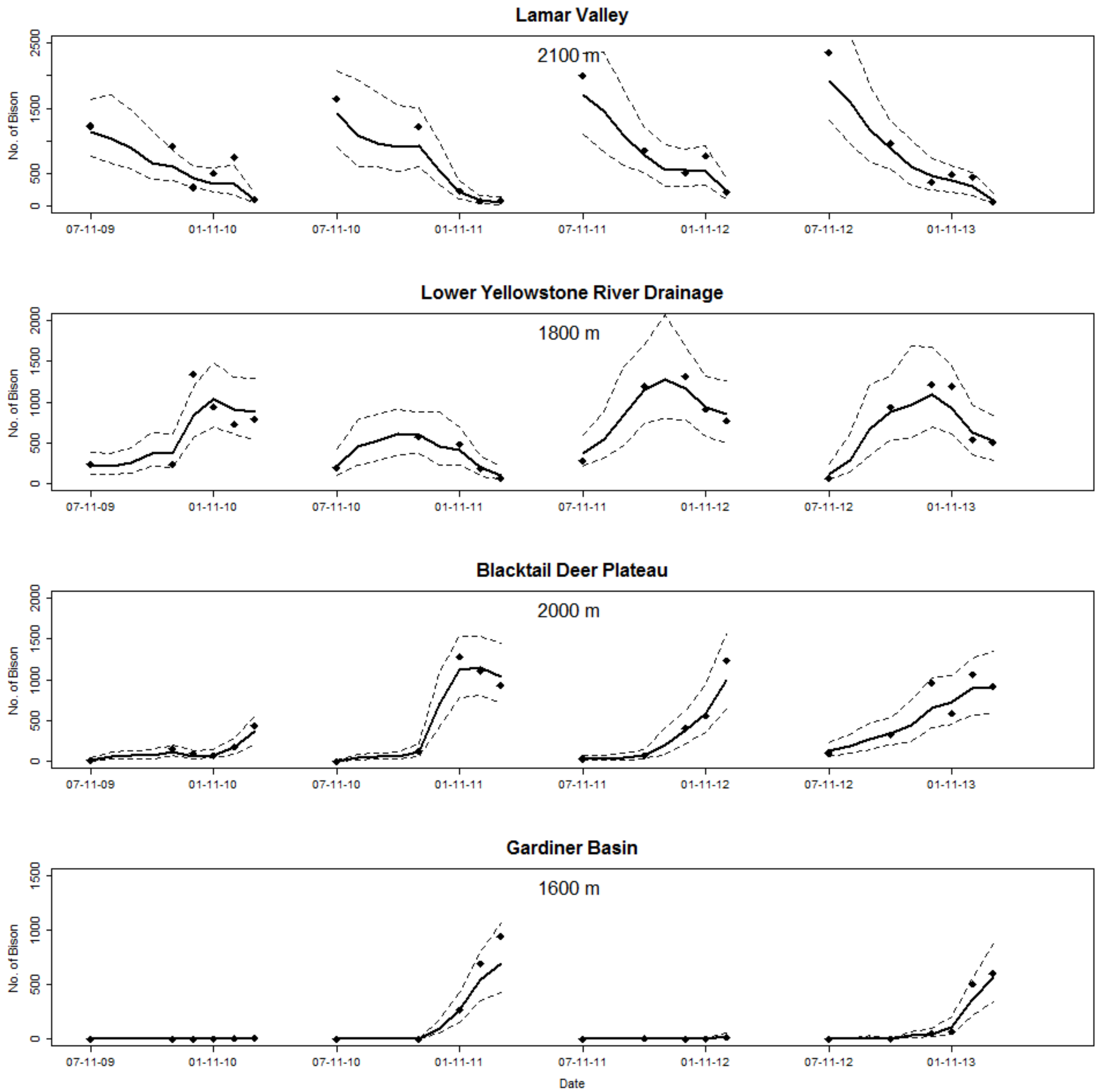

Figure 4. Counts (diamonds) of bison in the northern portion of Yellowstone National Park and nearby areas of Montana during winter. Solid lines represent the average, while dashed lines represent the 95% range. Movements to the lowest elevation (Gardiner basin) varied each year with herd sizes and snow pack establishment. Trend curves begin in July each year and continue until peak migration or the month of the last aerial count.

Implementation of 2013 Strategy

The population exceeded the end-of-winter abundance guideline of 3,000 to 3,500 bison in 2013 with 3,693 (3,530-3867) surviving animals, including approximately 1,200 in the central and 2,500 in the northern herd. Winter management actions removed at least 237 bison that included 227 harvests, 4 lethal removals by agency personnel, and 6 animals that were dispatched due to improper harvest. Montana-licensed hunters harvested 37 bison and tribal hunters harvested at least 190 bison (Table 5). Removals were biased towards males and central herd members and consisted of approximately 60 central herd females, 60 central herd males, 5 central herd calves, 35 northern herd females, 50 northern herd males, and 15 northern herd calves (Table 6). Increased removals from the central herd resulted from herd members migrating to both the northern and western management areas during state and tribal hunting seasons.

Removal guidelines for the 2013 winter included 425 (400 adult female, 25 adult male) bison in the northern management area and 25 (adult male) bison in the western management area. Migrations into the northern management area were delayed and gather-and-consignment of bison during late winter was not used to supplement harvests. Numbers of bison began to increase during mid-January with 106 (51-196) bison present. Abundance increased through February (368, 224-568) with more animals regularly exiting the park, and peaked in late March (559, 336-891). Most migrants returned during early April with few (less than 100) bison remaining through May. Approximately 150-200 bison occupied the Hebgen Lake basin wintering area in the western management area during December through March. Animals often moved outside of the park, which supported regular hunting opportunities such that harvests exceeded recommendations. Abundance in the Hebgen Lake basin increased dramatically during April (445, 243-775), with most of these animals outside of the park through late May.

During 2013, the population moved further away from guidelines for herd and age structure, and sex composition. The current herd structure is unequal with the northern herd making up 70% (68-72%) of the entire population. The sex ratio of the Yellowstone bison population is biased towards females, with 80 (73-87) males per 100 females, females outnumbering males in the northern herd, and males outnumbering females in the central herd (Table 2). The juvenile proportion was near the guideline of 30% in the central herd (29, 26-30%), but substantially larger in the northern herd (56, 50-62%).

PREDICTED MIGRATIONS DURING WINTER 2014

We predict approximately 600 bison moving to the Gardiner basin during winter 2014, assuming average snow and standing crop conditions (Table 7). There is not much chance under average winter conditions that large numbers of animals will move to northern hunting districts before February. For example, there is a 21% chance of more than 500 bison, and only 5% chance of more than 1,000 bison, moving to the Gardiner basin by January. Abundance in the Gardiner basin is predicted to rapidly increase in March (48% chance of more than 500 bison; 20% of more than 1,000 bison; Table 7). Bison from both the northern and central herds move to the Gardiner basin during winter, which complicates implementing management reductions. We predict that most bison in the Gardiner basin by March will be from the northern herd, with an 82% chance of fewer than 100 central herd animals. Our prediction of central migrants moving to northern Yellowstone is lower than estimates during recent winters, which is likely due to emigration and a lower central herd size. Most central herd migrants are predicted to move to the Hebgen Lake basin. We predict 100-200 bison occupying the Hebgen Lake basin from December through March, with numbers increasing substantially in April and May (32% chance of more than 500 bison; Table 7). Current migration predictions are highly uncertain (Table 7) and the precision (ranges) of estimates substantially increases as information becomes available on snow conditions and from aerial counts during early winter.

Table 7. Average and 95% range for predicted numbers of bison within the Gardiner and Hebgen Lake basins during winter 2013-2014. Predictions were made each month through peak migration, which occurs in March in the Gardiner basin and May in the Hebgen Lake basin. We assumed average snow and standing vegetation conditions and above average snow conditions would result in abundance near the upper ends of 95% ranges.

	Gardiner Basin			**Hebgen Lake Basin**
	Total	Northern Herd	Central Herd	Central Herd
December	177 (3 - 965)	176 (3 - 771)	1 (0 - 194)	108 (0 - 623)
January	277 (11 - 1,335)	275 (11 - 1,063)	2 (0 - 272)	129 (0 - 769)
February	403 (24 - 1,775)	397 (24 - 1,410)	6 (0 - 365)	150 (0 - 883)
March	551 (44-2,25)	537 (44- 1,780)	14 (0 - 445)	178(0 – 1,022)
April				218 (0 - 1,178)
May				276 (0 - 1,378)

REMOVAL RECOMMENDATIONS

Ranges of demographic conditions that met long-term conservation needs for Yellowstone bison included: 1) end-of-winter breeding herd sizes greater than 1,000; 2) sex ratio between 65 males to 100 females and 150 males to 100 females (e.g., neither sex exceeds 60%); 3) age structure between 28 juveniles to 100 adults and 50 juveniles to 100 adults (e.g., based on three standard deviations above and below equilibrium conditions); and 4) total population size between 3,000 to 3,500 bison.

Progressing Toward Desired Conditions: The 2013 end-of-winter population size included 3,693 (3,530-3,867) bison and we predict a 2014 end-of-winter population size of 4,335 (3,353-5,740) bison that increases to 5,957 (3,771-9,826) bison by the end of winter in 2016 (Tables 8 and 9; Scenario 1: No Action). In the absence of management removals (i.e., harvests, culls), we found a negligible (5%) chance of meeting the desired end-of-winter population condition of 3,000-3,500 bison in 2014 and only 1% chance by 2016 (Table 8). The removal of at least 600 bison is needed to offset growth such that the end-of-winter population size is similar between 2013 and 2014. Removals should be focused on bison from the northern herd because there is a 13% chance that the central herd will not meet the desired condition of more than 1,000 bison by the end of next winter without any removals (Table 8). However, some central herd migrants will almost certainly be inadvertently removed in the northern management area.

In Scenario 2 (Absolute Control), where we could perfectly remove animals according to herd, age and sex classes, the removal of 300 females (approximately 45 yearling and 255 adult), 165 males (approximately 25 yearling and 140 adult), and 135 calves from the northern herd during each of the next three winters improves our chances of meeting all desired population and herd conditions within one year (Table 8). This management recommendation increases our chances of an end-of-winter population of 3,000-3,500 bison more than 19 times over a no action alternative within three years (Table 9).

As we include uncertainty in numbers of central and northern bison moving to the northern management area, we increase the chance of the central herd diverging away from population objectives. Further, chances of meeting northern herd conditions improve compared to no action, but these improvements are smaller in magnitude and become less certain as we predict further into the future (Tables 8 and 9). One alternative for improving management effects on northern herd conditions would be to increase the total number of bison removed in the northern management area. However, such an approach would also increase our chances of decreasing the central herd below 1,000 bison. Also, as winter severity increases, the chances of bison from the central herd moving to the northern management area where they may be inadvertently removed also increases. Therefore, there is the potential to remove hundreds of central herd bison in the northern management area if winter is severe.

Implementation: Under scenarios of average or below average snow conditions, nearly all migrants would need to be removed to reach the recommended removal level. Removals could be implemented through public and treaty hunting in Montana and gather-and-consignment (shipment to slaughter, terminal pastures, or research facilities) at the northern boundary capture facility. We recommend that most hunting be focused in the northern management area. To support hunting, gather-and-consignment could be implemented throughout the winter with small numbers (e.g., 25-50) of bison removed weekly during February and March. This stepwise approach would: 1) limit the number of bison held within capture facilities and minimize effects on hunting opportunities; 2) reduce logistical constraints of transporting large numbers of bison to slaughter houses over brief periods; 3) limit transporting females to slaughterhouses late in pregnancy (which could occur if gather-and-consignment occurred after the close of hunting seasons); and 4) lower the chances of out-of-park abundance surpassing levels which exacerbates conflict. As winter progresses, biologists could track the age and sex composition of harvests to appropriately adjust gather-and-consignment efforts.

Predicted migrations suggest that it is unlikely sufficient numbers of bison will move to the northern management area to enable the selective removal of enough actively infected bison to suppress brucellosis transmission. Removal of small (25-50) groups of bison gathered through weekly efforts should mimic non-selective culling, which is a preferable alternative for conservation. Management culling is the dominant source of mortality for Yellowstone bison. Non-selective removals, in contrast to selective removals based on brucellosis exposure, avoid artificially allowing brucellosis to act as a key selective force on the bison population. We also recommend that vaccine-eligible individuals gathered in capture facilities are consigned during weekly efforts until removal guidelines are met.

If winter is severe, with hundreds of bison moving to the northern management area by early winter, the implementation of weekly gather-and-consignment of small groups of bison could begin in January. Using consistent, small consignments during early winter would reduce the chance of total harvests and consignments exceeding removal recommendations by late winter. As hunting seasons wane in late winter when females are late in pregnancy, larger groups of bison could be gathered into the capture facility for holding, and/or selective removal based on brucellosis exposure and vaccination of eligible animals.

We recommend prioritizing population and herd conditions that support long-term conservation over brucellosis suppression. Space and time separation of bison and livestock has been effective at preventing the spillover of brucellosis from bison to cattle. However, large numbers of bison migrating outside Yellowstone during winter threaten the separation of bison and livestock, and generate safety and property concerns from some people. Currently, we recommend a desired condition of 3,000-3,500 bison per decade with near equal abundance in each herd. Abundance of both herds can be affected using removals in the northern management area. Building evidence suggests that herd sizes of more than 3,000 northern and more than 1,500 central bison may be necessary to maintaining annual migrations where sufficient numbers of animals move beyond the northern park boundary to support removals that offset growth. However, populations of around 4,500 animals necessitate an annual removal of nearly 600 animals to stabilize population growth.

Table 8. Chances of meeting desired conditions under no action and scenarios of removing 600 (300 female, 165 male, 135 calf) bison each of the next three winters. Scenarios 2-4 represent increasing uncertainty caused by unknowns in winter severity and numbers of central and northern herd animals moving to the northern management area. Numbers in parentheses show changes (improvement more than 1.0, reduction less than 1.0) in chances of meeting desired conditions if management is implemented. For example, a value of (1.5) indicates that successful implementation of the management guideline increases our chances of meeting the desired condition by 1.5 times.

		No Action			**Scenario 2**			**Scenario 3**			**Scenario 4**		
	Condition	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
Central	1,000+ (end-of-winter)	87%	85%	83%	82% (1.0)	80% (1.0)	79% (1.0)	79% (0.91)	72% (0.85)	70% (0.84)	81% (0.93)	76% (0.89)	73% (0.88)
	65:100 – 150:100 male:female	66%	57%	53%	66% (1.0)	57% (1.0)	52% (1.0)	62% (0.94)	52% (0.91)	48% (0.91)	65% (0.98)	56% (0.98)	52% (0.98)
	28:100 – 50:100 juvenile:adult	59%	50%	46%	58% (1.0)	47% (1.0)	45% (1.0)	55% (0.93)	45% (0.90)	41% (0.89)	58% 0.98)	49% (0.98)	45% (0.98)
Northern	1,000+ (end-of-winter)	100%	100%	100%	100% (1.0)	100% (1.0)	99% (0.99)	100% (1.0)	100% (1.0)	99% (0.99)	100% (1.0)	100% (1.0)	100% (1.0)
	65:100 – 150:100 male:female	60%	61%	60%	62% (1.03)	60% (0.98)	53% (0.88)	62% (1.03)	61% (1.00)	53% (0.88)	61% (1.02)	61% (1.0)	58% (0.97)
	28:100 – 50:100 juvenile:adult	43%	47%	49%	46% (1.07)	49% (1.04)	43% (0.88)	46% (1.07)	49% (1.04)	47% (0.96)	45% (1.05)	48% (1.02)	49% (1.0)
Total	3,000-3,500 end of winter	5%	2%	1%	24% (4.8)	22% (11)	19% (19)	24% (4.8)	21% (10.5)	18% (18)	19% (3.8)	15% (7.5)	13% (13)

Table 9. Predicted average herd and population conditions under no action and scenarios of removing 600 (300 female, 165 male, 135 calf) bison each of the next three winters. Scenarios 2-4 represent increasing uncertainty caused by unknowns in winter severity and numbers of central and northern herd animals moving to the northern management area.

		No Action			**Scenario 2**			**Scenario 3**			**Scenario 4**		
	Condition	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
Central	end-of-winter herd size	1,232	1,290	1,359	1,232	1,290	1,359	1,177	1,188	1,225	1,187	1,206	1,228
	male:100 female	126	125	125	126	125	125	132	135	135	127	128	127
	juvenile:100 adult	31	30	30	31	30	30	30	28	28	31	29	29
Northern	herd size	3,078	3,761	4,528	2,511	2,491	2,433	2,577	2,625	2,630	2,681	2,865	3,040
	male:100 female	71	78	84	73	84	97	73	84	95	73	80	89
	juvenile:100 adult	52	49	47	51	48	43	51	48	43	51	49	45
Total	end-of-winter size	4,336	5,092	5,960	3,762	3,832	3,857	3,777	3,853	3,903	3,905	4,124	4,352

LITERATURE CITED

Geremia, C., P. J. White, R. L. Wallen, F. G. R. Watson, J. J. Treanor, J. Borkowski, C. S. Potter, and R. L. Crabtree. 2011. Predicting bison migration out of Yellowstone National Park using bayesian models. PLoS ONE 6:e16848.

Hess, S. 2002. Aerial survey methodology for bison population estimation in Yellowstone National Park. Dissertation, Montana State University, Bozeman, Montana.

Horne, J. S., E. O. Garton, S. M. Krone, and J. S. Lewis. 2007. Analyzing animal movements using Brownian bridges. Ecology 88:2354-2363.

Meagher, M. 1973. The bison of Yellowstone National Park. National Park Service Scientific Monograph Series No. 1.

Meagher, M. 1989. Range expansion by bison of Yellowstone National Park. Journal of Mammalogy 70:670-675.

U.S. Department of the Interior, National Park Service [USDI], and U.S. Department of Agriculture, Forest Service, Animal and Plant Health Inspection Service [USDA]. 2000a. Final environmental impact statement for the Interagency Bison Management Plan for the State of Montana and Yellowstone National Park. Washington, D.C.

USDI and USDA. 2000b. Record of decision for final environmental impact statement and bison management plan for the state of Montana and Yellowstone National Park. Washington, D.C.

Plumb, G. E., P. J. White, M. B. Coughenour, and R. L. Wallen. 2009. Carrying capacity, migration, and dispersal in Yellowstone bison. Biological Conservation 142:2377-2387.

Rhyan, J. C., K. Aune, T. Roffe, D. Ewalt, S. Hennager, T. Gidlewski, S. Olsen, and R. Clarke. 2009. Pathogenesis and epidemiology of brucellosis in Yellowstone bison: serologic and culture results from adult females and their progeny. Journal of Wildlife Diseases 45:729-739.

Sawyer, H., M. J. Kauffman, R. M. Nielson, and J. S. Horne. 2009. Identifying and prioritizing ungulate migration routes for landscape-level conservation. Ecological Applications 19:2016-2025.

Treanor, J. J., C. Geremia, P. Crowley, J. J. Cox, P. J. White, R. L. Wallen, and D. W. Blanton. 2011. Estimating probabilities of active brucellosis infection in Yellowstone bison through quantitative serology and tissue culture. Journal of Applied Ecology 48:1324-1332.

Walters, C., and C. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71:2060-2068.

White, P. J., R. L. Wallen, C. Geremia, J. J. Treanor, and D. W. Blanton. 2011. Management of Yellowstone bison and brucellosis transmission risk- Implications for conservation and restoration. Biological Conservation 144:1322-1334.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2007. Adaptive management: the U.S. Department of Interior technical guide. Adaptive management working group, U.S. Department of the Interior, Washington, D.C.