# Supplementary Material

**GEEM parameters**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Grass | Shrub | Elk | Sage Grouse | Mule Deer | Prairie Dog | Grass-hopper | Jackrabbit | Prong-horn | Ferret | Coyote | Swift Fox |
| Basal metabolism parameter (kcal) | 4,190.05  (naive)  3,796  (complex) | 21,129.2  (naïve)  13,227 (complex) | 1,581,212  (48) | 42110  (54) | 568,967  (53) | 15,026  (49) | 12131  (50) | 54,388  (51) | 335,584  (52) | 28,622  (55) | 90,656  (57) | 22,180  (56) |
| Stress parameter |  |  | 0.75 | 1.00 | 1.25 |  |  |  |  |  |  |  |
| Energy content per kg of biomass (kcal) | 4,200  (25) | 5068  (26) |  |  | 1,890  (30) | 1,806  (27) | 2,186  (28) | 1323.2  (29) |  |  |  |  |
| Biomass consumption at the undisturbed scenario (kg) | 0.0101649  (13) | 0.0579607  (14) | 2,620  (15) | 25  (21) | 639.8  (20) | 8.637  (16) | 11.35  (17) | 99.39  (grass)  28.40  (shrub)  (18) | 209  (19) | 79.50  (22) | 20.08  (mule deer)  240.9 (jackrabbit)  (24) | 26.83  (prairie dog)  9.86  (grasshopper)  (23) |
| Density (individuals per ha) | 115,200  (1) | 80,000  (2) | 0.0496  (3) | 0.025  (9) | 0.09  (8) | 24.5  (4) | 61  (5) | 3  (6) | 0.3  (7) | 0.02  (10) | 0.0027  (12) | 0.0568  (11) |
| Life span (years) | 5  (33) | 42  (34) | 14  (35) | 9  (41) | 10  (40) | 6  (36) | 2  (37) | 7  (38) | 10  (39) | 7  (42) | 6  (44) | 6  (43) |
| Average weight (kg) | (58) | (58) | 315.5  (59) | 1.5  (63) | 123.8  (59) | 1.13  (60) | 0.1943  (61) | 3.2  (62) | 46.4  (59) | 1.05  (64) | 10  (66) | 2.1  (65) |
| Predation risk | 0.110806 (naïve)  0.0141738  (complex) | 12.8272  (naïve)  0.0133488  (complex) |  |  | 0.005  (45) | 0.005  (45) | 0.005  (45) | 0.005  (45) |  |  |  |  |
| Leaf area parameter (m2/kg) | 10  (46) | 7.1  (47) |  |  |  |  |  |  |  |  |  |  |
| Extinction parameter | 0.3  (31) | 0.4  (32) |  |  |  |  |  |  |  |  |  |  |
| Parameter of the willingness to supply | 0.0111887  (elk)  0.0596103  (grasshopper)  0.0256718  (jackrabbit)  0.018219  (prairie dog) | 0.000324506 (sage grouse)  0.0298972  (mule deer)  0.00325545  (pronghorn)  0.044232  (jackrabbit) |  |  | 0.0238097  (coyote) | 0.0220818  (Ferret)  0.0211652  (Swift fox) | 0.00272519  (swift fox) | 0.0191795  (coyote) |  |  |  |  |
| Respiration parameter | 4.8177\*107  (naïve)  4.36462\*107  (complex) | 7.47215\*106  (naïve)  4.67759\*106  (complex) | 0.460699 | 134.751 (naïve) | 2.80332 | 417.875 | 189.427 | 8.13841 | 15.3652 | 9.05792 | 2.86559 | 41.0128 |
| Energy expenditure price (kcal/kg) | 44,488  (naïve)  54,428  (complex) | 18,530.1  (naïve)  67,767.5  (complex) | 2,992.51  (grass) | 1,564.48 (shrub) | 3,264.14  (shrub) | 108.088 (grass) | 1,854.43  (grass) | 3,262.94  (grass)  4,419.82  (shrub) | 1841.3 (shrub) | 1,076.86  (prairie dog) | 1,484.45  (mule deer)  601.25  (jackrabbit) | 1,190.41 (grasshopper) 462.422  (prairie dog) |
| Minimum nitrogen requirement | 4.11092  (naïve)  3.20773  (complex) | 11.7505  (naïve)  2.62302  (complex) |  |  |  |  |  |  |  |  |  |  |

References of Table:

0. The sun’s energy is 150,182 kcal m-2 year-1, assuming a glucose efficiency parameter of 32%.

1. From studies of Wyoming big sagebrush and mountain big sagebrush (Artemisia tridentata) communities in south east Oregon that contain the native grasses common to Wyoming: Idaho fescue (Festuca idahoensis), prairie junegrass (Koeleria macrantha), bluebunch wheatgrass (Pseudoroegneria spicata), Thurber's needlegrass (Achnatherum thurberianum), needle and thread (Hesperostipa comata), squirreltail (Elymus elymoides), and Sandberg bluegrass (Poa secunda). Davies and Bates (2010, p. 464) report grass densities of both communities and we use an average of 11.52 individual (ind) plants m-2 or 115200 ind ha-1.

2. An average of Wyoming big sagebrush density (1.1 ind m-2) and mountain big sagebrush (0.5 ind m-2) was used to obtain 8,000 ind ha-2 (Davies and Bates, 2010, p. 464).

3. Stewart, Bowyer, Dick, Johnson and Kie (2005) state a high and low population density of 4.51 elk km-2 5.41 elk km-2. The mean value of approximately 4.96 elk km-2 is used here, which translates to 0.0496 elk ha-1.

4. Severson and Plumb (1998) estimate that prairie dog densities range from 8 to 41 ha-1. An average of 24.5 prairie dogs ha-1 is used.

5. Kemp and Dennis (1993) use annual adult rangeland grasshopper data from Montana (1951-1991) and find that densities fluctuate between 6.1-6.3 grasshoppers per m2. This translates into 61,000 ind ha-1.

6. Studies have reported jackrabbit densities between 0.02 ha-1 and 35 ha-1 (Anderson and Shumar, 1986; Fagerstone, Lavoie and Grith, 1980; Fagerstone and Ramey, 1996), where the highest density estimates are usually observed around agricultural lands. The density estimate used is 3 ha-1.

7. Yoakum (2004) reports a pronghorn density for Wyoming of 3.0 ind km-2, or 0.03 ha-1.

8. BLM lands hold over 323,748.5 ha of crucial range for 85,000 mule deer within the great divide resource management area (Biodiversity Conservation Alliance, 2005). This translates to 0.2625 mule deer ha-1.

9. A study of the Hart Mountain National Antelope Refuge in Lake County, Oregon revealed a sage grouse density in the 1980s of 2.5 birds km-2 which is converted to 0.025 grouse ha-1 (Pyle and Crawford, 1996).

10. Forrest, Clark, Richardson and Campbell (1985) estimate that 1 ferret occupies 50 ha of prairie dog colony at Meeteetse, Wyoming. This translates to 0.02 ferret ha-1.

11. Lindberg (1986) reports swift fox densities of 8.0, 32.3, and 3.9 ind mile-2 for Albany, Laramie, and Carbon counties respectively. The average of the three figures is calculated and converted to 0.0568 ind ha-1.

12. Estimates of coyote population densities range from 0.14 km-2 to 0.39 km-2 (Henke and Bryant, 1999; Pyrah, 1984). An average density of 0.27 coyote km-2 is used and converted to 0.0027 coyote ha-1.

13. Using data from reference (1), the average biomass production of grasses over both communities was 300 kg ha-1 (Davies and Bates, 2010, p. 464). We assumed this was grazed with a moderate intensity as defined by cattle grazing and note that ungrazed blue gamma has 1.68 more standing biomass than grazed blue gamma (Hart and Ashby, 1998, p. 394). Applying this yields 504 kg ha-1. Also, Hart and Ashby (1998) report blue gamma biomass of 667 kg ha-1 which is averaged with data from Davies and Bates (2010) to obtain 585.5 kg ha-1. We convert to wet weight with a ratio of wet weight to dry weight ratio of 2 (Dahl, Judge, Gallo and England, 1993) to obtain 1,171 kg ha-1. Finally, dividing by the number of plants yields 0.01016 kg ind-1.

14. Severson and May (1967) report annual forage production for Wyoming big sagebrush to be 206.85 lb DW acre-1. This is converted to (206.85 lb DW acre-1) (2 WW DW-1) (0.453592 kg lb-1) (2.471 acre ha-1) (ha (8000 ind)-1) = 0.05796 kg WW ind-1.

15. Estimates of daily forage intake for elk range from 7 kg days-1 (Fraser, 2004; Jiang and Hudson, 1992) to 9.5 kg days-1 (Hudson and Nietfeld, 1985). Using the average, annual forage intake is 3011 kg. Ngugi, Powell, Hinds and Olson (1992) study diet composition of grazing and browsing animals in South central Wyoming 198 and report that elk diet consisted 84% to 90% of grass. We used the average of 87% to scale elk demand for grass down to 2620 kg years-1.

16. Yearly forage consumption estimates of a prairie dog range from 10.95 kg to 11.339 kg (Hansen and Cavender, 1973; Hyde, 1981). Grasses make up from 60% to 95% of prairie dogs diet (Natural Resource Conservation, 2003; Uresk, 1984; Summers and Linder, 1978). The average yearly consumption (11.1445 kg) and average diet composition (77.5%) is used to calculate forage consumption of 8.6369875 kg year-1.

17. Onsager (1984) reports that a theoretical “average" rangeland grasshopper weighs 81.6 mg (dry weight) in the adult stage and consumes 53 mg of forage per day in the adult stage. Grasshoppers are short-lived (one year for all stages) and no adults survive more than 90 days (Onsager, 1984). We used the 90 days, or 0.25 years, as the longevity for consumption and calculate forage consumed by an individual as (53 mg days-1) (90 days) (kg 1000000 mg-1) = 0.00477 kg years-1. This is likely a high estimate given the high longevity, although we do not include consumption in the instar stages. This consumption is converted to WW using a WW DW ratio of 2.38. To convert wet weight (WD) to dry weight (DW) we used formulas that convert body length to both WW and DW for Orthoptera (Sage, 1982, Table 1). For body length we used the average of five important destructive species (Onsager, 1984) and the average of both sexes' lengths from Capinera, Scott and Walker (2004). The WW DW ratio used is 2.38. Therefore, 81.6 DW = 194.31 mg WW =.00019431 kg ind-1 and 0.19431 unit-1. The consumption per individuals is converted to population units by (0.00477 kg DW ind-1 years-1) (2.38 WW DW-1) (1000 ind unit-1) = 11.35 kg WW unit-1 years-1.

18. Hansen (1972) estimates an intake rate of 0.389 kg days-1 for jackrabbits. This is extrapolated to an intake of 141.985 kg years-1. For shrub-steppe and mixed shrub-grass communities, diet composition of 70% grass and 20% shrub is used (Johnson, 1979; Johnson and Anderson, 1984). This is translated to an annual intake of 99.39 kg (of grasses) and 28.40 kg (of shrubs).

19. Severson, May and Hepworth (1980) report pronghorn daily forage intake rate to be 0.8 kg ind-1, which is converted to 292 kg ind-1 years-1. Annual antelope diet consisted from 65% to 78% sagebrush in South central Wyoming and in the Red Desert (Olsen and Hansen, 1977; Severson et al., 1980). The average is used to scale down annual forage requirement to 209 kg.

20. Alldredge et al. (1974) report mean forage intake rate of 0.998 kg (45.36 kg)-1 day-1 for Colorado mule deer. Using the weight, 123.8 kg, total intake is calculated: 994.2 kg years-1. Shrubs have been documented to comprise between 46% and 82.7% of mule deer diets in various studies (Anthony and Smith, 1977; Hansen and Reid, 1975). The mean value of 64.35% is used to scale the forage requirement down to 639.8 kg year-1.

21. Savory (1978) studies food intake of red grouse in Scotland and reports that annual intake vary from 18 kg to 25 kg (both in terms of dry weight). The higher estimate is taken to be a reasonable approximation of the food intake of sage grouse.

22. Prairie dogs comprised 87% to 91% of ferrets' diet in existing studies (Campbell, Clark, Richardson, Forrest and Houston, 1987; Sheets and Linder, 1972). Farrell and Wood (1968) predict a prey requirement of 0.22 g (g body mass)-1 days-1, which is converted to 0.00022 kg (0.001 kg body mass)-1 days-1. For an adult ferret of 1.1 kg, daily prey requirement is then 0.242 kg. We assume 90% of this annual requirement is from prairie dogs, or 79.497 kg.

23. Kilgore (1969) reports that average food consumption of a swift fox is about 200 g days-1 which is converted to 73 kg years-1. Uresk and Sharps (1986) report that 49% of swift fox's diet consists of mammals and 27% insects. Prairie dogs comprised about 75% of the mammals (0.75 (0.49) (73 kg years-1) 26.83 kg years-1), and insects were almost all grasshoppers and beetles. We arbitrarily assigned half of insects to grasshoppers ((0.5) (0.27) (73 kg years-1) 9.86 kg years-1).

24. Huegel and Rongstad (1985) report a daily consumption of 1.1 kg for an adult male coyote weighing 10.8 kg, which translates to a total consumption of 401.5 kg years-1. Smith (1979) reports that mule deer and 199 jackrabbits comprised 5% and 63% of coyote diet. The relative diet frequency of 5% for mule deer and 60% for jackrabbits is used in keeping with most of the coyote food studies (Bowyer, McKenna and Shea, 1983; Henke and Bryant, 1999). Thus coyote derive 20.08 kg years-1 and 240.9 kg years-1 of biomass from mule deer and jackrabbits, respectively.

25. From Kelsey, Nelson, Smith and Peiper (1973, p. 293).

26. Dietz (1972) reports a gross energy content of 5.068 kcal g-1 for sagebrush from South Dakota. This is converted to 5068 kcal kg-1.

27. Powell and Clark (1985) find that the average prairie dog is 841 g with a gross energy percentage of 6.13 kcal g-1 DW, which is the equivalent of 6,130 kcal kg-1 DW. Using the conversion 3.394 WW DW (Golley, 1960) yields 1,806 kcal kg-1 WW.

28. From Wiegert (1965) the caloric value for grasshoppers is 5203 cal g-1 or 5203 kcal kg-1 in DW. Using 2.38 WW DW ratio yields 2186 kcal kg-1.

29. Collopy (1986) reports a caloric content of black-tailed jackrabbits of 5.54 kJ g-1, or 1,323.21 kcal kg-1.

30. The caloric content of wet deer tissue is 1,890 kcal kg-1 (Laundre, 2005; Ackerman, Lindzey and Hemker, 1986).

31. The extinction coefficient is low for vertically inclined leaves (for example, 0.3-0.5 for grasses), but higher for a more horizontal leaf arrangement (Lambers, Chapin and Pons, 2006, p. 26).

32. Light extinction for shrub formations is higher than for grasses. We use 0.4.

33. Perennials are assumed to have 5 years average longevity (Walker, Kinzig and Langridge, 1999, p. 102).

34. In a Wyoming big sagebrush community in Wyoming the plants ranged from 26 to 57 years of age. Average age reported of 42 years is used (Sturges, 1977).

35. The average lifespan for an elk is 14 to 16 years for males and 15 to 17 years for females (Zachow, 1997). The lower value for males of 14 years is used.

36. Male prairie dogs have an average lifespan of 3 to 5 years in the wild and female prairie dogs sometimes live as long as 8 years (Hoogland, Angell, Daley and Radcliffe, 1987; Hoogland, 1996). A lifespan of 6 is used.

37. Grasshoppers are short-lived (one year for all stages) and no adults survive more than 90 days (Onsager, 1984). We used 2 years.

38. Egoscue, Bittmenn and Petrovich (1970) report that a captive black-tailed jackrabbit lived for 6 years and 9 months. In calibration, 7 years is used as lifespan in the wild.

39. Pronghorns have an estimated lifespan of 5 to 15 years (Byers, 1997); we used the average of 10 years.

40. Maximum age for female mule deer range from 12 to 14 years, while for males it is 8 years (Pac, Mackie and Jorgensen, 1991; Mackie, Pac, Hamlin and Dusek, 1998; Mackie, Kie, Pac and Hamlin, 2003). A life span of 10 years is used.

41. Greater sage grouse can survive at least 9 years in the wild (Zablan, 1993; Stinson, Hays and Schroeder, 2004).

42. The average lifespan for black-footed ferrets is 6 to 8 years (Wolf, Wildt, Vargas, Marinari, Kreeger, Ottinger and Howard, 2000). The average value of 7 years is used.

43. Gedir, Everest and Moehrenschlager (2004) report an average lifespan of 6 to 8 years for swift foxes: 6 years is used.

44. The average life span of coyotes is 5 to 6 years in the wild (Coates et al., n.d.; Bekoff, 1982).

45. We assumed a predation risk of 0.005 for all herbivore species.

46. Approximately the middle of the range for the inverse of g m-2 (Jurik and Kleibenstein, 2000, p. 58).

47. Reich, Ellsworth and Walters (1998) report that mean specific leaf area for evergreen shrubs is 71 cm2 g-1, or 7.1 m2 kg-1.

48. Brody, Procter and Ashworth (1934) obtained M = 70:5 as the power function relationship between daily metabolic rate in kcal per day (M) and body weight in kg () for mammals. Using a weight of 315.5 kg, total metabolic energy requirement is about 1,756,902 kcal year-1. Because 90% of elk's diet is accounted for in the food web, the basal metabolism requirement is scaled down to 1,581,212 kcal year-1.

49. Using the power function and a weight of 0.680 kg (DesertUSA, nd), total metabolic energy requirement 19388.47 kcal years-1 is calculated. Because 77.5% of prairie dog's diet is accounted for in the food web, the basal metabolism requirement is scaled down to 15026.06 kcal year-1.

50. Use the formula (Wiegert, 1965, Table 3) where is consumed oxygen and is mg DW, yields mm3 O2 h-1 grasshopper-1. Thus, (Bailey and Mukerji, 1977).

51. Using the power function relationship and a jackrabbit weight of 3.2 kg (Fagerstone and Ramey, 1996), total metabolic energy requirement is 6,0431.32 kcal years-1. This is scaled down to 54388.19 kcal years-1 because only 90% of a jackrabbit's diet is accounted for in the food web.

52. Using a weight of 315.5 kg in the power function, total metabolic energy requirement is about 430,235 kcal years-1. Because 78% of pronghorn's diet is accounted, the basal metabolism requirement is scaled down to 335,584 kcal years-1.

53. Using the power function and the average mule deer weight 123.8 kg, the metabolic energy requirement is about 884,176 kcal years-1. Because 64.35% of a deer's diet is accounted for in the food web, the basal metabolism requirement is scaled down to 568,967 kcal years-1.

54. Brody and Procter (1932) obtained as the power function relationship between daily metabolic rate in kcal day-1 () and body weight in kg () for wild birds. Using the weight of an adult female sage grouse of 1.5 kg (Remington and Braun, 1988), total metabolic energy requirement of 42,109.62 kcal years-1 is calculated.

55. Powell and Clark (1985) report that basal metabolic rate (BMR) for Mustela species is 16% greater than mammals in general. They use BMR = kcal h-1 or 31,803 kcal years-1. In the model 90% of a ferret's diet is accounted for, and the BMR is scaled down to 28,622 kcal years-1.

56. Using the power function and the average swift fox weight of 2.10 kg (Harrison, 2003), the total metabolic energy requirement is 44,359.92 kcal years-1. About 50% of a swift fox's diet is accounted for between prairie dogs and grasshoppers, so BMR is scaled down to 22,179.96 kcal year-1.

57. Using the power function relationship and an average coyote weight of 10 kg (Golightly and Ohmert, 1984), the total metabolic energy requirement is 139,470.38 kcal years-1. Because 65% of a coyote's diet is accounted for in the food web, the energy requirement is scaled down to 90,655.75 kcal years-1.

58. If the biomass accumulation represents only the 46.5% of the total weight, the other 53.5% of comes from the weight of the roots (Bakker and Wilson, 2001).

59. Weight is an average of the ranges of male and female weights from Whitaker (1980).

60. Prairie dogs weigh 1.5 to 3 lbs (DesertUSA, nd). We use the lower value, 1.5 lb. or 0.68 kg.

61. Onsager (1984) reports that a theoretical "average" rangeland grasshopper weighs 81.6 mg (dry weight) in the adult stage This consumption is converted to WW using a WW DW ratio of 2.38. The wet weight (0.0000816 kg DW) (2.38 WW DW ) = 0.1943 kg WW.

62. Jackrabbit weight is taken from Fagerstone and Ramey (1996).

63. Remington and Braun (1988).

64. Hygnstrom and Virchow (1994) report that adult male ferrets weigh between 0.9 and 1.2 kg; an average of 1.05 is used here.

65. Swift fox weight is an average from Harrison (2003).

66. The average weight of a coyote is 10 kg (Golightly and Ohmert, 1984).

**Nitrogen parameters**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Layer | Soil layer depth (m) | Available nitrogen (kg/ha) | Proportion of nitrogen uptake of grass’ roots | Proportion of nitrogen uptake of shrub’s roots |
| Naïve and Complex | Naïve / Complex |
| 1 | 0 – 0.15 | 2.45\*108 | 56% | 31% / 8% |
| 2 | 0.15 – 0.3 | 1.59\*108 | 24% | 20% / 43% |
| 3 | 0.3- - 0.46 | 1.06\*108 | 9% | 18% / 17% |
| 4 | 0.46 – 0.61 | 7.83\*107 | 4% | 13% / 14% |
| 5 | 0.61 – 0.91 | 1.09\*108 | 7% | 12% / 12% |
| 6 | 0.91- 1 .22 | 6.54\*107 | 0 | 4% |
| 7 | 1.22 – 1.52 | 5.35\*107 | 0 | 1% |
| 8 | 1.52-1.83 | 5.16\*107 | 0 | 0.1% |

More information on the sources of the GEEM and nitrogen parameters can be found in Hussain and Tshchirhart (2013) and Cisneros-Pineda et al. (2020).

**Supplemental Material References**

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