

Table 1. Parameters affecting the forage intake and energy balance of the herbivores. \* denotes x,y pairs defining a function: x1,y1,x2,y2, etc. In the case of an 0-1 “effect” function, the resultant 0-1 effect is multiplied by the maximum rate.

Parameter	Bison	Elk
Maximum forage intake rate kg kg <sup>-1</sup> d <sup>-1</sup>	0.035	0.035
Effect of forage biomass (g m <sup>-2</sup> ) on intake rate*	0,0, 156,1	0,0, 92,1
Effect of snow depth (cm) on intake rate*	50,1, 85,0.15,150.,0	30,1,65.,015,85,0
Reach height (m)	1.5	2.25
Effect of forage digestibility on intake*	0.3,0.7, 0.6,1	0.3,0.7, 0.6,1
Multiplier on standard cattle digestibility vs. standard digestibility of forage*	0.48,1.25,0.65,1.0	not used
Body sizes - newborn, yearlings, mature female, mature male (kg)	160,300,450,650	114,162,210,330
Minimum and maximum energy use rates (MJ kg <sup>-1</sup> d <sup>-1</sup> )	0.09, 0.15	0.1,0.16
Effect of condition on voluntary energy use rate (Enuserate)*	0,0, 0.5,1	0.1,0, 0.5,1
Gestation costs	as in Robbins (1983), Hobbs (1985)	as in Robbins (1983), Hobbs (1985)
Travel costs	based on time and movement rate, as in Hobbs (1985), equation of Robbins (1984)	based on time and movement rate, as in Hobbs (1989), equation of Robbins (1983)
Hours spent traveling by month	1.2,2.0,2.2,2.9,1.5,2.0, 2.0,2.0,2.0,1.5,1.5,1.2	0.9,0.9,1.1,1.1,1.1,3.1, 3.1,3.1,3.1,3.1,3.1,0.9
Hours spent eating by month	16.1,16.1,17.0,17.4,15.5,16.0, 160.,16.0,160.,16.0,16.0,17.9	11,11,11.5,12,13,13.5, 14,13,13,12,11.5,11
Fraction of travel in unbroken, broken, and no snow when traveling in snow	0.06,0.74,0.20	0.33,0.77,0.0
Walking rates while traveling and feeding m min <sup>-1</sup>	60,3	60,3
Lower critical temperature for thermoregulation °C	-40	-10

Table 2. Dietary compositions for bison and elk in different seasons. Coarse (mesic) grasses in the model would include reedgrass, timothy, sedges, and rushes. Fine-grasses in the model include upland grasses as well as Dechampsia (hairgrass).

Species	Season	Fine-leaved Grass	Reed Grass, Timothy	Deschampsia	Grasses Total	Sedges	Rushes	Forbs	Sage	Willow	Other Shrub	Conifer	Aspen	Source
Bison	Winter 1962-70				34	56	9	tr	1	0	0	tr		Singer and Norland 1994
Bison	Winter 1985-88	39	11	2	53	32	11	1	0.1	0.1	1.2	0.3		Singer and Norland 1994
Bison	Winter								0.1		1.2			Singer and Renkin 1995
Bison	Winter				34	56	9	tr	1	1		tr		Meagher 1973
Bison	Spring				46	49	1	3	tr	tr		tr		Meagher 1973
Bison	Summer				32	50	8	6	0	1		tr		Meagher 1973
Bison	Fall				30	37	32	tr	0	tr		tr		Meagher 1973
Elk	Winter 1962-70				79	2	tr	3	2	3	6	5		Singer and Norland 1994
Elk	Winter 1985-88	63	9	3	75	8	3	3	4	0.1	4	3		Singer and Norland 1994
Elk	Winter								3.8		4			Singer and Renkin 1995
Elk	Winter				97	tr	tr	tr	tr		tr	1	tr	Vore 1990
Elk	Fall				46			34			18	6		Marcum 1979
Elk	Summer				26	22		21			9		7	Marcum 1979

Table 3. Tissue nitrogen and dry matter digestibility (DMD) parameters used in the model, for each plant type.

Parameter	Fine-leaved Grass	Dryland Forb	Coarse Grass	Alpine Grass	Sagebrush	Deciduous Shrub	Vaccinium	Willow	Conifer
Max, min leaf N:B ratio	0.025, 0.012	0.03, 0.017	0.022, 0.011	0.026, 0.018	0.023, 0.02	0.019, 0.011	0.016, 0.013	0.0375, 0.022	0.012, 0.011
Dead leaf N:B ratio	0.0075	0.013	0.006	0.0065	0.007	0.0074	0.007	0.008	0.0045
Current annual growth twig N:B ratio					0.007	0.009	0.007	0.007	0.0036
Minimum, maximum live leaf DMD	0.5, 0.7	0.57, 0.76	0.55, 0.7	0.42, 0.71	0.45, 0.7	0.38, 0.7	0.24, 0.28	0.35, 0.55	0.35, 0.35
Dead leaf DMD	0.48	0.45	0.43	0.42	0.45	0.38	0.24	0.5	0.35
Stem DMD	0.4	0.27	0.4	0.4	0.35	0.35	0.24	0.35	0.25
CAG twig DMD					0.5	0.35	0.24	0.49	0.3

Table 4. Simulated bison winter diet composition.

	Years	Fine Grass	Coarse Mesic Sedge/ Grass	Coarse Forest Grass/ Sedge	Forb
<b>Northern</b>	1969-1981	0.387	0.544	0.048	0.021
	1982-1993	0.430	0.352	0.195	0.024
	1994-2001	0.270	0.333	0.380	0.016
<b>Central</b>	1969-1981	0.488	0.380	0.103	0.028
	1982-1993	0.493	0.364	0.105	0.036
	1994-2001	0.426	0.403	0.139	0.031

Table 5. Simulated bison summer diet composition.

	Years	Fine Grass	Coarse Mesic Sedge/ Grass	Coarse Forest Grass/ Sedge	Forb
<b>Northern</b>	1969-1981	0.273	0.443	0.260	0.024
	1982-1993	0.362	0.389	0.221	0.028
	1994-2001	0.290	0.439	0.248	0.023
<b>Central</b>	1969-1981	0.407	0.477	0.087	0.029
	1982-1993	0.381	0.471	0.116	0.032
	1994-2001	0.303	0.533	0.139	0.025

Table 6. Simulated winter elk diets.

	Years	Fine Grass	Coarse Mesic Sedge/ Grass	Coarse Forest Grass/ Sedge	Forb	Sage- brush spp.	Decid- uous Shrubs	Vaccin- ium spp.	Willow
<b>Northern</b>	1969- 1981	0.491	0.136	0.058	0.074	0.023	0.142	0.026	0.050
	1982- 1993	0.466	0.116	0.094	0.077	0.020	0.130	0.046	0.032
	1994- 2001	0.446	0.12	0.112	0.076	0.021	0.124	0.049	0.039
<b>Madison</b>	1969- 1981	0.473	0.264	0.006	0.071	0.000	0.045	0.023	0.117
	1982- 1993	0.427	0.277	0.005	0.076	0.000	0.051	0.023	0.137
	1994- 2001	0.395	0.33	0.004	0.080	0.000	0.043	0.028	0.116

Table 7. Simulated summer elk diets.

	Years	Fine Grass	Coarse Mesic Sedge/ Grass	Coarse Forest Grass/S edge	Forb	Sage- brush spp.	Decid- uous Shrubs	Vaccin- ium spp.	Willow
<b>North</b>	1969- 1981	0.520	0.167	0.054	0.110	0.003	0.118	0.007	0.023
	1982- 1993	0.459	0.161	0.088	0.111	0.003	0.134	0.015	0.025
	1994- 2001	0.440	0.182	0.096	0.111	0.003	0.124	0.012	0.028
<b>Madison</b>	1969- 1981	0.171	0.637	0.002	0.055	0.000	0.020	0.001	0.114
	1982- 1993	0.155	0.630	0.003	0.058	0.000	0.029	0.001	0.117
	1994- 2001	0.093	0.742	0.003	0.046	0.000	0.018	0.000	0.091

Table 8. Derivation of bison nominal age/sex class survival rates and initial age/sex class distribution from age/sex class data in Pac and Frey (1991) and Gogan et al. 1998). Numbers are the fractions of the total population in each sex/age class. "Calculated" survival rates are age/sex class specific survival rates calculated from the mean age/sex class distribution. "Simplified" survival rates were calculated as the mean survival rate for age classes 1-5, 6-10, and 10-15. A "smoothed" series of survival rates was calculated by applying the simplified rates to each age class.

Observed Age Class Distributions							Survival Rate					
Age	Pac and Frey		Gogan et al.		Mean		Calculated		Simplified		Smoothed	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male		
0	0.094	0.068	0.072	0.173	0.083	0.121						
1	0.05	0.085	0.082	0.096	0.066	0.091	0.795	0.751	0.855	0.798	0.777	0.704
2	0.053	0.075	0.056	0.114	0.055	0.095	0.833	1.044	0.855	0.798	0.604	0.495
3	0.05	0.085	0.051	0.018	0.051	0.052	0.918	0.545	0.855	0.798	0.469	0.349
4	0.023	0.105	0.036	0.014	0.03	0.06	0.584	1.000	0.855	0.798	0.364	0.245
5	0.03	0.06	0.046	0.018	0.038	0.039	1.000	0.650	0.855	0.798	0.283	0.173
6	0.053	0.015	0.036	0.014	0.045	0.015	1.000	0.372	0.833	0.655	0.220	0.122
7	0.023	0.01	0.036	0	0.03	0.005	0.656	0.345	0.833	0.655	0.171	0.086
8	0.02	0.025	0.031	0.009	0.026	0.017	0.864	1.000	0.833	0.655	0.132	0.060
9	0.007	0.01	0.026	0.009	0.017	0.01	0.647	0.559	0.833	0.655	0.103	0.043
10	0.007	0.015	0.026	0.009	0.017	0.012	1.000	1.000	0.833	0.655	0.080	0.030
11	0	0.005	0.01	0	0.005	0.003	0.303	0.208	0.626	0.604	0.062	0.021
12	0.007	0.01	0	0	0.004	0.005	0.700	1.000	0.626	0.604	0.048	0.015
13	0	0	0.01	0	0.005	0	1.000	0.000	0.626	0.604	0.038	0.010
14	0	0	0.005	0	0.003	0	0.500		0.626		0.029	0.007
15	0.01	0	0.005	0	0.008	0			0.626		0.022	0.005
4+yrs	0.18	0.26	0.267	0.073	0.228	0.166						
Total	0.427	0.568	0.527	0.473	0.483	0.525						



Table 9. Summary statistics based upon Table 8.

	<b>Meagher 1971</b>	<b>Pac and Frey 1991</b>
<b>Calf Ratio</b>	0.353	0.228
<b>Prop. +4 yrs Bulls</b>	0.220	0.255
<b>Prop. Bulls</b>	0.280	0.415
<b>Bull Ratio</b>	0.635	1.465

Table 10. Population parameters for elk and bison. Age class 1 refers to animals 0-1 years old, 2 refers to 1-2 years old, etc. Maximum survivorship is the fraction of animals that survive that age class. Fecundity is births per female per year.

Age	Bison			Elk		
	Maximum survivorship - females	Maximum survivorship - males	Fecundity	Maximum survivorship - females	Maximum survivorship - males	Fecundity
1	0.958	0.910	0	1.0	0.988	0
2	0.958	0.910	0.05	1.0	0.988	0.07
3	0.958	0.910	0.30	1.0	0.988	0.56
4	0.958	0.910	0.55	1.0	0.988	0.56
5	0.958	0.910	0.60	1.0	0.988	0.56
6	0.958	0.747	0.80	1.0	0.805	0.56
7	0.958	0.747	0.87	1.0	0.805	0.56
8	0.958	0.747	0.87	1.0	0.805	0.54
9	0.958	0.747	0.87	1.0	0.805	0.54
10	0.958	0.747	0.87	1.0	0.805	0.54
11	0.701	0.689	0.87	1.0	0.592	0.54
12	0.701	0.689	0.87	1.0	0.592	0.54
13	0.701	0.689	0.87	0.963	0.592	0.54
14	0.701	0	0.87	0.963	0.592	0.54
15	0.701		0.87	0.963	0.592	0.54
16	0.701		0	0.873	0	0.22
17	0		0	0.873	0	0.22
18				0.731	0	0.22
19				0.731	0	0.22
20				0.731	0	0.22
21				0.731	0	0.22
22				0	0	0

Table 11. Alternative age/sex class distributions for bison. Model 1 assumed 0.84 survival for female, 0.737 for male, with 58:42 female:male birth sex ratio. Model 2 assumed a 50:50 birth sex ratio. Model 3 assumed 58:42 female:male birth sex ratio and a 4+yr old bull:cow ratio observed in 1970 (Taper et al. 2002).

Age	Model 1		Model 2		Model 3	
	Female	Male	Female	Male	Female	Male
0	0.116	0.084	0.104	0.104	0.111	0.08
1	0.098	0.062	0.087	0.076	0.093	0.059
2	0.082	0.046	0.073	0.056	0.078	0.044
3	0.069	0.034	0.061	0.042	0.066	0.032
4	0.058	0.025	0.052	0.031	0.055	0.037
5	0.049	0.018	0.043	0.023	0.046	0.027
6	0.041	0.013	0.036	0.017	0.039	0.02
7	0.034	0.01	0.031	0.012	0.033	0.015
8	0.029	0.007	0.026	0.009	0.027	0.011
9	0.024	0.005	0.022	0.007	0.023	0.008
10	0.02	0.004	0.018	0.005	0.019	0.006
11	0.017	0.003	0.015	0.004	0.016	0.004
12	0.014	0.002	0.013	0.003	0.014	0.003
13	0.012	0.002	0.011	0.002	0.011	0.002
14	0.01	0.001	0.009	0.001	0.01	0.002
15	0.009	0.001	0.008	0.001	0.008	0.001
<b>Total</b>	<b>0.682</b>	<b>0.318</b>	<b>0.609</b>	<b>0.391</b>	<b>0.649</b>	<b>0.351</b>

Table 12. Summary statistics based upon values in Table 11.

	Model 1	Model 2	Model 3
<b>Calf Ratio</b>	0.294	0.341	0.428
<b>Prop. 4+ yr Bulls</b>	0.092	0.113	0.136
<b>Prop. Bulls</b>	0.135	0.186	0.211
<b>Bull Ratio</b>	0.366	0.506	0.474

Table 13. Elk sex/age class distribution. Total - mean totals in Houston tables 5.6,5.7. Fraction of total - totals fractionally distributed. Adjusted fractions - total male numbers adjusted to obtain bull ratio of 0.36 as observed in 1971-75, then fraction of total numbers recalculated. Normalized - adjusted male plus female fractions normalized so they sum to 1.0. Calf numbers were set to obtain a calf/cow ratio of 0.45 and a sex ratio of 0.66:0.44). Final result gives observed calf and bull ratios and male:female newborn calf ratio.

Age	Total		Fraction of Total		Normalized	
	Female	Male	Female	Male	Female	Male
0	25.84	17.23	0.11	0.073	0.1373	0.0914
1	13.14	27.17	0.056	0.116	0.0699	0.0708
2	13.14	13.67	0.056	0.058	0.0699	0.0356
3	10.29	7.4	0.044	0.031	0.0547	0.0193
4	8.57	12.6	0.036	0.054	0.0456	0.0328
5	7.71	8.6	0.033	0.037	0.041	0.0224
6	7.43	8	0.032	0.034	0.0395	0.0208
7	10.14	7.6	0.043	0.032	0.0539	0.0198
8	8	5.4	0.034	0.023	0.0425	0.0141
9	7	0.6	0.03	0.003	0.0372	0.0016
10	1.67	0.12	0.007	0.001	0.0089	0.0003
11	1.67	0.12	0.007	0.001	0.0089	0.0003
12	1.67	0.12	0.007	0.001	0.0089	0.0003
13	1.67	0.12	0.007	0.001	0.0089	0.0003
14	1.67	0.12	0.007	0.001	0.0089	0.0003
15	1.67	0.12	0.007	0.001	0.0089	0.0003
16	0.79		0.003		0.0042	
17	0.79		0.003		0.0042	
18	0.79		0.003		0.0042	
19	0.79		0.003		0.0042	
20	0.79		0.003		0.0042	
21	0.79		0.003		0.0042	
<b>Total</b>	125.98	108.97	0.536	0.464	0.67	0.33

Table 14. Sightability-corrected numbers of bison and elk, and numbers of bison and elk removed either due to management or hunting. Years are numbered such that 1969 includes the winter of 1969/69, for example. Bison data 1969-1997 are from Taper et al. (2000). Bison data 1998-2000 are from Hess (2001). Elk data 1969-1978 from Houston (1982), 1979-1990 from Coughenour and Singer (1996b), 1991-2000 from Taper et al. 2000) Sightability corrections are explained in text.

Year	Bison				Elk	
	Pre-removal Number		Removals		Pre-Removal Number	Removals
	Northern	Central	Northern	Central	Northern	
1969	322	597	0	0	5714	50
1970	470	680	0	0	7409	50
1971	700	733	0	0	9625	45
1972	504	874	0	0	10884	75
1973	630	1040	0	0	13287	154
1974	620	1094	0	0	14064	210
1975	396	1064	8	0	16735	147
1976	336	1081	0	0	16148	1529
1977	594	1272	0	0	14352	219
1978	339	1566	0	0	16945	1063
1979	562	1805	0	0	14572	342
1980	453	2047	0	0		661
1981	429	2349	0	0	13300	376
1982	704	1935	0	0	21532	1359
1983	627	1902	0	0		1881
1984	918	1899	0	0		2061
1985	840	2181	88	0		1571
1986	919	2350	41	16	22028	1498
1987	925	2706	0	7	24244	1739
1988	1127	2713	2	37	23182	579
1989	755	2486	567	2	22535	2896
1990	703	3036	1	3	21940	1299
1991	962	3051	0	14	16344	1005
1992	740	3511	249	22	19648	4515
1993	1091	3347	0	79	23619	2055
1994	1000	3836	0	5	25373	572
1995	1001	3655	307	119	22592	2538
1996	1182	3327	26	344	22411	1706
1997	944	2352	725	358	16644	3320
2/1998	430	1672			15569	1440
8/1998	590	1579	0	11		
1/1999	416	1733			14887	1120
8/1999	565	1914	0	94		
1/2000	518	2303			19258	1102
8/2000	654	2212	0	0		
2/2002	818	2769				

Table 15. Regression analyses of observed numbers of bison outside park boundary on west and north sides derived from GIS analysis of M. Meagher's data, against simulated mean snow depth (cm) on the bison winter range and number of animals in either the northern or central subpopulations, respectively, using data from 1980-1997 for months of January-May.

Y Variable	Population Sizes Included	Equation - X Variables	N	R <sup>2</sup>	P
Out-West	All	$-6.3 + 0.83 \cdot \text{Snow}$	33	0.13	0.04
	All	$-51.1 + 0.89 \cdot \text{Pop}$	40	0.09	0.06
	All	$-36.6 + 0.001 \cdot \text{Snow} \cdot \text{Pop}$	33	0.33	0.001
	>1500	$-17.08 + 1.39 \cdot \text{Snow}$	17	0.28	0.03
	<1500	Snow (NS)	16	0.04	0.45
Out-North	All	$-19.7 + 0.78 \cdot \text{Snow}$	33	0.27	0.002
	All	$63.5 - 0.07 \cdot \text{Pop}$	40	0.07	0.1
	All	Snow*Pop (NS)	33	0	0.80
	>600	$-16.7 + 0.57 \cdot \text{Snow}$	9	0.44	0.05
	<600	$-21.7 + 0.86 \cdot \text{Snow}$	24	0.26	0.01

Table 16. Mean numbers of animals total, and in different management areas in January-April in years 20-50 of eight 50-year simulations in which there was no culling or hunting. Numbers are means for January-April except where indicated.

		Mean	SD	Min	Max
Northern Bison	Number	2417	281	1820	3530
	Out	102	46	9	231
	Eagle Crk.	300	151	0	781
Central Bison	Number	3776	518	2430	5630
	Out Jan.-Apr.	46	63	0	450
	Out May	329	266	0	1486
Northern Elk	Number	23628	5405	12000	42900
	Out	3248	2257	0	12514
	Eagle Crk.	906	732	0	3139



Table 17. Mean numbers of animals total, in different management areas in January-April, and mean numbers removed in years 20-50 of eight 50- year simulations in which 45% of bison outside the park were removed per month, or elk were hunted at a rate of 9% per month in the management zones from November thru May (bison) or December-February (elk). Numbers are means for January-April except where indicated. Removals are totals for the year.

		Mean	SD	Min	Max
<b>Northern Bison</b>	<b>Number</b>	473	81	288	779
	<b>Out</b>	18	11	0	53
	<b>Eagle Crk.</b>	37	35	0	164
	<b>Removal</b>	77	33	17	214
<b>Central Bison</b>	<b>Number</b>	1946	156	1440	2470
	<b>Out Jan.-Apr.</b>	2	9	0	112
	<b>Out May</b>	554	226	125	1102
	<b>Removal</b>	95	70	40	382
<b>Northern Elk</b>	<b>Number</b>	18476	3463	9510	29300
	<b>Out</b>	2231	1768	0	7948
	<b>Eagle Crk.</b>	624	580	0	2950
	<b>Hunted</b>	1690	848	284	4230

Table 18. Mean numbers of animals total, in different management areas, and mean numbers removed in eight 50-year simulations in which no bison were removed while elk were hunted in order to maintain their numbers at about 5,000.

		Mean	SD	Min	Max
Northern Bison	Number	3107	461	1930	4840
	Out	39	52	0	281
	Eagle Crk.	107	154	0	852
Central Bison	Number	4474	738	2790	6840
	Out	49	128	0	1335
Northern Elk	Number	5061	489	3820	6370
	Out	98	272	0	2383
	Eagle Crk.	29	82	0	731
	Hunted	790	296	0	1750