Scoping the Consistency of Sage-grouse Habitat Use

AFTER 2 DECADES OF CHANGE

PREPARED BY

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Background

Greater sage-grouse habitat, including critical habitat, was identified and mapped using species location and environmental data from nearly two decades ago. Landscape changes have occurred, including vegetation transitions, crop conversion, increases and reductions in oil and gas and other built infrastructure. Population sizes have also declined, prompting the translocation of sage-grouse from Montana into the Alberta population to increase its size and genetic diversity. In combination, these changes have the potential to alter the patterns of habitat use by this smaller and mixed-origin flock and it is unclear whether existing habitat maps still represent areas used by contemporary flocks. These habitat maps are a central element in a spatially explicit population model (using the HexSim platform; based on Heinrichs et al., 2018, 2019) that projects the return on conservation actions and investments for this species. An understanding of how well the original habitat and population inputs approximate recent population states and habitat use will influence decisions of how to use, interpret, and update the HexSim model.

OBJECTIVES

Project Tasks: Part A) Assess the degree to which older habitat selection maps predict recent habitat use locations of translocated grouse; Part B) Create an inventory of HexSim model inputs that rely on habitat and population data from the early 2000s and identify parameters that may be evaluated or updated with translocation data.

PART A: EVALUATE (DIS)AGREEMENT AMONG TRANSLOCATION RECORDS AND HABITAT MAPS

Approach: We overlaid seasonal locations of translocated grouse on habitat layers and quantified the proportion of use locations in each resource selection classification bin. We assessed the consistency among the observed (translocation locations) and expected (RSF bin) distributions using map visualizations, use-available ratio comparisons, Kolmogorov–Smirnov tests for comparing distributions, and other simple statistics.

Methods: Translocated bird location data were provided by Alberta Environment and Parks as a geodatabase that describes the locations of 112 sage-grouse that were translocated from Montana to Alberta between 2011 and 2019. We filtered the translocated sage-grouse data records to identify subsets for different analyses, using the following criteria (see Appendix for more information):

- Season: Nest (date of nest), brood-rearing (day off nest to 45 days), or winter (Nov. 1-Mar. 15; Carpenter et. al., 2010)
- In/out map area of interest: Only used locations that overlapped with the map being evaluated in each analysis
- Time since translocation: Only used locations occurring >4 weeks since release for nesting hens; 8 weeks for non-nesting hens. All season-selected data met this requirement by default.
- Removed locations associated with:
    - Inaccurate or low-quality coordinate fixes: Accuracy > 1km, or few messages
    - Males (n=3)
    - Locations after mortality or transmitter failure

- All remaining data were pooled across hens, release years, and years.

Habitat data included:

1. Aldridge nest occurrence (Aldridge and Boyce 2007); nesting
2. Aldridge brood occurrence (Aldridge and Boyce 2007); summer
3. Carpenter winter occurrence (Carpenter *et. al.* 2010); winter
4. Critical habitat (Environment Canada 2013); nesting but relevant for all seasons of habitat use

We evaluated the consistency of recent sage-grouse locations (2011-2019) with the areas predicted to be suitable by resource selection function maps during, three distinct behavioral phases, nesting, brood rearing, and winter. Nest and brood occurrence models created by Aldridge and Boyce (2007) were developed in the Manyberries region of southern Alberta, and extrapolated to include the entire 9 township x 9 township area in extreme southeast Alberta (Fig 1; green). A winter occurrence model developed by Carpenter et al. (2010) in the Manyberries area and was not extrapolated beyond the development area (Fig 1; blue). A critical habitat model developed by Parks Canada (2010) and Environment Canada (Environment Canada 2013) modified the spatial inputs of the Aldridge and Boyce (2007) model and thresholded the map to characterize many of the locations used by birds in all three seasons. The critical habitat map is the only layer that extends into Saskatchewan (Fig.1; black). For each of the 4 RSF map evaluations, we present simple summaries of the number of locations, the results of statistical tests, and interpretation.

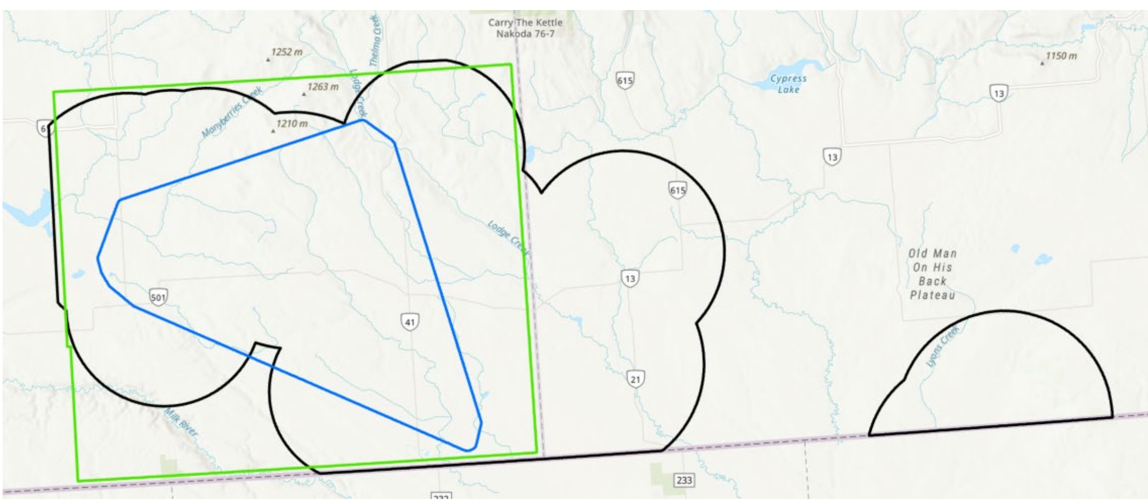

Figure 1: The spatial extents of the sage-grouse habitat models that were used to evaluate the consistency of habitat use by Greater sage-grouse translocated to southern Alberta in 2011, 2012, 2016, and 2019. The extent of the Aldridge & Boyce 2007 nest and brood occurrence models is shown in green, the extent of the winter occurrence model developed by Carpenter et al (2010) is shown in blue, and the Environment Canada critical habitat (Environment Canada 2013) extent is shown in black.

1. NESTING HABITAT: ALDRIDGE AND BOYCE 2007

Nesting locations for translocated grouse were characterized as a single nest site (as per Sage_Grouse_Nests in file geodatabase). All nest sites were confirmed by field personnel. We included both successful and failed nest locations as 'use' locations in assessing translocated nest locations relative to the Aldridge and Boyce (2007) nest occurrence model. We used the original RSF bin thresholds (uppercut values; Aldridge, pers comm. Mar. 3, 2022) to bin the continuous surface across its extrapolated extent. We layered the translocation nest coordinates on the RSF surface and extracted the pixel value associated with the use locations in the habitat map and summed the number of nests within each RSF bin. To characterize available locations, we summed the number of pixels in the habitat map that fell within each RSF bin. To characterize the strength of habitat selection by translocated birds, we calculated the area-adjusted selection ratio for each RSF bin (Table 2). We compared this ratio to the same metric created by Aldridge (pers comm. Mar. 3, 2022) for wild birds in the original study to assess congruence in habitat selection strength across the gradient of resource conditions. We also calculated the Spearman Rank statistic which evaluates the strength and direction of the relationship between the selection ratio of nests in each bin and the ordinal bin ranking. Lastly, we conducted a Kolmogorov–Smirnov test (K-S test), to determine whether the distribution of nest data among RSF bins differed between the original (Aldridge) nest data and the translocated hen nest data. As a simple exploration, we used a single factor ANOVA to assess if there was a relationship between nest survival for translocated hens and the pixel values in the suitability map.

Nest Data: Fifty-three translocated hens produced 80 nests in southern Alberta since their release. Seventy-eight of these were first nests and four were renesting attempts after the first nest was depredated. Of the 80 observed nests, 40 were successful in hatching at least one chick (Table 1). Seventeen hens nested over multiple years, nine in two years, six in three years, and one each in four and five years. A total of 42 hens (37.5%) nested the year they were translocated (22.2%, 15.4%, 52.6%, and 41.0% in 2011, 2012, 2016, and 2019, respectively). Two hens nested in Montana (one in 2019 depredated, one in 2020 successful; included in Table 1) and were excluded from both the assessment of nest occurrence models and nest survival.

Table 1: The number of nests initiated by translocated Greater sage-grouse hens in southern Alberta since the translocation efforts began in 2011.

Year (# birds released)	First nest	Successful first nest	Re-nests	Successful re-nest
2011 (9)	2	1	0	N/A
2012 (26)	4	0	0	N/A
2013	2	2	0	N/A
2014	3	1	2	1
2015	—	—	—	—
2016 (38)	19	9	1	1
2017	10	6	0	N/A
2018	5	3	0	N/A
2019 (39)	16	9	0	N/A
2020	10	4	0	N/A
2021	5	2	1	0
Total	78	38	4	2

Numbers in parentheses beside years indicate the number of hens released. No nest observations were available in 2015.

Nest Location-Map Evaluation: Over a third of translocated hen nests (37%; n = 35) occurred in good or high ranked habitat bins in the nest occurrence map that comprise approximately 21% of the landscape (Table 2, Fig.2). Visually, nests of translocated hens largely coincide with areas with higher probabilities of nest occurrence in the Aldridge and Boyce (2007) map (Fig.3). There was perfect ($\rho = 1.0$, $P = 0.001$) correlation between the ordinal bins and the ranked selection ratio associated with those bins. However, the 2-sample K-S test indicated a significant difference between the distribution of translocated nests in RSF bins compared to that of the training location data from Aldridge and Boyce (2007). The D statistic was greater than the critical D value, rejecting the hypotheses that the distributions are the same. Differences among the distributions was observed in the lower RSF bins (poor and low probability bins; Fig. 4), with approximately a third of nests (33%) of translocated hens occurring in these bins, compared to 10% of nests in the Aldridge and Boyce (2007) study. We found no statistical relationship between nest fate of translocated hens and their associated RSF pixel values in the relative probability of nest occurrence map (Aldridge and Boyce 2007; ANOVA $F = 0.079$, $P = 0.779$).

Table 2: Nests of translocated sage-grouse in nest occurrence bins, as defined by Aldridge and Boyce (2007).

Nest occurrence bin	Upper cut point	Translocated Nest count	Area cell count	Percent of nest sites	Percent of available	Selection ratio*	Scaled selection ratio	Scaled selection ratio
Source:	Aldridge and Boyce 2007	Translocated hens, intersected with habitat map						Aldridge and Boyce 2007
Poor	0.00223	1	355786	1.25	8.018	0.156	0.059	0.030
Low	0.01430	26	1899297	32.50	42.802	0.759	0.287	0.111
Moderate	0.02750	18	1247686	22.50	28.117	0.800	0.302	0.202
Good	0.03770	6	326605	7.50	7.360	**1.019**	0.385	0.455
High	0.765482	29	608061	36.25	13.703	**2.645**	1	1
Total		80	4437435	100.00	100			

*A selection ratio of 1 indicates habitat bins are being used as expected, values less than one bins of that class are being used less than expected, and values greater than one indicated bins that are used more than expected.

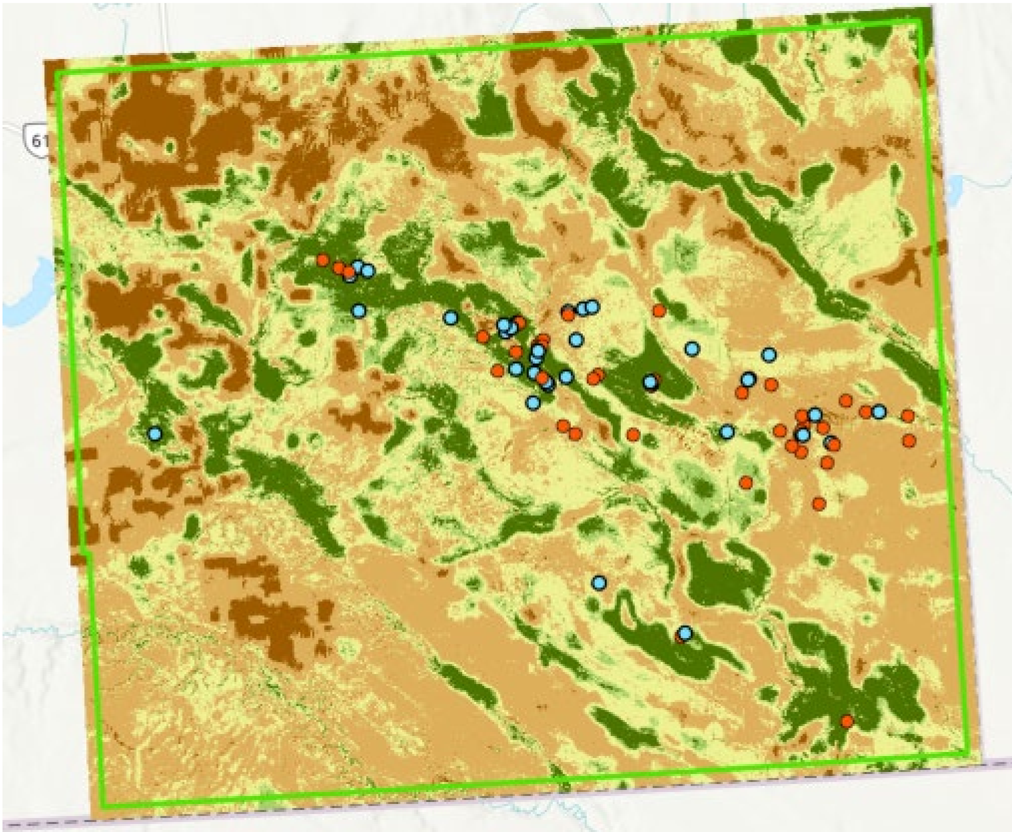

Figure 2: Aldridge and Boyce (2007) nest occurrence map, binned using defined cut points. Dark green indicates high relative probability of nest occurrence and dark brown indicates poor relative probability of nest occurrence. Nest sites of translocated sage-grouse (2011-2021) are shown with blue and red markers identifying successful and failed nests, respectively.

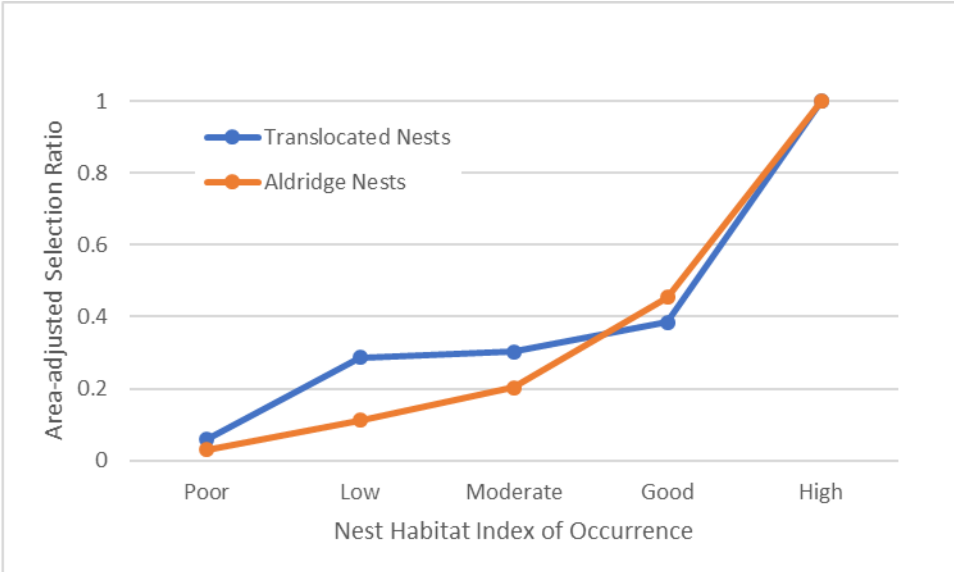

Figure 3: Scaled, area-adjusted habitat selection ratios associated with nests of translocated and wild (Aldridge and Boyce 2007) sage-grouse hens.

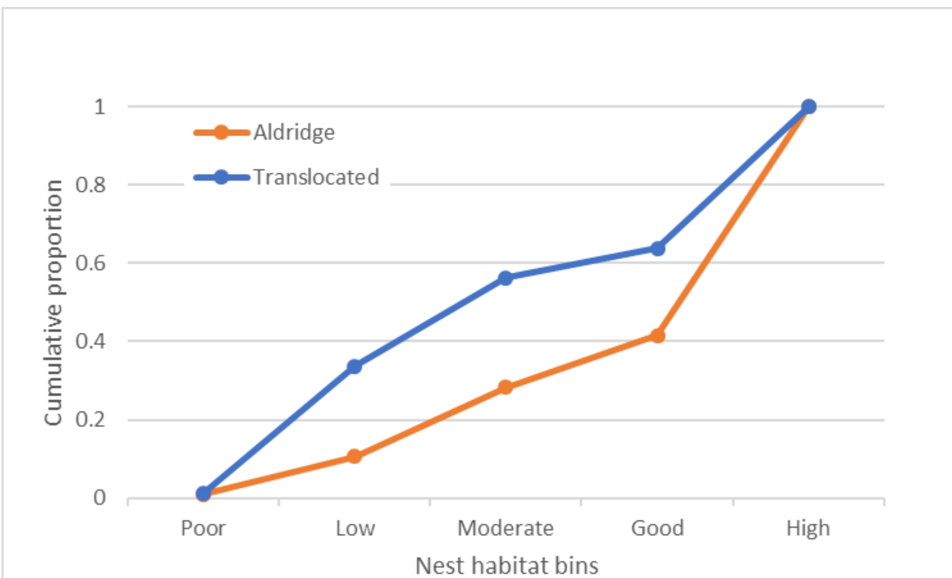

Figure 4: Kolmogorov–Smirnov test (K-S test) comparing the cumulative proportion of nests in habitat bins among translocated and wild hens (per Aldridge and Boyce 2007).

2. BROOD HABITAT: ALDRIDGE AND BOYCE 2007

Assessments of habitat use by translocated hens during the brood-rearing season followed the same methods as for nesting, using brood locations that were identified as occurring between the nest off date and the date of the 45-day post-hatch check. We used the original bin thresholds and location counts per bin (provided by Aldridge, pers. comm. Mar. 3, 2022) to compare area-adjusted habitat selection ratios among original and translocated bird studies. We conducted analyses using 1) all brood locations (non-rarified) and 2) a rarified data set which reduced locations to one location per hen every 2 days, between 6am and 6pm, replicating the field techniques used in Aldridge and Boyce (2007). We did not assess brood survival in reference to RSF pixel values.

Brood Data: We identified 7,919 brood locations by translocated hens that coincided with the Aldridge and Boyce (2007) brood-rearing habitat map extent (Fig. 1). These locations represented habitat use of 22 broods from 19 different hens (2011 – 2021). Twenty-two of 39 successful nests (56%) resulted in a successful brood (to 45 days). Rarifying the data reduced the number of locations for the brood habitat evaluation to 442. Every hen and brood were still represented in the reduced dataset.

Brood Location-Map Evaluation: Most brood locations associated with translocated hens were within good or high-ranked habitat bins (53% and 58% of the non-rarified and rarified data sets), in an area accounting for approximately 11% of the landscape (Table 3 and 4, Fig.5). Brood locations associated with translocated hens were roughly consistent with the spatial patterns of higher selection bins in Aldridge and Boyce (2007; Fig. 6). The selection ratios of non-rarified and rarified data sets were similar despite the reduction in sample size. In both datasets, there was high correlation ($\rho = 0.9$, $P = 0.05$) between ordinal bins and the ranked selection ratio associated with those bins. However, the 2-sample K-S tests indicated significant differences between the distribution of translocated nests in RSF bins compared to that of the training location data from Aldridge and Boyce (2007). We noted disagreement particularly in the lower 3 bins (Fig. 7). Approximately 40% of brood locations occurred in poor and low probability of occurrence bins, whereas Aldridge and Boyce (2007) had half as many brood locations in the same bins. We noted three broods that only resided in locations characterized as ‘poor.’ Additional evaluations are needed to better understand the unexpected use of these areas.

Table 3: Non-rarified brood locations of translocated sage-grouse, summarized in brood occurrence bins, as defined by Aldridge and Boyce (2007).

Brood occurrence bin	Upper cut point	Brood location count	Area cell count	Percent of brood locations	Percent of available	Selection ratio	Scaled selection ratio	Scaled selection ratio
Source:	Aldridge and Boyce 2007	Translocated hens, intersected with habitat map						Aldridge and Boyce 2007
Poor	0.8870	2412	2704284	30.458	64.983	0.469	0.059	0.020
Low	0.9614	1004	779209	12.678	18.724	0.677	0.085	0.052
Moderate	0.9750	257	225237	32.454	5.412	0.600	0.075	0.144
Good	0.9879	828	226835	10.4556	5.451	**1.918**	0.241	0.282
High	0.999905	3418	225992	43.162	5.430	**7.948**	1	1
Total		7919	4161557	100	100			

Table 4: Rarified brood locations of translocated sage-grouse, summarized in brood occurrence bins, as defined by Aldridge and Boyce (2007).

Brood occurrence bin	Upper cut point	Brood location count	Area cell count	Percent of brood locations	Percent of available	Selection ratio	Scaled selection ratio	Scaled selection ratio
Source:	Aldridge and Boyce 2007	Translocated hens, intersected with habitat map						Aldridge and Boyce 2007
Poor	0.8870	119	2704284	26.923	64.983	0.414	0.049	0.020
Low	0.9614	51	779209	11.538	18.724	0.616	0.072	0.052
Moderate	0.9750	14	225237	3.167	5.412	0.585	0.069	0.144
Good	0.9879	53	226835	11.991	5.451	**2.200**	0.258	0.282
High	0.999905	205	225992	46.380	5.430	**8.541**	1	1
Total		442	4161557	100	100			

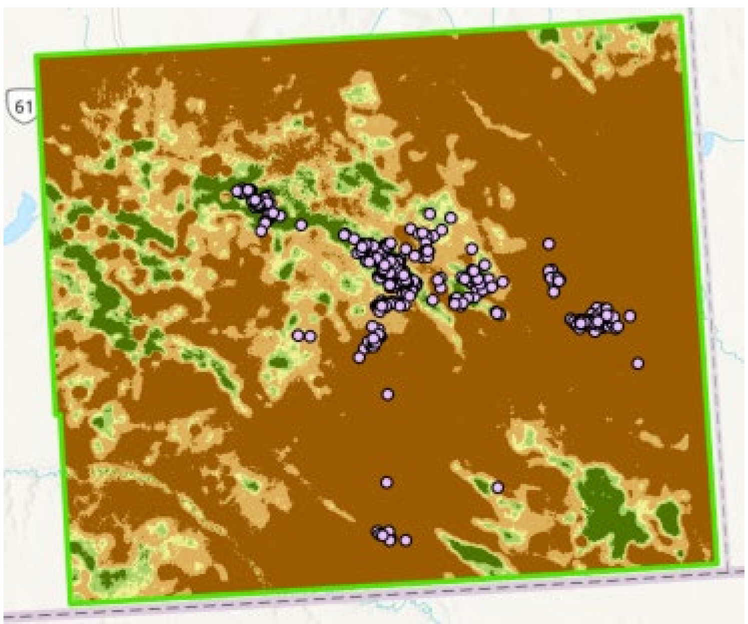

Figure 5: Aldridge and Boyce (2007) brood occurrence map (binned). Dark green indicates high relative probability of brood occurrence; dark brown indicates poor relative probability of brood occurrence. The rarified brood locations associated with translocated sage-grouse are shown in light purple.

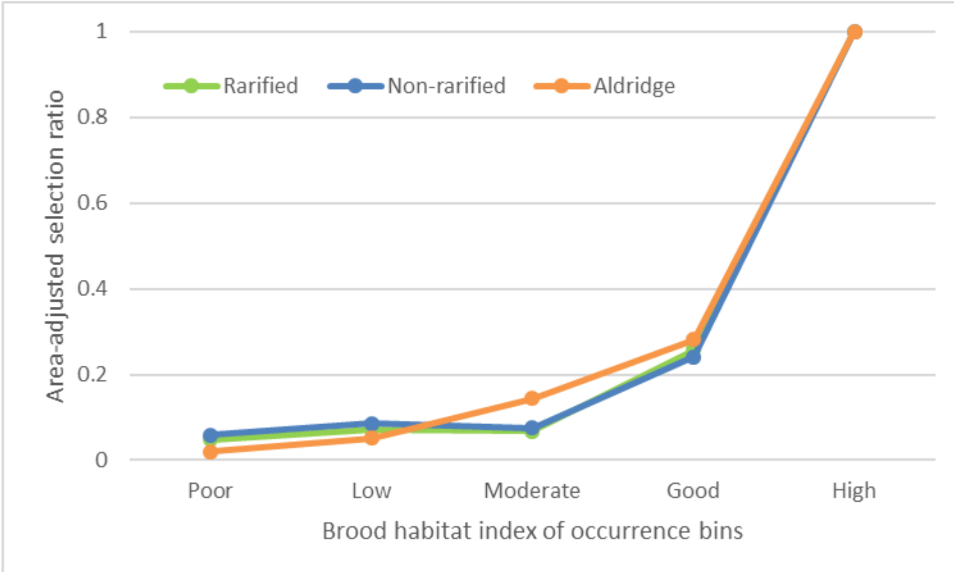

Figure 6: Scaled, area-adjusted habitat selection ratios of broods associated with translocated hens and wild sage-grouse broods (per Aldridge and Boyce 2007).

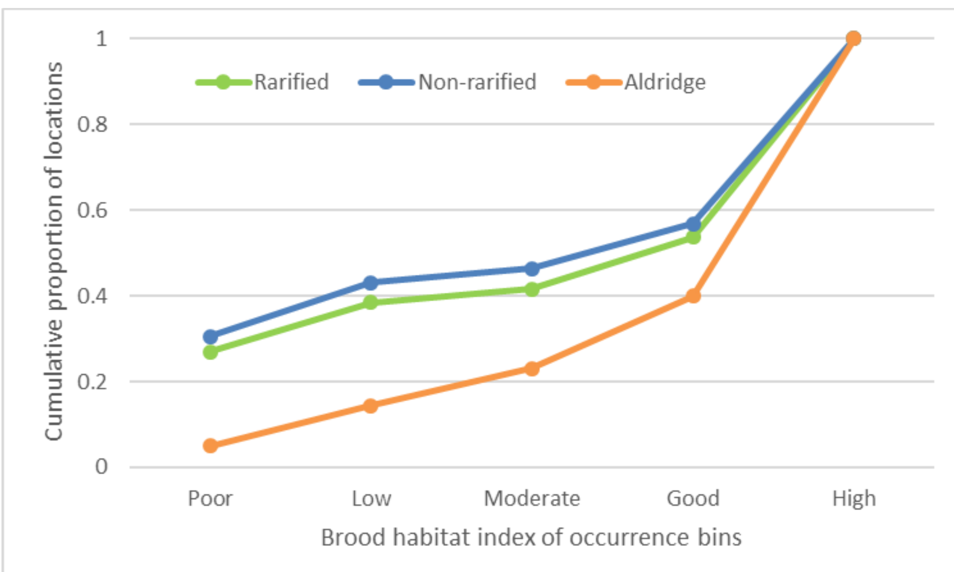

Figure 7: Kolmogorov–Smirnov test (K-S test) comparing the cumulative proportion of brood locations in habitat bins among translocated and wild hens (per Aldridge and Boyce 2007).

3. WINTER HABITAT: CARPENTER ET AL. 2010

Following Carpenter et al. 2010, we characterized winter locations as those falling between November 1 and March 15 and binned the winter continuous relative probability surface into 10 geometric bins. Carpenter reduced this to eight bins due to lack of evaluation data in each bin, but we lacked information to replicate this step and we retained all ten bins. We also lacked tallies of use locations in each RSF bins and could not calculate all metrics. Follow-on work could verify bin thresholds and obtain location records to support comparisons of selection ratios, and distribution of use locations (K-S test). We calculated the area-adjusted selection ratio and Spearman rank statistic as a partial assessment of consistency between RSF values and translocated bird use locations in winter. We conducted analyses using 1) all winter locations (non-rarified) and 2) a rarified data set which reduced locations to approximately one location per week, replicating field data collection (Carpenter et al. 2010).

Winter Data: We evaluated 54,344 winter locations of translocated hens that occupied areas in Alberta, Saskatchewan, and Montana. Twelve hens contributed locations over two winter seasons, five over three, and one each over 5 and 6 winter seasons. 40,515 locations from 46 translocated hens were within the Carpenter et. al., (2010) study area extent (Fig. 1). We further rarified these locations to approximate the field data collection methods of Carpenter et. al., (2010), resulting in 2,026 locations from 41 hens. The 5 hens that were excluded in the rarified dataset primarily occupied areas to the east of the Carpenter study area.

Winter Location-Map Evaluation: Just over half of the winter locations of translocated hens (56% and 55% of the non-rarified and rarified data sets) occurred in the highest ranked habitat bin (bin 10), which includes approximately 6% of the landscape (Tables 5 and 6, Fig. 8). Non-rarified and rarified datasets had virtually identical selection ratios (Fig. 9). Correlation between the ordinal bins (Carpenter et al. 2010) and the ranked selection ratio associated with those bins was high ($\rho = 0.964$, $P < 0.05$).

Table 5: Non-rarified winter (November 1 – March 15) locations of translocated sage-grouse hens in winter occurrence bins, derived by geometrically binning the Carpenter et al. (2010) continuous relative probability map.

Winter habitat bin	Upper cut point	Winter location count	Area cell count	Percent of winter locations	Percent of available	Selection ratio	Scaled selection ratio
1	0.001300	169	492105	8.3412	30.009	0.278	0.032
2	0.003969	46	210766	2.2700	12.852	0.177	0.020
3	0.009449	45	189797	2.2210	11.574	0.192	0.022
4	0.020704	53	152612	2.6160	9.306	0.281	0.032
5	0.043815	48	124103	2.3690	7.568	0.313	0.036
6	0.091275	54	104369	2.6650	6.364	0.419	0.048
7	0.188736	94	87316	4.6400	5.325	0.871	0.099
8	0.388874	116	78764	5.7260	4.803	1.192	0.136
9	0.799862	289	97318	14.2650	5.934	**2.404**	0.274
10	1	1112	102734	54.8860	6.265	**8.761**	1
Total		2026	1639884	100	100		

Table 6: Rarified winter (November 1 – March 15) locations of translocated sage-grouse hens in winter occurrence bins, derived by geometrically binning the Carpenter et al. (2010) continuous relative probability map.

Winter habitat bin	Upper cut point	Winter location count	Area cell count	Percent of winter locations	Percent of available	Selection ratio	Scaled selection ratio
1	0.001300	3230	492105	7.972	30.009	0.266	0.030
2	0.003969	889	210766	2.194	12.852	0.171	0.019
3	0.009449	915	189797	2.258	11.574	0.195	0.022
4	0.020704	1082	152612	2.671	9.306	0.287	0.032
5	0.043815	1041	124103	2.569	7.568	0.340	0.038
6	0.091275	1213	104369	2.994	6.364	0.470	0.053
7	0.188736	1766	87316	4.359	5.325	0.819	0.092
8	0.388874	2119	78764	5.230	4.803	1.089	0.122
9	0.799862	5593	97318	13.805	5.934	**2.326**	0.260
10	1	22667	102734	55.947	6.265	**8.931**	1
Total		40515	1639884	1	1		

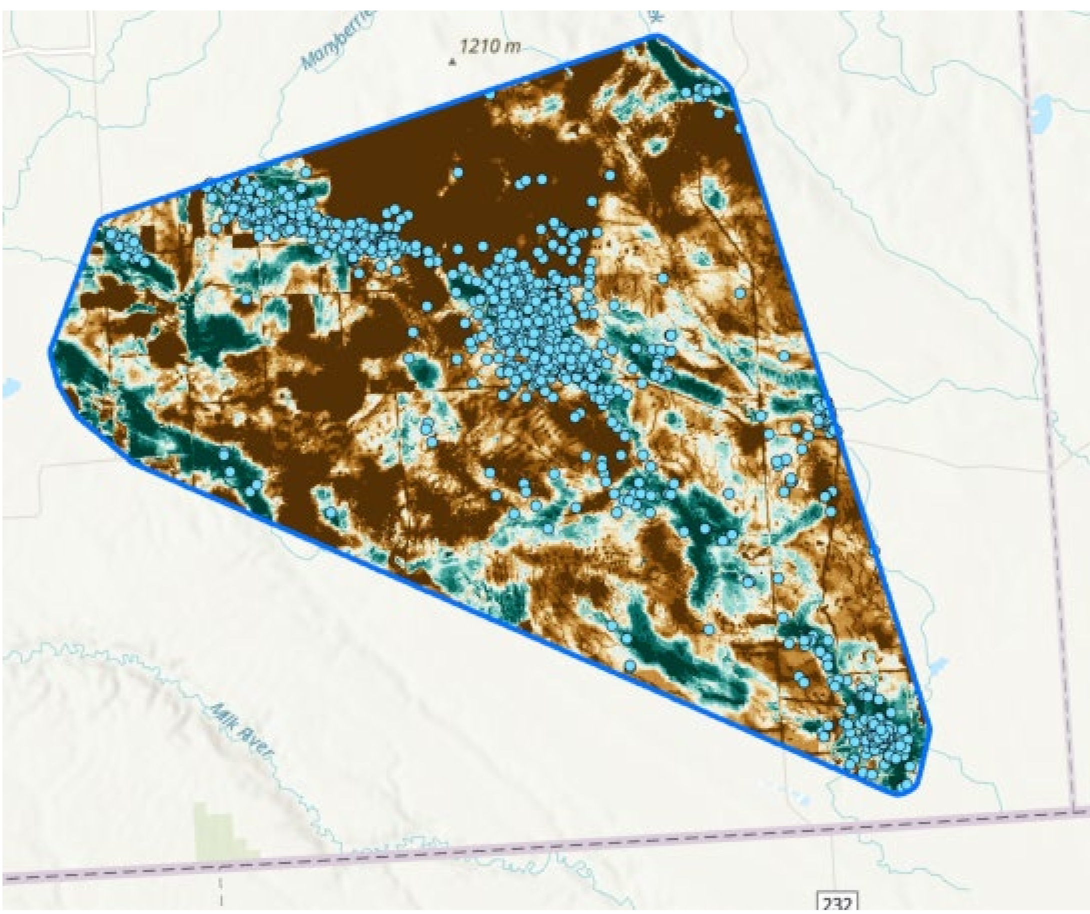

Figure 8: Carpenter et al. (2010) winter sage-grouse occurrence model, displayed in 10 geometric bins. Dark green indicates high relative probability of winter occurrence and dark brown indicates poor relative probability of winter occurrence. The rarified winter locations from translocated sage-grouse are shown in blue.

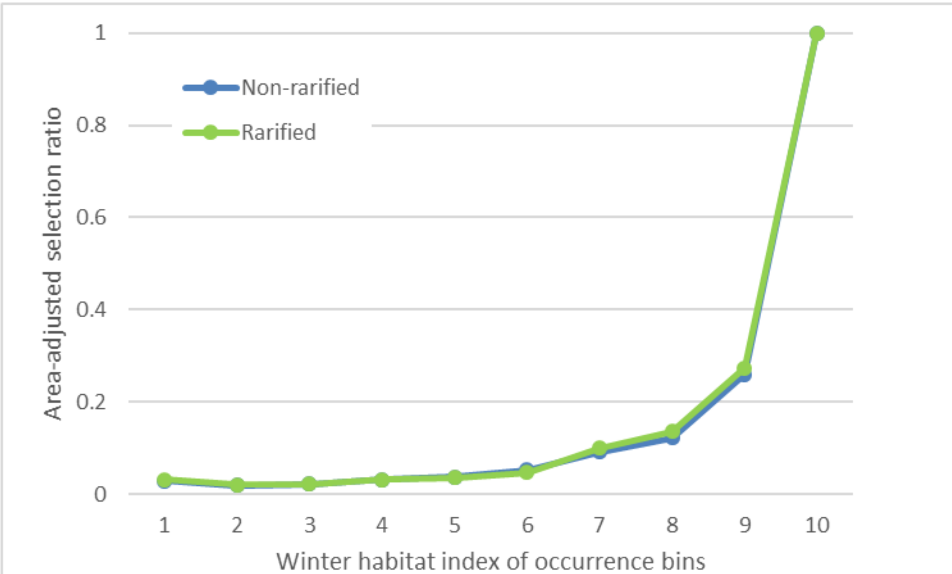

Figure 9: Scaled, area-adjusted habitat selection ratios of translocated sage-grouse winter locations for non-rarified and rarified datasets.

1. CRITICAL HABITAT (ENVIRONMENT CANADA 2013)

We assessed the congruency of translocated sage-grouse use locations with suitable habitat as characterized by the critical habitat layer (Environment Canada 2013). We iteratively evaluated agreement in use locations and higher suitability pixels using location data from each behavioral phase (nest, brood, and winter). We binned the continuous critical habitat surface in two ways, 1) at the critical habitat threshold and, 2) into 10 equal-area quantile bins. Using each binned surface, we calculated the number and proportion of locations captured within each bin. We calculated a spearman rank statistic to compare the ordinal bins to the rank selection ratio associated with each bin. We calculated statistics for the 1) full (non-rarified) and 2) rarified data sets for brood and winter. We additionally assessed the relationship between nest fate (success) and associated habitat pixel values using the continuous surface.

Nesting Location- Binary Map Evaluation: We binned the continuous critical habitat layer using the threshold identified by Parks Canada (2010; 0.3579) to classify critical habitat in the western range (AB and western SK). This threshold implicated 37.3% of the landscape as critical sage-grouse habitat (Figs. 1, 10). The majority of nests (62.5%; n = 80) were within critical habitat. Less than half of nests in critical habitat were successful at producing at least one chick (44.2%; 28.2% of all nests). Of the 30 nests that were in non-critical habitat, half (50%; n = 15) were successful. Location of nests inside or outside of critical habitat had no effect on nest fate (χ^2 = 0.120, not significant at P = 0.05). Similarly, nest fate was not associated with RSF pixel values in the continuous relative probability map (F = 0.191, P = 0.663).

Nesting Location-Quantile Binned Map Evaluation: We binned the continuous surface into 10 bins to make comparisons to the Aldridge and Boyce (2007) nesting model, from which the critical habitat was developed. If nest site selection was random, we would expect to observe roughly 10% of nests in each bin. Although we see this for lower bins (2-6), we found a disproportionate number of locations in bins 7 and 8 (Table 7, Fig. 11, Fig. 12), indicating stronger selection for resources characterized in these bins. There was a slight correlation among bin rank and nest site selection ($\rho = 0.690$, $P = 0.058$), with the largest discrepancies in the lower end bins. It was necessary to collapse the lower 3 of the 10 quantile bins as the spearman rank statistic requires at least 5 locations per bin.

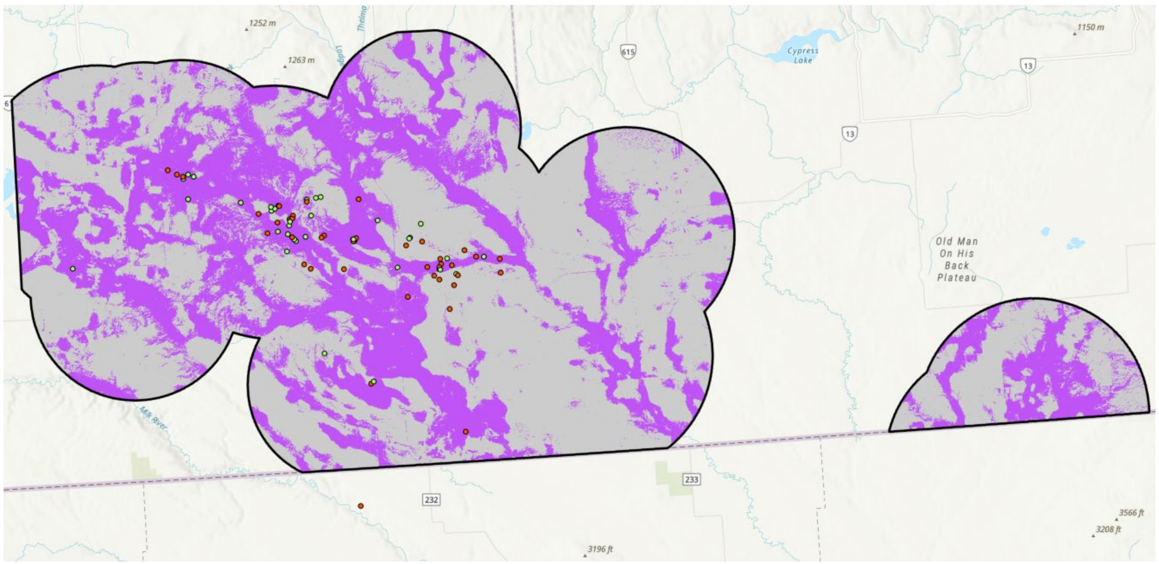

Figure 10: The binary critical habitat map (critical habitat, purple; non-critical habitat, gray; Environment Canada 2013). Nest sites of translocated sage-grouse (2011-2021) are displayed with green and red markers identifying successful and failed nests, respectively.

Table 7: Number of translocated sage-grouse nests occurring in critical habitat model bins.

EC critical habitat bin	Nest count	Area cell count	Percentage of Nests	Percentage of available	Selection ratio
1-3	9	1569276	11.250	29.373	0.383
4	8	568465	10.000	10.640	0.940
5	6	560402	7.500	10.489	0.715
6	7	558427	8.750	10.452	0.837
7	5	530248	6.250	9.925	0.630
8	7	522841	8.750	9.786	0.894
9	14	516936	17.500	9.676	**1.809**
10	24	515950	30.000	9.657	**3.106**
Total	80	5342545	100	100	

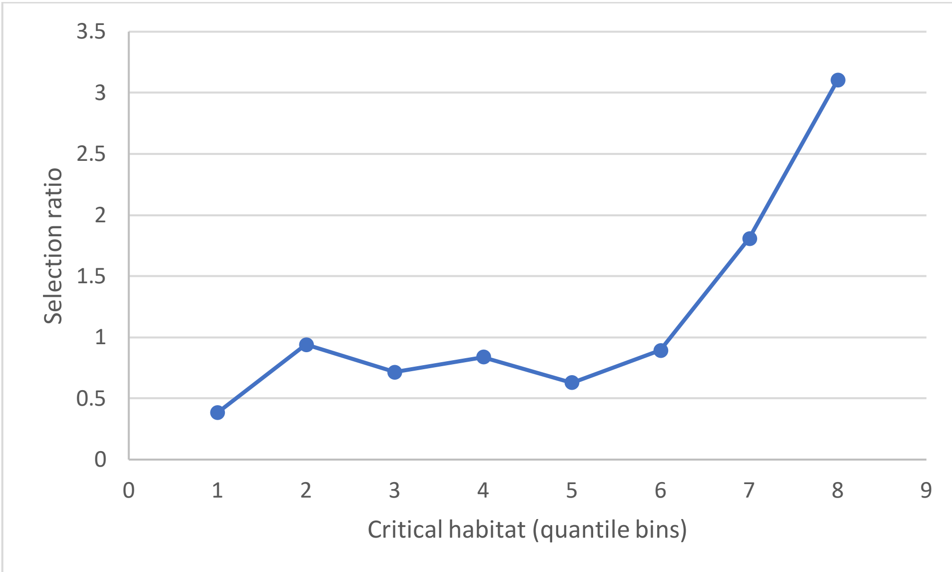

Figure 11: Nest site selection ratios of translocated sage-grouse hens, in quantile bins created from the critical habitat model (Environment Canada 2013). Bins 1-3 were combined due to lack of representation but are shown here as bin 1.

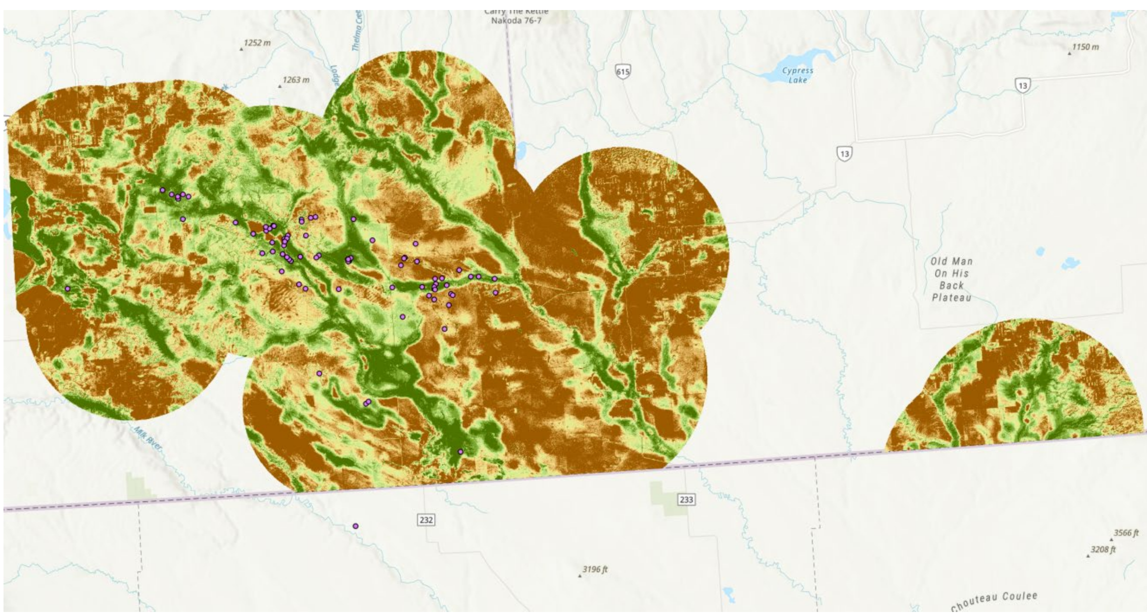

Figure 12: The quantile-binned habitat surface derived from the critical habitat model (Environment Canada 2013), displaying nest sites (2011-2021) of translocated sage-grouse hens. Habitat ranges from poor (dark brown) to high (dark green) relative probability of occurrence.

Brood Locations: We used the 7,912 brood locations that were within the critical habitat map extent to evaluate correspondence with this model. We retained the same 442 brood locations in the rarified dataset.

Brood Location- Binary Map Evaluation: The majority of brood locations were within critical habitat (i.e., above the critical habitat threshold; 65.7% and 67% for non-rarified and rarified datasets, respectively. Translocated birds selected for areas above the critical habitat threshold, with selection ratios of 1.763 and 1.795 for non-rarified and rarified data sets, respectively.

Brood Location- Quantile Binned Map Evaluation: We interpreted disproportionate increases in brood locations within a bin as habitat selection (Table 8; Fig. 13). For non-rarified and rarified data sets, locations were fewer than expected for bins 1-8 and greater than expected in bins 9 and 10. Visually, brood locations corresponded will with areas of higher selection in the critical habitat map (Figure 14) and captured more brood locations in visualized habitat than the Aldridge and Boyce 2007 map. We found a strong correlation between the ordinal bin and the ranked proportion of brood locations in each bin for both non-rarified and rarified datasets ($\rho = 0.867$, $P = 0.001$).

Table 8: Brood locations of translocated sage-grouse in critical habitat map bins, using quantiles to bin equal proportions of the landscape. The binned surface was derived from the Environment Canada critical habitat model (Environment Canada 2013).

Critical habitat bin	Area cell count	Proportion of available	Non-rarified brood location count	*Proportion non-rarified brood locations	Rarified brood location count	*Proportion rarified brood locations
1	506773	0.0949	478	0.060	21	0.048
2	514521	0.0963	221	0.028	13	0.029
3	547982	0.103	288	0.036	16	0.036
4	568465	0.106	377	0.048	24	0.054
5	560402	0.105	573	0.072	30	0.068
6	558427	0.105	657	0.083	36	0.081
7	530248	0.099	526	0.066	26	0.059
8	522841	0.098	637	0.081	29	0.066
9	516936	0.097	1599	**0.202**	105	**0.238**
10	515950	0.097	2556	**0.323**	142	**0.321**
Total	5342545	1	7912	1	442	1

*Because quantile binning was used, the proportion of brood locations in a bin indicates the selection ratio. A value of 0.1 indicates habitat bins are being used as expected, values less than 0.1 indicate that bins of that class are being used less than expected, and values greater than 0.1 indicate bins that are used more than expected.

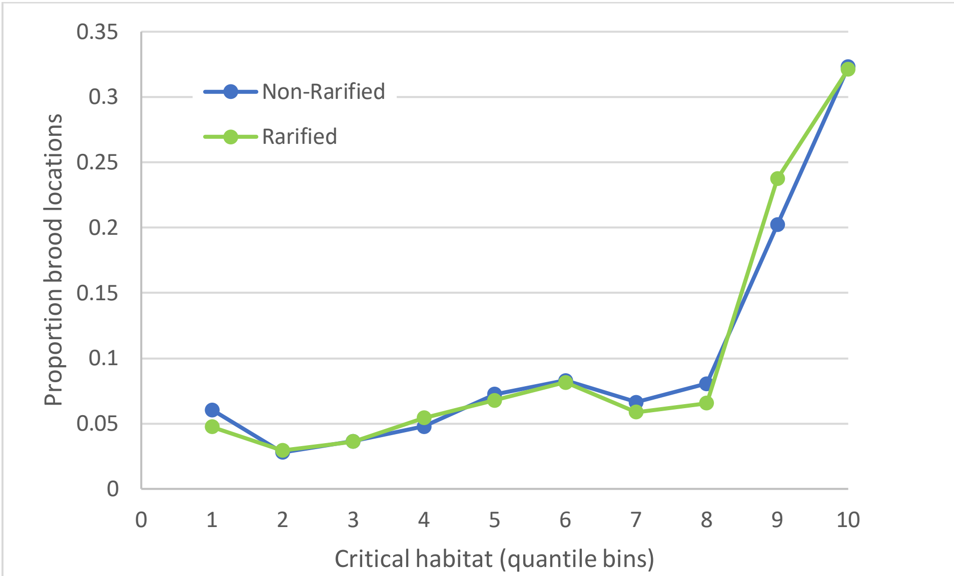

Figure 13: Selection ratios for brood locations of translocated sage-grouse hens in critical habitat map bins, derived from the critical habitat model (Environment Canada 2013). Values above 0.1 indicate selection.

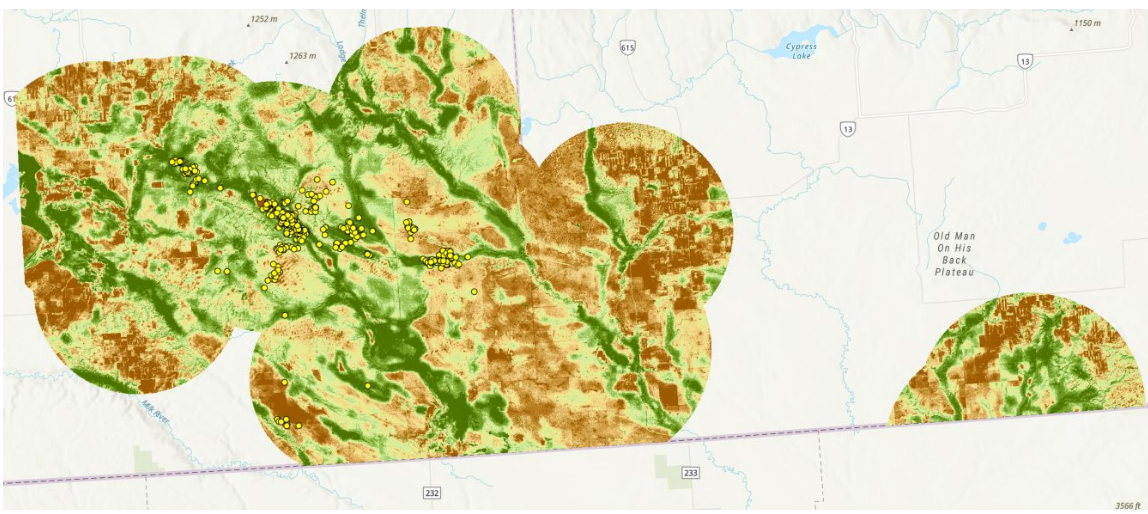

Figure 14: The quantile-binned habitat surface (10 bins) derived from the Environment Canada critical habitat model (Environment Canada 2013), with rarified brood locations (2011-2021) of translocated sage-grouse hens (yellow). Habitat ranges from poor (dark brown) to high (dark green) relative probability of occurrence.

Winter Locations: More winter locations (non-rarified, n = 52,963) coincided with the larger critical habitat map extent compared to the Carpenter et al. (2010) map. The rarified dataset included 2,649 locations.

Winter Location - Binary Map Evaluation: A high percentage (83.2% and 82.2%, for non-rarified and rarified datasets, respectively) of winter locations occurred within areas designated as critical habitat. Selection ratios for critical habitat were also high (2.230 and 2.203 for non-rarified and rarified datasets, respectively).

Winter Location – Quantile Binned Map Evaluation: Selection was less than expected for bins 1-7, approximately as expected for bin 8, and above expected for bins 9 and 10, for both rarified and non-rarified datasets (Table 9; Fig 15). There was visual correspondence in translocated hen winter locations in areas depicted as higher selection in the critical habitat map (Fig. 16).

Table 9: Winter locations of translocated sage-grouse in critical habitat map bins, using quantiles to bin equal proportions of the landscape. The binned surface was derived from the critical habitat model (Environment Canada 2013).

Critical habitat bin	Area cell count	Proportion of available	Non-rarified winter location count	Proportion non-rarified winter locations	Rarified winter location count	Proportion rarified winter locations
1	506773	0.0949	1342	0.025	73	0.028
2	514521	0.0963	906	0.017	41	0.015
3	547982	0.103	1173	0.022	64	0.024
4	568465	0.106	1432	0.027	79	0.030
5	560402	0.105	1584	0.030	70	0.026
6	558427	0.105	2082	0.039	122	0.046
7	530248	0.099	2742	0.052	128	0.048
8	522841	0.098	5766	0.109	306	0.116
9	516936	0.097	11802	**0.223**	572	**0.216**
10	515950	0.097	24134	**0.456**	1194	**0.451**
Total	5342545	1	52963	1	2649	1

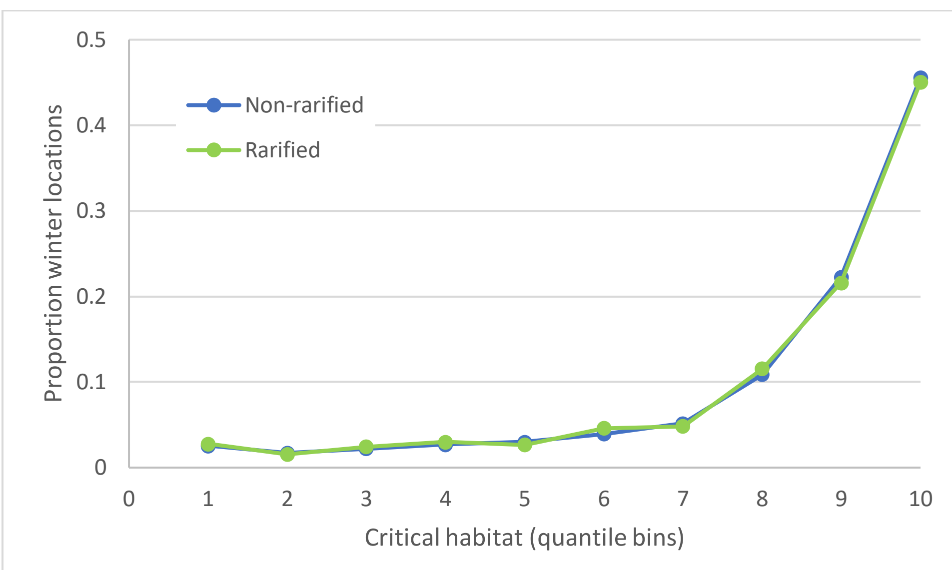

Figure 15: Selection ratios for winter locations of translocated sage-grouse hens in critical habitat map bins. Bins were derived from the critical habitat model (Environment Canada 2013). Values above 0.1 indicate selection.

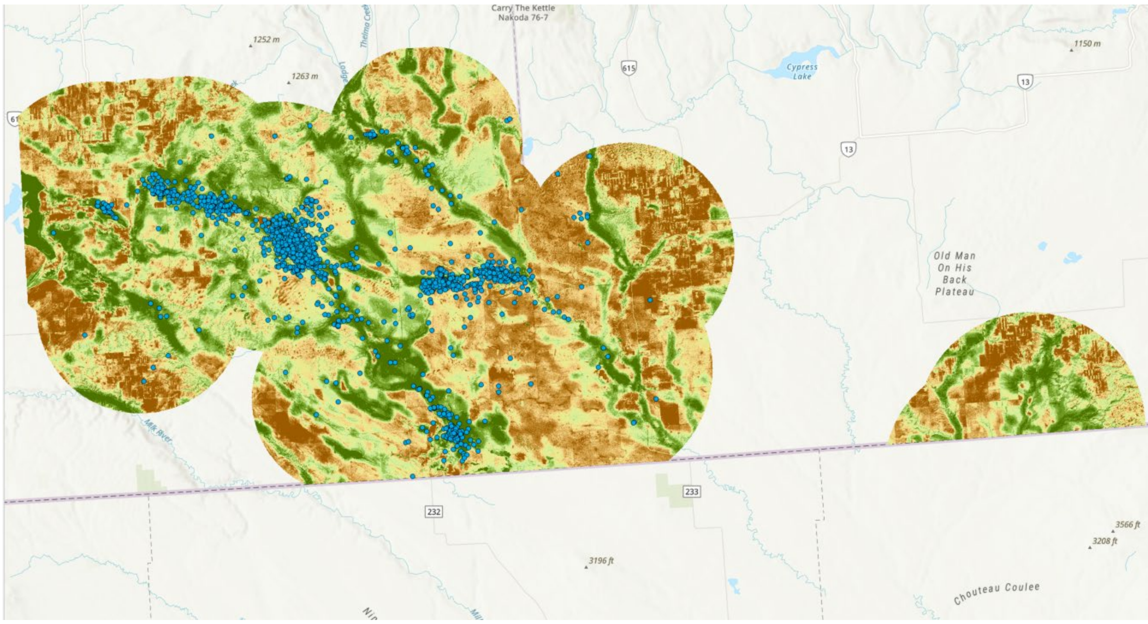

Figure 16: The quantile-binned habitat surface, which is derived from the critical habitat model (Environment Canada 2013), displaying winter locations (2011-2021) of translocated sage-grouse hens. Habitat selection ranged from low/poor (dark brown) to high/good (dark green) relative probability of occurrence.

Table 10: A summary of statistics for each evaluation of habitat maps and translocation data. Comparisons should not be made across all models as values are influenced by the bin type and number.

			Non-rarified				Rarified			
Model	Bin type	Number of bins	N	Selection ratio of top bin	Spearman rank correlation	K-S Test	N	Selection ratio of top bin	Spearman rank correlation	K-S Test
Nesting										
Aldridge & Boyce 2007	Geometric	5	80	2.645	1.000	Sig.	—	—	—	—
Critical habitat - binary	Threshold	2	80	1.676	N/A	N/A	—	—	—	—
Critical habitat - binned	Quantile	8	80	3.106	0.690	Sig.	—	—	—	—
Brood										
Aldridge & Boyce 2007	Geometric	5	7,919	7.948	0.900	Sig.	442	8.541	0.900	Sig.
Critical habitat - binary	Threshold	2	7,912	1.763	N/A	N/A	442	1.795	N/A	N/A

Critical habitat - binned	Quantile	10	7,912	3.345	0.867	N/A	442	3.327	0.867	N/A
Winter										
Carpenter et al. 2010	Geometric	10	40,515	8.931	0.964	N/A	2,026	8.761	0.964	N/A
Critical habitat - binary	Threshold	2	52,963	2.230	N/A	N/A	2,649	2.203	N/A	N/A
Critical habitat - binned	Quantile	10	52,963	4.718	0.964	N/A	2,649	4.667	0.903	N/A

N indicates the number of locations used to assess model performance and K-S test refers to the Kolmogorov–Smirnov test of distributions.

CONCLUSIONS AND RECOMMENDATIONS

Habitat Maps

We conducted a rapid assessment of the degree to which contemporary sage-grouse location records are consistent with previously developed habitat maps. We generally found agreement among use locations of translocated hens and higher selection areas in habitat maps (Table 10). This suggests that translocated birds (from the 2010s) are perceiving much of the landscape in a similar way as wild birds in past studies (from the 2000s). However, we also found areas of disagreement, where translocated birds are using areas mapped as lower selection (Fig. 17). Additional analyses are required to identify all the areas of disagreement and elucidate the likely causes. Possible explanations include that a) the landscape has changed in these areas, causing birds to occupy unexpected areas; b) translocated birds behave differently than wild birds causing use of low-suitability habitats; c) selection by translocated birds is consistent with wild birds but habitat maps inadequately characterize conditions in some locations; d) a combination of these (or other) factors are jointly creating disagreement.

Recommendation 1: Pursue follow-up analyses that a) more fully identify areas of disagreement in each map, b) assess the accuracy of map predictions or extrapolations in these areas, c) explore the influences of binning and thresholding on comparison results, and d) characterize which types of birds are associated with instances of disagreement i.e., stage, time-since-release, reproductive state/history.

Recommendation 2: Calculate additional metrics for the critical habitat map evaluation.

- Binary map: Estimate CVI (% nests - % available landscape available to those birds that is critical habitat). To be comparable to previous methods, this requires a detailed characterization of available habitats, which was not conducted in our rapid assessment. Calculate 95% confidence intervals on the percent of nest, brood, and winter locations.
- Continuous map: Calculate AVI and CVI curves for the full continuous RSF rather than 10-binned version. AVI and CVI curves for all possible values would support comparisons to the original critical habitat evaluation.

HexSim Spatial Inputs

The HexSim model developed for sage-grouse in this study system (Heinrichs et. al., 2018, 2019) uses the habitat selection maps assessed in Part A (except winter; Carpenter et. al., 2010). These habitat selection surfaces are used in HexSim to guide seasonal movement, habitat selection, and spacing of individuals (see Part B). The translocation-habitat map results (Part A of this report), suggest the continued use of these maps in the HexSim model are likely to produce results that are generally consistent with how translocated birds use the landscape. However, areas of disagreement could meaningfully influence spatially dependent results and outputs e.g., source-sink maps, estimates of returns on spatially-specific habitat restoration or other recovery actions.

Recommendation 3: Use results from recommendation 1 to determine if the scope of disagreement warrants changes to HexSim spatial inputs. Changes could include:

- Re-thresholding RSF maps to include more locations from translocated birds (i.e., Aldridge and Boyce 2007 – nesting and brood maps)
- Replacing Aldridge and Boyce 2007 nesting and brood RSF maps with the continuous critical habitat maps. If this option is taken, the use of the companion risk maps (i.e., Aldridge and Boyce 2007 nest and chick survival maps) that are used in the HexSim model should be re-examined or re-developed per the following recommendation.

Recommendation 4: Examine the consistency of translocated bird nest successes/failures and chick survival/death locations with Aldridge and Boyce (2007) risk maps.

Recommendation 5: If sufficient data exists, we recommend assessing locations of chick, yearling, and adult mortalities to create a 'survival/death' (risk) map that could be added to the HexSim model to represent areas with higher risk of death. Risk maps for yearlings and adults have not yet been developed.

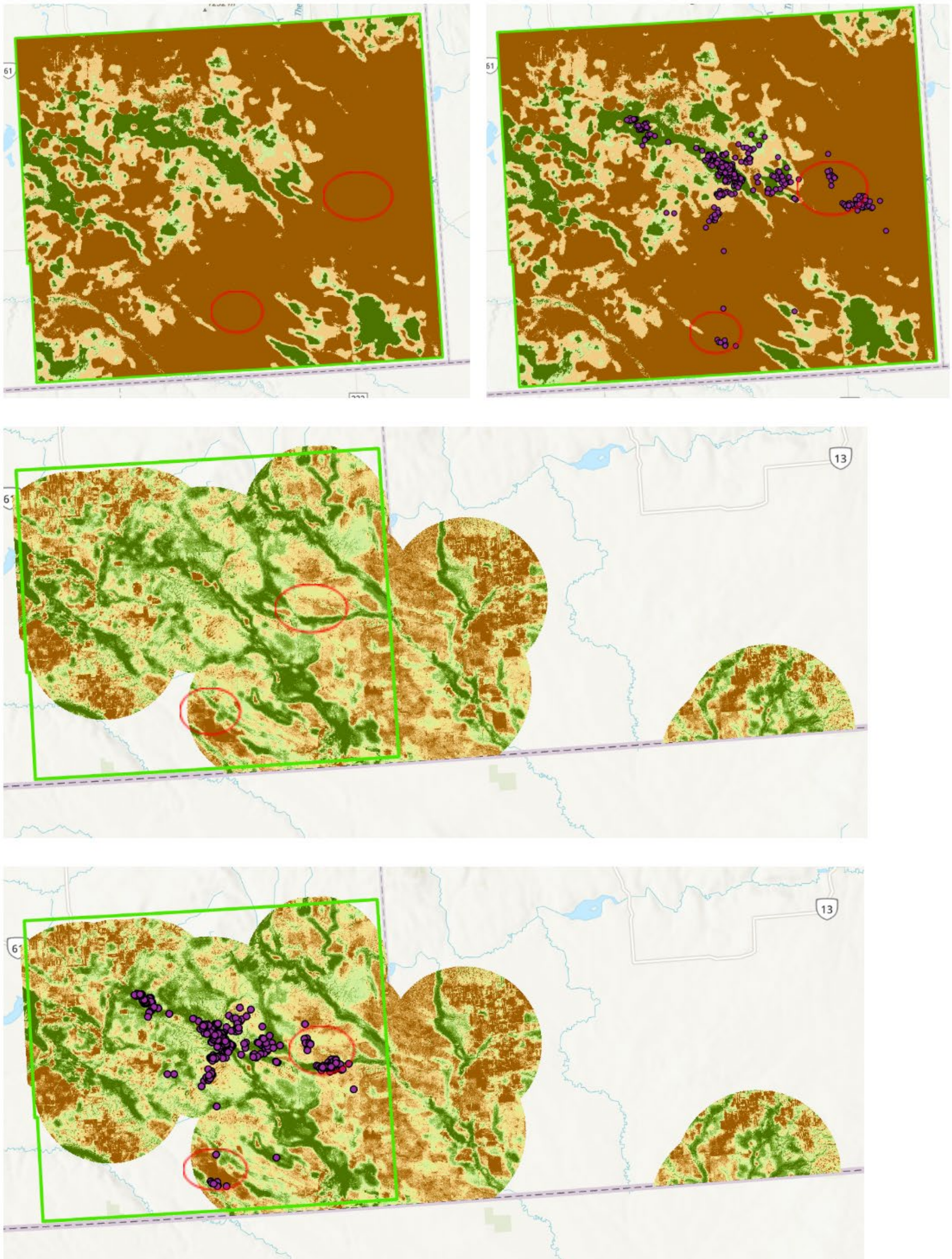

Figure 17: Areas where the critical habitat maps areas are occupied by translocated birds and not visualized in the Aldridge and Boyce 2007 brood habitat model. Additional differences (and similarities) may be observed in non-binned visualizations. The area highlighted in the eastern part of the Aldridge and Boyce (2007) study area was also used for nesting by translocated sage-grouse and is not captured by the Aldridge and Boyce (2007) nest habitat model.

PART B: HEXSIM INVENTORY

Task 2 Approach: Review the HexSim model and develop an inventory of input parameters that are based on environmental or population data from the early 2000s. Assess information available from the Alberta sage-grouse (translocation) dataset and identify opportunities and analyses needed to use newer data to evaluate or update existing parameterization.

Methods: We reviewed the original HexSim model and documentation (Heinrichs et. al., 2018 and 2019) and summarized model inputs by parameter, data source, and data years (Tables 11 – 13). We appended core model documentation (Heinrichs et. al., 2018 and associated appendix) to this report. Our model inventory focuses on the original model parameterization as the documentation is largely complete, and few changes have been made to these basic model inputs. Figure 18 highlights additions that have extended the functionality of the HexSim model.

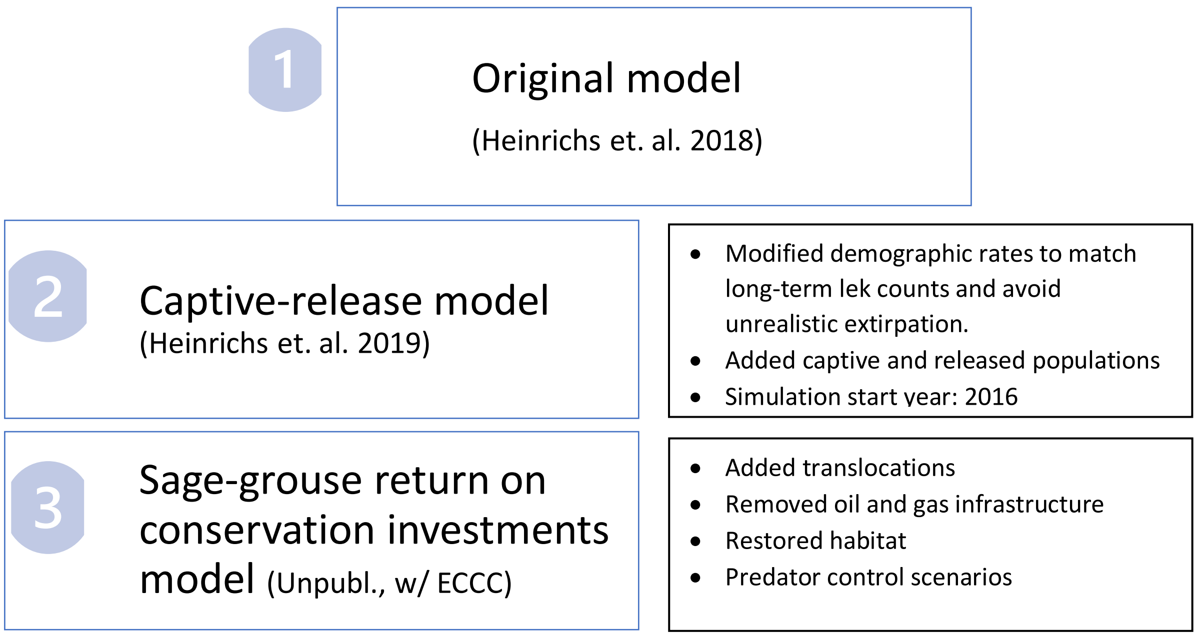

Figure 18. HexSim model progression from the original published version to the contemporary, unpublished adaption to support assessments of restoration and recovery actions.

Recommendations to Use Translocation Data to Improve HexSim Inputs:

1. Additional Spatial Input Recommendations: Add lek-specific counts from recent years, verify that trend-matching parameterization used in recent versions of the model approximate observed lek counts from 2017-2022.
2. Demographic Inputs: Develop scoping analyses that assess the consistency of translocated hen demography with wild demography.
    a. This could assess apparent demographic rates and/or develop alternative demographic simulations in HexSim and determine what level of demographic change is likely to result in different HexSim model predictions.
3. Update Movement Inputs:
    a. Calculate nest density
    b. Estimate dispersal distances (and distributions) for lek-nest; nest-brood rearing areas
    c. Estimate the proportion of individuals moving in/out of the study extent
    d. Estimate site fidelity to release sites, release leks, annual leks, nest sites, summer locations
    e. Evaluate avoidance/attraction to landscape features e.g., infrastructure, movement barriers

Table 11. Spatial Data – HexSim Inputs

Spatial data	Extent	Data source	Conditions Date	HexSim Usage
Lek locations	AB/SK	Various	2000 – 2016	Initial lek count, activity status
Nesting habitat RSF	AB: 9 x 9	Aldridge & Boyce 2007	Early 2000s	Movement, habitat selection No influence on demography
Brood-rearing habitat RSF	AB: 9 x 9	Aldridge & Boyce 2007	Early 2000s	Movement, habitat selection No influence on demography
Nest survival map	AB: 9 x 9	Aldridge & Boyce 2007	Early 2000s	Influenced nest success/failure locations; averaged pixels in 1-hex radius
Brood risk map	AB: 9 x 9	Aldridge & Boyce 2007	Early 2000s	Influenced juvenile survival locations; averaged pixels in 1-hex radius
Critical habitat map RSF	ALL AB and SK range	EC 2013	Early 2000s	Movement, habitat selection No influence on demography
winter habitat	n/a			Not used in the HexSim model

Table 12. Demographic Data – HexSim Sources

Demography	Note	Data Years	Field Data Source	Rate Citation
Chick survival	To 56 days	2001-2003	Aldridge 2005; Aldridge and Boyce 2007	Aldridge and Boyce 2007 (mean); Heinrichs et al 2018: (variance)
Juvenile survival	First CAN estimate	1998-2006	Aldridge 2000, 2005; Carpenter 2007	Heinrichs et al. 2018
Yearling survival		1998-2006	Aldridge 2000, 2005; Carpenter 2007	Heinrichs et al. 2018
1st nest initiation/attempt	100%	1998-2004	Aldridge	
Nest survival by nest attempt	Includes incubation and laying	1998-2006	Aldridge 2000, 2005; Carpenter 2007	Heinrichs et al. 2018
Clutch size, hatch rates		1998-2004	Aldridge and Boyce 2007	Aldridge and Boyce 2007
Sex ratio	50-50		Bush 2009; Atamian and Sedinger 2010	Bush 2009; Atamian and Sedinger 2010
Probability of renesting (2nd nest)		1998-2006	Aldridge and Brigham 2001; Aldridge 2005; Aldridge and Boyce 2007; Carpenter 2007; Carpenter et al 2020)	Heinrichs et al. 2018

Table 13. Movement Data – HexSim Sources

Movement and Space Use (Hens)	Note	Data Years	Field Data Source	Rate Citation
Nest density	Max. 1 hen per hexagon (3.46 ha/hex; 200-m wide)		U.S. nest density observations	Various
Lek-nest dispersal distance	AB: 12.2 km (mean)	SK: 5.3 km	AB: Parks Canada, unpublished data	SK: Tack et al. 2009
Nest-brood dispersal	2.2 km	Various	Wyoming	Fedy et al 2012
Brood-winter	N/A	This model does not currently include a wintering season or map.		
Migration	N/A	The model does not currently model large distance movements among populations e.g., AB to Eastern SK or CAN-US.		

ADDITIONAL RECOMMENDATIONS

Update the Database: CEG added filterable columns to the geodatabase and created several accessory datasheets that are likely to be useful for future analyses. We can provide these upon request. Please note that some mortality dates and locations were not fully resolved prior to our use of this database and were excluded from our analysis. There are numerous hens that had successful nests but had no chicks survive 45 days. Are there any brood observations between the nest off date and the 45 day check?

Database structure considerations:

- Split out date and time from combined column for easier filtering. Have specific columns for day, month, year, hour, and minute.
- Remove all locations where lat/long is 0
- Remove all pre-release locations
- Tag locations that are separated by a minimum time interval. There are a lot of locations within minutes of each other for some birds.

Create a Multi-partner Database: Additional datasets describing sage-grouse locations could be added to the Alberta Environment and Parks dataset to fully describe locations, and derived movement, demography and habitat use through time. In addition to the datasets described in this report (that currently exist in different databases), those collected by the Calgary Zoo, Tack, Smith, and studies near the Montana border could be compiled in one dataset.

Wish-list Analyses: The translocation dataset could be used to conduct several new analyses. The steering committee has highlighted several ideas:

Movement and behavior:

- Space use using GPS data
- Post-release movement and habitat selection patterns
- Site fidelity to lek, nest, brood, and winter locations
- Proximity/avoidance of anthropogenic features, movement barriers

Habitat selection maps: Assess selection

- By individual or sub-groups in the population e.g., nesting vs. non-nesting hens
- Using step-selection functions

Demography:

- Statistically estimate survival, reproduction metrics
- Compare nest fate and brood survival rates to 45 days with Aldridge results and ideally with the rates in source populations (Montana).
- Calculate the proportion of nesting hens by stage, time since translocation
- Develop risk maps using translocated bird data

PART C: SUPPLEMENTAL INFORMATION

Data Preparation

We received a file geodatabase from Alberta Environment that contained the spatial data needed to assess existing habitat surfaces. We modified the hen movement spatial data files by adding many filterable attributes (Table 1). In some cases, we needed to cross walk information in the stand-alone tables with the hen movement data. Dates needed to determine 'brood' classification were found in the 'brood' table. Specific release dates were found in the 'birds' table and nest status of hens in the 'Sage Grouse Nests' feature file, both necessary to assign Post_Rel_Ex values. We assumed the 'last location date' provided in the 'Sage Grouse Mortality' feature file was true and any locations after that date in the hen movement files were deemed unreliable. The three hen movement files, containing data from four years of translocation events were merged together and this pooled data was used for all subsequent analysis.

Table 1: Attributes added to the Hen Movement spatial data files.

Attribute	**Possible values**	**Definition**
In_SA	Yes or No	The location falls within the boundaries of the Greater Sage Grouse Critical Habitat Amendment (Yes).
Release_YR	2011, 2012, 2016, 2019	The year the bird was released.
Bird_ID	1 - 116	Identifying number of the bird to whom the location record belongs.
Breed	0 or 1	Currently all the records in this field are <null> as we had no need for this information. Could be updated.
Brood	0 or 1	Is this a brood location? Determined by date, and are specific to each hen. Hen must have a successful nest and have at least one chick survive until the 45 day check. Locations between 'off nest date' and '45-day check date' (see brood table) are classed as brood locations (1). Hens with no broods, or with no chicks surviving until the 45-day check will have 0's in this field.
Winter	0 or 1	Winter locations were determined by date. If locations occurred between November 1 and March 15 they were classified as winter locations (1).
Post_Rel_Ex	Yes or No	Should this location be excluded based on time since release and nest status? This only applies to locations the year the bird was released. 8 weeks was used if the hen did not nest the year of release, 4 weeks if the hen nested (Anderson). (Yes = exclude; No = keep)
Accurate	Yes or No	Is this location considered accurate based on criteria provided by Alberta Environment (No: Qual_IDX = A and Quality = no estimate < 4msgs, **or** Qual_IDX = B and Quality = no estimate < 3msgs **or** accuracy >1000m; Yes = everything else)
Male	Yes or No	Only 3 males, BIRD IDs 17,37, and 38 – all released in 2012.
After_MORT	Yes or No	Is location after the 'last location date' attribute in the Mortality shapefile. The date may either be associated with the death of the bird or transmitter malfunction or end of life. (Yes = exclude, No = keep)