BIGHORN SHEEP, HORIZONTAL VISIBILITY, AND GIS

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Abstract: Habitat evaluation models are commonly used in bighorn sheep (*Ovis canadensis*) reintroduction and restoration, and many of these models incorporate high horizontal visibility as necessary for suitable bighorn habitat. Other variables like cover type and canopy closure are easier to quantify and often are used as indices for horizontal visibility. Few studies have directly measured bighorn sheep preferences of horizontal visibility without using such indices. We measured horizontal visibility at a sample of locations used by sheep and paired locations 200 m away at 3 sites in western Montana, and we did not detect significant differences. This variable may be more important at coarser scales (2nd order) of selection than that which we measured (3rd order). We also used multiple regression and analysis of variance to assess the relationship between horizontal visibility and 3 explanatory variables easily quantified in a GIS (cover type, slope, and aspect). All 3 of our explanatory variables had significant relationships with horizontal visibility ($P \leq 0.001$). Simple indices such as cover type alone are insufficient to accurately predict horizontal visibility.

INTRODUCTION

Bighorn sheep suffered a dramatic population decline and reduction in geographic range during the latter part of the 19th century. Intensive restoration and translocation efforts begun during the 1950's have since returned their numbers from an estimated 20,000 in the contiguous U.S. in 1960 to nearly 50,000 in 1991 (Buechner 1960, Valdez and Krausman 1999). Sheep were extirpated from much of their native range, so these restoration efforts have focused on returning populations to unoccupied but suitable habitat. Bighorns rarely recolonize areas through dispersal due to strong site fidelity (Geist 1970, 1971), so management has been focused on artificial translocations and reintroductions (Hansen et al. 1980).

This management strategy places much emphasis on identifying suitable habitat where reintroduction efforts will be most successful. Many models have been developed to aid managers in identifying suitable bighorn habitat across their notably diverse North American range (Hansen 1980, Grunigen 1980, Holl 1982, Smith et al. 1991, McCarty 1993, Dunn 1996, Schirokauer 1996, Sweanor et al. 1996, Hughes 1997, Johnson and Swift 2000, Zeigenfuss et al. 2000, Dicus 2002). These modeling efforts continue today with changing approaches to defining and evaluating each feature of bighorn sheep habitat.

One such habitat feature, horizontal visibility (estimated as a percentage from 0-100), relates to the preference of bighorn sheep for open areas with little visual

obstruction. Their predator avoidance strategy relies on an ability to detect danger at a distance, giving them ample time to retreat to safer terrain when needed (Geist 1971, Risenhoover and Bailey 1980).

We found few studies that directly measured bighorn sheep preference of horizontal visibility. Hayes et al. (1994) measured visibility at 70 locations used by a captive population of bighorn sheep, and compared these to measures of visibility at 30 randomly selected points within the same area. They did not find a significant difference in visibility between used and random sites. McCarty (1993) also sampled used and random points within a study area for visibility, and he did detect preference of more open areas. Etchberger et al. (1989) found significantly higher visibility values in areas used by sheep than those in a neighboring unused area.

Risenhoover and Bailey (1985) found habitat types preferred by sheep provided greater visibility than avoided habitat types. Their study was the more typical approach to horizontal visibility; this involved associating it with another habitat variable such as cover type or canopy closure. For example, field measures are used to estimate an average visibility for each cover type in a study area. Preference or avoidance of a cover type is then inferred to indicate preference or avoidance of the associated level of horizontal visibility. In this way, the biologists are not truly measuring the animal's preference for horizontal visibility, but are instead attributing different levels of preference between cover types to visibility. This is an indirect and potentially confounded assessment of how bighorn sheep respond to horizontal visibility.

Accurate measures of horizontal visibility come from site-specific work in the field, but indices are often used to incorporate this variable into habitat modeling (Hansen 1980, Holl 1982, Smith et al. 1991, Johnson and Swift 2000). This is also done by associating levels of visibility with different cover types or levels of canopy closure. Recently, the use of geographic information systems (GIS) and satellite imagery data has become popular in habitat modeling. However, horizontal visibility is a variable that escapes direct measurement through remotely-sensed data.

In this paper, we address 2 key questions concerning horizontal visibility and habitat modeling with regards to bighorn sheep habitat selection. First, we directly estimated the relationship between bighorn sheep habitat use and horizontal visibility by measuring visibility in the field at sites used by wild bighorn sheep and paired "available" sites. This avoided the problem of using selection of cover types to infer selection of horizontal visibility. However, we acknowledge that some index of horizontal visibility is required for future modeling in the GIS environment. Our second objective was to test what other habitat variables, if any, could be used to accurately predict horizontal visibility in a GIS framework.

METHODS
Do bighorn sheep prefer sites with higher horizontal visibility?
We captured 21 bighorn sheep among 3 herds in western Montana in March, 2001, using net-gunning from a helicopter (Krausman et al. 1985). We used radio-telemetry between March, 2001 and August, 2002, to collect locations of groups of radio-collared sheep among these 3 herds (Bearmouth, Garrison, and Skalkaho). We selected a systematic sample (every other location) of these locations for field measurements of horizontal visibility. For

each of these selected "use" locations, we selected another location 200 m away in a random direction to measure visibility at "available" sites. To avoid disturbing sheep, we did not measure visibility at these sites on the same day in which sheep were located. The time period between locating sheep and returning to measure visibility ranged between 1 week and 12 months, which meant vegetative conditions during measurement were not always the same as when sheep were observed. We always measured visibility for both the use and the available sites during the same day, so we believe a valid estimate of the relative difference between them was maintained.

We used the staff-ball method to estimate horizontal visibility in the field (Collins and Becker 2001). Collins and Becker (2001) found this method to be more precise than both the cover-pole (Griffith and Youtie 1988) and checkerboard target (Nudds 1977, Smith and Flinders 1991), and we found it convenient in the field because it required only a single person. We cut 2 holes through a bright orange tennis-ball and mounted it on top of a gardening stake (staff); the staff was driven into the ground at the location of interest, and the bottom of the tennis ball was adjusted to 90 cm above the ground (Risenhoover and Bailey 1985). The observer walked a circle around the staff with a radius of roughly 20 m. While walking this circle, the observer stopped every eighth step and, with his or her eye-level also at 90 cm, looked for the "dimensionless point" where the ball and the right side of the staff intersected (Collins and Becker 2001). Collins and Becker (2001) suggested using the point of intersection between the ball and staff to yield a distinct yes or no result instead of subjective estimates or counts used with other methods. After completing the circle, the observer divided the number of times the point was visible by the total number of attempts, e.g. 12 visible/20 total = 60% horizontal visibility.

A biologically meaningful radius to measure visibility was difficult to select. A radius of 20 m was used in previous studies of horizontal visibility (McCarty and Bailey 1992) and fell in between other commonly used distances of 14 m (Risenhoover and Bailey 1980, Smith and Flinders 1991), 28 m (Johnson and Swift 2000) and 40 m (Risenhoover and Bailey 1985, Hayes et al. 1994). Twenty meters also corresponded to the diagonal radius of a 30 m by 30 m pixel which is the spatial scale of our GIS data.

We used a paired-samples T-test to detect differences between horizontal visibility at used and available sites. We analyzed data separately for each sex at each of 3 study sites (Bearmouth, Garrison, and Skalkaho). Bighorn sheep are known to have seasonal ranges, and make different tradeoffs in habitat selection to accommodate seasonal needs. For example, ewes may sacrifice forage quality for lamb security by retreating to rocky outcroppings in the spring. We suspected that horizontal visibility might have varied importance throughout the year so we divided ewe locations into 3 biologically meaningful seasons (winter, lambing, fall) for each herd and analyzed seasons separately. Roughly, the lambing season lasted from early May through late July, the fall season from early August through late November, and the winter season from early December through late April. The number of ram locations was insufficient to separate by season.

Can we model horizontal visibility in a GIS?
We did a simple exercise in modeling horizontal visibility using several predictor variables. We compiled GIS data sets for

each of the 3 study sites (Bearmouth, Garrison, and Skalkaho). We began with 2 vegetation layers commonly associated with horizontal visibility, cover type and canopy cover, with 30 m x 30 m resolution (Wildlife Spatial Analysis Lab, The University of Montana 2001). We reduced our cover type layer into 3 categories: xeric grass/shrub lands (Grass), open forests (OpenFor), and closed forests (ClosedFor). Two of the 3 study sites were burned during the fires of 2000, which was after the vegetation layers were created. We used fire severity GIS layers to add 3 more categories to our cover type layer: burned grass/shrub (GrasBurn), low-moderately burned forest (LowBFor), and severely burned forest (SevBFor) (Wildlife Spatial Analysis Lab, The University of Montana 2000). We were unable to correct the canopy cover layer for changes due to the fires, so the canopy cover data were omitted from the modeling process.

While vegetation certainly affects horizontal visibility, our field measurements were just as often affected by the topography of the area. Ridges and valleys often concealed the staff-ball target, even when the vegetation was open grassland. For this reason, we suspected that topographic variables like slope, aspect, or ruggedness might also contribute to some of the variation in horizontal visibility. Terrain ruggedness is often quantified by the density of contour lines on area maps (Beasom et al. 1983), and Ebert (1993) found it was highly correlated with slope values. Because of this correlation between ruggedness and slope, we used only slope and aspect layers created from the USGS National Elevation Data Set DEM, with a pixel size of 30 m x 30 m. We left slope as a continuous variable and categorized aspect into 1 of the 4 cardinal directions (N, S, E, W).

We pooled the use and availability locations for this analysis, and associated each location with a value for cover type, slope, and aspect from the GIS. To avoid sampling bias between sites, we randomly selected 100 points from each site for analysis. Before modeling, we visually assessed the relationships between predictor variables and horizontal visibility using simple boxplots and scatterplots. We then used multiple regression and analysis of variance to assess the relationship between each predictor variable and horizontal visibility. We began with a saturated model (all 3 predictor variables) and used the Type III Extra-Sums-of-Squares F test to assess variable significance. We used Student's T tests to evaluate parameter coefficients.

RESULTS
Do bighorn sheep prefer sites with higher horizontal visibility?
Visibility did not appear to be a significant variable at this scale of habitat selection ($P = 0.013 – 0.968$). We measured visibility at 644 locations (322 used, 322 available, Table 1). None of the tests for ewes at any site or season gave results indicating significant differences in visibility between used and available locations. When ewe data were pooled across seasons, results remained insignificant. Effect sizes were very small, but the magnitude of the difference did indicate generally higher visibility values at used sites during winter and fall. Ram data were pooled across all seasons, and 2 of the 3 sites revealed significantly higher visibility for used sites.

Can we model horizontal visibility in a GIS?
Simple boxplots and scatterplots did reveal some visual relationships between predictor variables and horizontal visibility. For example, changes in cover type had apparent effects on visibility values (Figure 1).

The Type III Extra-Sums-of-Squares F test revealed significant relationships between horizontal visibility and all 3 predictor variables: slope ($P = 0.001$), cover type ($P < 0.001$) and aspect ($P < 0.001$). Slope and visibility were negatively correlated, so higher slopes led to lower visibility (Table 2). Cover type and aspect are categorical variables, so coefficients presented in Table 2 are relative to an alias or reference category; grassland was the alias category for cover type and South the alias category for Aspect. All categories of cover type had lower values of horizontal visibility than grasslands, and West and North aspects had higher values of horizontal visibility than South aspects

DISCUSSION

We detected significant preference for areas of high visibility in the rams of 2 of our 3 study sites; it is questionable whether the magnitude of these differences (mean differences in % visibility of 20 and 10) are biologically significant. Selection was not observed for ewes for any season or site, though the magnitude of the differences indicated generally higher visibility at used sites during fall and winter. A biological explanation might suggest that ewes protecting lambs sacrifice good forage and high visibility for other habitat features like steep slopes and escape terrain, where rams, unhindered by young, choose areas with better forage and high visibility. However, the scale of our analysis could also explain the results.

We used a radius of 20 m to measure visibility, which is an important decision of scale. Sheep may perceive horizontal visibility at smaller or larger scales than this 20 m radius. Measurement at another radius might yield different results. Our comparisons were also limited to used sites

and paired available sites 200 m away. This 200 m distance might not be adequate to detect habitat preferences. Perhaps the sheep are making selections at much larger scales, so the observer would have to go further than 200 m to get an appropriate comparison.

Risenhoover and Bailey (1985) found that visibility was an important habitat characteristic until a threshold was reached, beyond which other variables became more important. In terms of Johnson's (1980) different scales of selection, visibility might be an important variable of second order, or home range, selection. Third order selection occurs within the home range. For a bighorn sheep, much of this area might already exceed some threshold of horizontal visibility, and other fine-scale variables become more important. Because our methods were really measuring third-order selection (within the home range), we would be unable to detect any selection going on at a larger scale.

The average visibility values for sites used by ewes in each herd (56%, 59%, 61%) were all considerably lower than that required by Smith et al.'s (1991) bighorn habitat suitability model. Their model designated all areas with visibility less than 80% as unsuitable for bighorn sheep. Cut-offs of 62% (Johnson and Swift 2000) or 55% (Zeigenfuss et al. 2000) seem more reasonable given our data, and researchers and managers might be more liberal with this parameter in future bighorn habitat modeling. The lag-time between observed use of a site and the follow-up measurement of visibility in our data may bias our mean visibility values.

Several variables were correlated with horizontal visibility. Though our intent was to use all reasonable predictor variables in

modeling, much unexplained variation remained. Our vegetation data were simplified into a few basic classes. More detailed and accurate distinctions between vegetation types may be possible as the quality of these remotely sensed data improves. Topography appeared to have important relationships with visibility, and more complex measures of topographic diversity might be incorporated into future modeling. Landscape configuration measures such as the diversity of aspects or slopes within a given radius might better estimate subtle topographic barriers to visibility. Divine et al. (2000) found that the resolution of digital elevation model (DEM) data had a significant effect on measures of terrain ruggedness. Thirty meter pixel sizes provided more precise measures of topographic variables such as slope than 100 m pixels. Future development of 10 m resolution DEM data in some areas may further improve our ability to quantify topography for visibility estimation.

We recommend researchers take into account the highly variable nature of horizontal visibility values before using simple indices like cover type to quantify it. Multiple regression modeling procedures such as ours may be useful in certain, site-specific cases to accurately predict horizontal visibility in a GIS framework.

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Table 1. Paired-samples T-tests compare horizontal visibility values for paired used and available locations for bighorn sheep at 3 study sites, 2001-2002. Means of used/available values, the sample size of paired values, and *P*-values are presented.

		Site					
		Bearmouth		**Garrison**		**Skalkaho**	
Sex	**Season**	used/avail	*P*	used/avail	*P*	used/avail	*P*
Ewe	Winter	56/51 n=24	0.364	68/64 n=39	0.289	66/63 n=45	0.509
	Lambing	53/54 n=13	0.913	48/44 n=38	0.437	56/60 n=29	0.562
	Fall	62/49 n=9	0.204	60/71 n=28	0.105	58/53 n=30	0.471
	Pooled	56/51 n=46	0.279	59/59 n=105	0.968	61/59 n=104	0.633
Ram	Pooled	69/49 n=25	0.028	67/67 n=31	0.935	65/52 n=39	0.013

Figure 1. Box plots of horizontal visibility values for each category of cover type at 3 study sites in western Montana, 2001-2002.
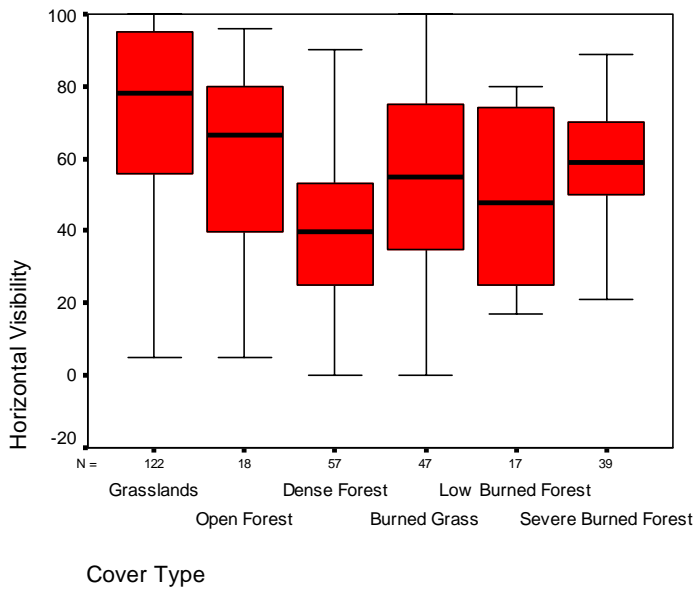
Table 2. Parameter estimates for multiple regression modeling of horizontal visibility data in bighorn sheep habitat in western Montana, 2001-2002. Coefficients and *P*-values for categories of Cover Type and Aspect are relative to their respective alias categories.

Parameter		β	Std. Error of β	t	*P*	95% Confidence Interval for β
Constant		80.927	4.584	17.655	0.000	(71.905, 89.948)
Slope		-.530	.164	-3.226	0.001	(-0.853, -0.207)
Cover Types[a]	OpenFor	-14.984	6.171	-2.428	0.016	(-27.129, -2.840)
	ClosedFor	-29.612	4.225	-7.009	0.000	(-37.927, -21.297)
	GrasBurn	-13.293	4.220	-3.150	0.002	(-21.599, -4.988)
	LowBFor	-23.752	6.192	-3.836	0.000	(-35.939, -11.565)
	SevBFor	-14.662	4.900	-2.992	0.003	(-24.306, -5.018)
Aspect[b]	West	12.838	3.667	3.501	0.001	(5.620, 20.055)
	North	4.928	5.090	.968	0.334	(-5.090, 14.947)
	East	-1.970	3.751	-.525	0.600	(-9.352, 5.413)

a Alias variable for Cover Type = Grassland
b Alias variable for Aspect = South