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Analysis of Studies Used to Develop Herbaceous Height and Cover Guidelines for Sage Grouse Nesting Habitat

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Introduction

In August 2000 the State of Nevada initiated a sage grouse (*Centrocercus urophasianus*) planning effort when the Governor appointed a state-wide task force with representatives from industry, Native Americans, conservation organizations, land management agencies, legislators and biological professionals. The task force developed an initial strategy that led to the development of six regional planning groups. Coincident with, but independent from, creation of the state-wide task force was publication of guidelines to manage sage grouse populations and sage grouse habitat (Connelly et al. 2000). These guidelines were a revision of guidelines published by Braun et al. (1977). The current guidelines were established at the request of the Western States Sage and Columbian Sharp-tailed Grouse Technical Committee, which is under the direction of the Western Association of Fish and Wildlife Agencies (WAFWA) and are generally referred to as the WAFWA guidelines. Each local planning group in Nevada (and probably other states) has determined whether and how to incorporate these guidelines into their planning efforts.

Members of the local planning groups have often had strong divergent opinions about whether the herbaceous height and cover recommendations in guidelines (Table 1) are appropriate for sagebrush rangelands in Nevada. Many hours have been spent debating this issue.

Table 1. Characteristics of nest sites on sagebrush rangeland needed for productive sage grouse habitat. Data are extracted from Connelly et al. (2000), Table 3.

	Height (cm)	Canopy Cover (%)
Mesic Sites[a]		
Sagebrush	40-80	15-25
Grass-forb	>18[b]	≥25[c]
Arid Sites[a]		
Sagebrush	30-80	15-25
Grass-forb	>18[b]	≥15

a. Mesic and arid should be defined on a local basis; annual precipitation, herbaceous understory, and soils should be considered (Tisdale and Hironaka 1981, Hironaka et al. 1983).

b. Measured as “droop height”, the highest naturally growing portion of the plant.

c. Coverage should exceed 15% for perennial grasses and 10% for forbs. Values should be substantially greater if most sagebrush has a growth form that provides little lateral cover (Schroeder 1995).

This indicates the herbaceous height and cover components of the guidelines are very controversial. This controversy occurs, at least in part, because none of the studies used to develop the WAFWA guidelines were conducted in Nevada. Many in Nevada question whether the results of studies conducted in other states can be extrapolated to situations in Nevada. Controversy also occurs because the WAFWA guidelines do not clearly explain how the values they present were derived from the 12 studies they use to characterize sage grouse nest (Connelly et al. 2000).

Some planning group members want to adopt the guidelines in entirety, essentially converting them to standards. A standard is generally defined as a minimum acceptable level of quality. A guideline refers to general directions or instructions about how to accomplish something. The desire to adopt the guidelines as a standard lingers despite Connelly et al. (2000) stating,

> "…. There is much variability among sagebrush dominated habitats (Tisdale and Hironaka 1981, Hironaka et al. 1983) and some Wyoming sagebrush and low sagebrush breeding habitats may not support 25% herbaceous cover. In these areas total herbaceous cover should be $\geq$15% (Table 3). Further, the herbaceous height requirement may not be possible in habitats dominated by grasses that are relatively short when mature. In all other cases, local biologists and range ecologists should develop height and cover requirements that are reasonable and ecologically defensible."
>
> And,
>
> "Because of gaps in our knowledge and regional variation in habitat characteristics (Tisdale and Hironaka 1981), the judgment of local biologists and quantitative data from population and habitat monitoring are necessary to implement the guidelines correctly."

These statements clearly acknowledge that sagebrush landscapes in the western states are very variable (both within and between sagebrush community types and ecological sites), and that the guidelines are not standards. This variability is amply illustrated by data in Blaisdell (1958) who measured the height of the tallest leaf (at its bend) for bluebunch wheatgrass (*Pseudoroegneria spicata*) for 16 years on the U.S. Sheep Experiment Station, near Dubois, Idaho. All measurements occurred in exlcosures: ungrazed for at least the duration of the study. The average height of bluebunch wheatgrass (defined as a tall species in Gregg 1991), using the droop height definition initially defined by Gregg (1991), was less than 18 cm in 9 of the 16 years. The range was from 11.4 to 21.0 cm. Clearly, some ecological sites produce desired native herbaceous species that cannot regularly meet the WAFWA guidelines.

Despite acknowledgement in the WAFWA guidelines that they are not standards and that the specific numeric guidelines they present require modification to address local conditions, some participants in Nevada's local planning groups (as well as other states) want to adopt the guidelines as strict standards. It is unclear how the studies cited in the WAFWA guidelines were analyzed to develop the guidelines specific recommendations; therefore, I conducted a meta-analysis of all but one of the studies cited in the WAFWA guidelines. Two additional studies published since 2000 are also included in this analysis. This approach to synthesizing data across a suite of studies has been recommended by a number of wildlife biologists (Anderson et al. 2001, Johnson 2002a, Johnson 2002b, Popham and Gutierrez 2003).

What is Meta-Analysis and Why Use it to Synthesize Sage Grouse Studies

Meta-analysis is a formal approach that analyzes, synthesizes, and summarizes the results of a collection of previous studies (Hedges and Olkin 1985, Osenberg et al. 1999). The data points are the summary statistics (e.g., the mean) published in the original studies. One of the primary goals of meta-analysis is to understand the relationship between response estimates and environmental and biological variables (Osenberg et al. 1999). Meta-analysis has been used (and widely debated) for years in a variety of disciplines (e.g., social, psychological and medical sciences), and is receiving increasing interest as an approach to synthesize ecological research (Fernandez-Duque 1997, Osenberg et al. 1999).

The most powerful method of learning about causal mechanisms of change in ecology is manipulative experimentation. The foundations of manipulative experiments are experimental control, randomization and replication (Johnson 2002b). Experimental control results in a comparison of treated and untreated experimental units. Randomization requires that each experimental unit (and potential sample within experimental units) have a chance of being selected for measurement. True replication requires having multiple, independent experimental units (e.g., several independent areas of nesting habitat), with each experimental unit having several or more samples. Manipulative experimentation typically results in a definitive understanding about the bio-physical mechanisms that result in ecological change, within the parameters (conditions) of the study. Many wildlife management studies, including most if not all of the habitat studies cited in the WAFWA guidelines, are observational. They have no control of treatments, little or no true randomization of sample units or individual samples, and no replication of experimental units. Additional samples (i.e., more sage grouse nest sites) are not replication, but an increase in sample size within the sampling unit. Replicated studies would have multiple independent sample units (i.e., independent study areas) with multiple samples (sage grouse nests) in each sample unit. Replication often is absent from wildlife studies for very valid reasons. Funds may be inadequate to provide adequate personnel to study multiple sites simultaneously, or the scale (or type) of manipulative treatments may be too large to be socially or politically acceptable. The same general ecological questions, however, often are asked in a number of studies that have been conducted at different locations and/or at different times. The results from a series of independent studies that address the same general questions are a form replication (Johnson 2002b).

Johnson (2002b) argues that replication is the most critical experimental component and the best approach for learning about how our biological world functions. Johnson (2002b) defines metareplication as the replication of studies and includes studies conducted in different years, at different sites, with different methods, and by different investigators. According to Johnson (2002b),

> "Conducting studies in different years and at different sites reduces the chance that some artifact associated with a particular time or place caused the observed results; it should be unlikely that an unusual set of circumstances would manifest itself several times or, especially, at several sites. Conducting studies with different methods similarly reassures us that the results were not simply due to the methods or equipment employed to get those results. And having more than 1 investigator perform studies of similar phenomena reduces the opportunity for the results to be due to some hidden bias or characteristic of that researcher."

Metareplication of studies is important for widespread regional species like sage grouse that inhabits broad landscapes, with a very diverse habitat composition and structure. Any single, unreplicated study that measures sage grouse habitat will obtain data from a miniscule portion of the species' range. The information from a single study is from a very small spectrum of the habitat conditions the species experiences. The results from individual sage grouse studies may or may not find statistically significant differences in habitat attributes for areas used and not used by sage grouse, or at successful and unsuccessful nests. The appropriateness of extrapolating results from either a single study, or a subset of all studies, to all locations inhabited by sage grouse is very questionable, and probably not appropriate, unless the bio-physical environment is the same. Data from a series of relatively small independent studies can be used as replicates to allow ecologists and managers to evaluate whether the significant effects identified in any single study are applicable across the entire suite of conditions that sage grouse may encounter. In essence, is there a strong general relationship (i.e., is it robust), a weak relationship or no relationship (i.e., not globally applicable) between specific parameters of sage grouse biology (e.g., nest success) and one or more habitat attribute?

Methods

The WAFWA guidelines cited 12 studies that collected data about herbaceous community structure at nest sites (Klebenow 1969, Wakkinen 1990, Connelly et al. 1991, Gregg 1991, Klott et al. 1993, Fischer 1994, Schroeder 1995, Heath et al. 1997, Apa 1998, Sveum et al. 1998, Holloran 1999, Lyon 2000). Eleven of these papers were obtained and their data analyzed with respect to the herbaceous height and cover values presented in the WAFWA guidelines. Schroeder (1995) was not used due to difficulty in obtaining the manuscript. Gregg et al. (1994) was included because it is a published paper from the original thesis (Gregg 1991). Also included are data for two additional studies published since the WAFWA guidelines appeared (Aldridge and Brigham 2002, Popham and Gutierrez 2003). Data used from each study included percent nest success, grass height (cm), residual grass height (cm), percent grass cover, percent residual grass cover, percent residual cover (if it was not identified as grass or forb cover, respectively), forb height (cm), percent forb cover, percent sagebrush cover, and percent cover from all shrubs. The mean value for each habitat attribute was extracted directly from the original manuscript. Some studies reported nest success as a composite value across two or more plant community types, but habitat attributes for each respective community type. In these situations, I calculated a weighted mean across the community types (Steel and Torrie 1980).

Data for each study are presented by year when one or more variables had a statistically significant difference. When differences between years were not statistically significant the authors typically provided average values for the entire study, and those values are used in this paper. When possible, summary data presented here are for both individual year and study, and for successful and unsuccessful nests. Summary data for nest success and vegetation attributes were analyzed for predictive relationships using simple and multiple linear regressions. Analysis was conducted with Statistix 7 (Analytical Software 2000). Cover data from Klebenow (1969) was not used in the regression analysis because he reported basal cover values. All other studies reported canopy cover. Canopy cover and basal cover for the same plant typically have large differences. This prohibits inclusion of data from Klebenow (1969) in any global analysis of nest success with vegetation attributes. Other data not included in the regression analysis were Connelly et al. (1991) and Gregg et al. (1994). Their data sets included data from studies conducted by Wakkinen (1990) and Gregg (1991), respectively. Data from these latter two studies were included in the regression analysis because they provided summary statistics for more vegetation variables than did Connelly et al. (1991) and Gregg et al. (1994).

Results and Discussion

Derivation of the Numeric Values Presented as Guidelines

Text in the WAFWA guidelines does not clearly illustrate how the specific numeric values (or range of values) for herbaceous height and cover were developed. In the WAFWA guidelines, Table 1 identifies the average herbaceous height and cover values associated with sage grouse nests for 12 studies. On page 971, the guidelines state, "grass height and cover also are important components of sage grouse nest sites (Table 1)." Subsequent text cites only five papers to illustrate the importance of grass height (Wakkinen 1990, Connelly et al. 1991, Gregg 1991, Sveum et al. 1998, and Gregg et al. 1994). Of these studies, three found taller grasses at nest sites, or at nest areas than at random locations (Wakkinen 1990, Gregg 1991, Sveum et al. 1998). Connelly et al. (1991) found statistically taller grasses under non-sagebrush shrubs than under sagebrush. The WAFWA guidelines use this subset of studies to infer that taller grass height is an important habitat component for nesting sage grouse. The guidelines provide no comparative or quantitative analysis for these herbaceous attributes at successful and unsuccessful nests, or their relationship with nest success. The WAFWA guidelines cite Gregg (1991) as evidence that grasses 18 cm or taller are important. Gregg (1991) found grass cover at successful nests was almost twice that at unsuccessful nests; however, Gregg (1991) did not measure grass height as an independent variable. He measured the percent cover from grass species that were taller and shorter than 18 cm. Gregg (1991) measured a cover-height variable, This critical interaction is not mentioned in the WAFWA guidelines during interpretation of Gregg's study. Also, the WAFWA guidelines do not mention the nest success rates documented by Gregg (1991) were substantially less than in the other studies. Finally, the guidelines do not identify other studies that found little or no difference for herbaceous height (details in next section) and/or cover at successful and unsuccessful nests, or larger values at unsuccessful nests.

The WAFWA guidelines present their guideline values in Table 3 of Connelly et al. (2000). Text associated with this table cites only one of the 12 studies used to characterize the herbaceous height and/or cover attributes at sage grouse nest sites. The study cited, Apa (1998), did not report herbaceous vegetation attributes at successful and unsuccessful nests, and reported average grass height values 5 cm to 23 cm taller than those recommended in the guidelines. It is unclear how the guideline values are based on Apa (1998), let alone the remaining 11 studies cited in the guidelines. The WAFWA guidelines provide no integrated (collective) analysis (comparative or quantitative) about relationships between the herbaceous attributes they describe as important for sage grouse breeding habitat and nest success. Analysis and discussion along these lines is important because the intent of management guidelines should be to improve the outcome of management decisions and actions. The management guidelines for herbaceous height and cover should have been developed with the intent of improving and/or maintaining nest success rates. The specific goal (improve or maintain) would depend on the situation in the management unit. An analysis about relationships between nest success and vegetation attributes would have been appropriate and helpful.

What are the Data in the Original Studies Used to Develop the WAFWA Guidelines

Nest success and vegetation attributes from 13 studies are shown in Tables 2a-2f. Grass cover at the nest was the only herbaceous vegetation attribute measured in every study. The only herbaceous attributes regularly measured were grass height and forb cover. For grass height, grass cover, forb cover, and live grass and forb cover, there were studies where the herbaceous attributes were larger (or taller) at nest sites or nest areas, than at random locations. Likewise there were other studies where herbaceous height and/or cover were larger (or taller) at random locations (Tables 2a-2d). In some studies the numeric difference between values at nest sites and random locations was large, and in other studies it was small. A simple tally of the number of studies that had herbaceous attributes larger or taller at nest sites, than at random locations, provides little useful biological information about the herbaceous attributes needed to maintain or increase sage grouse populations. The results from any one unreplicated observational study can be contradicted by at least one and often numerous studies.

The pattern for sagebrush cover at nest sites and random locations is similar to that for herbaceous species (Table 2e). Random locations can have more or less sagebrush cover than nest sites or nest areas. The result changes when total shrub cover is compared across nest sites, nest areas, and random locations (Table 2f). Total shrub cover was more at nest sites, than at nest areas and random locations in every study but one. Nest areas, however, did not always have more total shrub cover than random locations. Differences in total shrub cover between nest areas and random locations were often about 1% or less, but as high as 6%.

Gregg (1991), Gregg et al. (1994), and Sveum et al. (1998) are often cited (or verbally stated) as justification for maintaining an 18 cm herbaceous height at sage grouse nest sites. Neither of these studies measured grass height as an independent variable. They measured percent grass cover in two height classes: tall ($\geq$18 cm) and short ($\leq$18 cm). Interpretation/extrapolation of the results of their work to other locations has to consider herbaceous height as it interacts with herbaceous (and probably shrub) cover, not height as a separate, independent variable. Their definition of what is a tall grass and short grass has not been used consistently. Delong et al. (1995) used 15 cm as the defining criteria for tall ($\geq$15 cm) and short ($\leq$15 cm) grasses.

Grass height was measured, or classified into cover classes (e.g., Gregg 1991), in 13 studies (Table 3). Only three studies defined how grass height was measured. The remainder described grass height as a measured variable, but not whether height meant the top of the tallest live leaf, the top of the tallest reproductive culm, or some other measurement. For most herbaceous species, the plant part used to measure height will result in substantially different values. Seed stalks typically are much taller, and fewer than are leaves. This results in less visual obstruction from seed stalks than from leaves. Also, the WAFWA guidelines define “droop height” as “the highest naturally growing portion of the plant.” The tallest part of most grass plants (and most forbs) is the top of the reproductive culm or stem. The definition of droop height in the WAFWA guidelines is very different from the definition of grass height in two studies that originally defined the term.

Table 2a. Nest success rate and mean grass height at nest sites, nest areas, and random locations. For all tables, blank spaces indicate that data was not collected or reported.

	Years	Nest Success (%)	Grass Height Nest Site (cm)	Grass Height Nest Area (cm)	Grass Height Random Locations (cm)
Aldridge and Brigham 2002	1998-1999	46	31.0		28.5
Apa 1998	1989	55	23.0	21.2	23.2
Apa 1998	1990	60	32.4	28.3	28.1
Apa 1998	1991	33	41.9	40.0	41.0
Connelly et al. 1991	1987-1989	52	19.0		
Fischer 1994 (Preburn)	1987-1989	52	19.8	20.2	17.6
Fischer 1994 (Postburn	1990-1992	43	22.1	21.5	23.0
Gregg1991 (Hart Mountain)	1989-1990	24			
Gregg 1991(Jackass Creek)	1989-1990	12			
Heath et al. 1997	1994-1996	33	14.8	13.8	13.4
Holloran 1999	1997	52	20.8		19.6
Holloran 1999	1998	67	17.1		16.1
Klebenow 1969	1965-1966	67			
Klott et al. 1993	1993	24	14.7		10.4
Lyon 2000	1998-1999	50	21.3		21.8
Popham and Gutierrez 2003	1998-2000	40	23.1		18.2
Sveum et al. 1998	1992	31			
Sveum et al. 1998	1993	47			
Wakkinen 1990	1987-1988	60	18.2	18.2	15.3

Table 2b. Nest success and mean grass cover at nest sites, nest areas, and random locations. All values are canopy cover except Klebenow (1969) who measured basal cover.

	Years	Nest Success (%)	Grass Cover At Nest Sites (%)	Grass Cover At Nest Area (%)	Grass Cover At Random Locations (%)
Aldridge and Brigham 2002	1998-1999	46	31.9		41.7
Apa 1998	1989	55	16.2	11.8	12.3
Apa 1998	1990	60	17.0	15.4	10.4
Apa 1998	1991	33	13.5	13.6	24.3
Connelly et al. 1991	1987-1989	52	7.4		
Fischer 1994 (Preburn)	1987-1989	52	7.2	8.3	7.1
Fischer 1994 (Postburn	1990-1992	43	29.3	28.6	31.2
Gregg 1991 (Hart Mountain)	1989-1990	24	17.7	13.8	13.1
Gregg 1991 (Jackass Creek)	1989-1990	12	11.1	11.4	8.9
Heath et al. 1997	1994-1996	33	8.9	7.5	6.7
Holloran 1999	1997	52	5.5		4.7
Holloran 1999	1998	67	4.1		4.6
Klebenow 1969	1965-1966	67	3.7		2.9
Klott et al. 1993	1993	24	1.0		5.0
Lyon 2000	1998-1999	50	10.6		5.4
Popham and Gutierrez 2003	1998-2000	40	12.5		11.0
Sveum et al. 1998	1992	31	34.0	29.0	40.0
Sveum et al. 1998	1993	47	44.0	35.0	41.0
Wakkinen 1990	1987-1988	60	6.5	8.0	5.5

Table 2c. Nest success and forb cover at nest sites, nest areas, and random locations. All values are canopy cover except Klebenow (1969) who measured basal cover.

	Years	Nest Success	Forb Cover At Nest Sites	Forb Cover At Nest Area	Forb Cover At Random Locations
		(%)	(%)	(%)	(%)
Aldridge and Brigham 2002	1998-1999	46	8.4		8.6
Apa 1998	1989	55	11.5	10.2	2.3
Apa 1998	1990	60	9.0	10.5	11.2
Apa 1998	1991	33	8.6	7.6	9.9
Connelly et al. 1991	1987-1989	52			
Fischer 1994 (Preburn)	1987-1989	52			
Fischer 1994 (Postburn	1990-1992	43	4.3	4.2	4.9
Gregg 1991 (Hart Mountain)	1989-1990	24	6.5	10.2	10.8
Gregg 1991 (Jackass Creek)	1989-1990	12	12.8	9.4	9.9
Heath et al. 1997	1994-1996	33	2.3	2.8	3.3
Holloran 1999	1997	52	6.7		6.5
Holloran 1999	1998	67	7.8		6.8
Klebenow 1969	1965-1966	67	3.0		2.9
Klott et al. 1993	1993	24	2.2		2.2
Lyon 2000	1998-1999	50	8.2		4.3
Popham and Gutierrez 2003	1998-2000	40			8.6
Sveum et al. 1998	1992	31	12.0	10.0	12.0
Sveum et al. 1998	1993	47	21.0	20.0	16.0
Wakkinen 1990	1987-1988	60			

Table 2d. Nest success and mean live forb and grass cover at nest sites, nest areas, and random locations.

	Years	Nest Success (%)	Live Forb and Grass Cover at Nest (%)	Live Forb and Grass Cover at Nest Area (%)	Live Forb and Grass Cover at Random Sites (%)
Aldridge and Brigham 2002	1998-1999	46	40.3		50.3
Apa 1998	1989	55	27.7	22.0	14.6
Apa 1998	1990	60	26.0	25.9	21.6
Apa 1998	1991	33	22.1	21.2	34.2
Connelly et al. 1991	1987-1989	52			
Fischer 1994 (Preburn)	1987-1989	52			
Fischer 1994 (Postburn	1990-1992	43	33.6	33.0	36.1
Gregg 1991 (Hart Mountain)	1989-1990	24	24.2	23.3	23.9
Gregg 1991 (Jackass Creek)	1989-1990	12	23.9	20.8	18.8
Heath et al. 1997	1994-1996	33	11.2	10.3	10.0
Holloran 1999	1997	52	12.2		11.2
Holloran 1999	1998	67	11.9		11.4
Klebenow 1969	1965-1966	67			
Klott et al. 1993	1993	24	3.2		7.2
Lyon 2000	1998-1999	50	18.8		9.7
Popham and Gutierrez 2003	1998-2000	40			
Sveum et al. 1998	1992	31	46.0	39.0	52.0
Sveum et al. 1998	1993	47	65.0	55.0	57.0
Wakkinen 1990	1987-1988	60			

Table 2e. Nest success and sagebrush cover at nest sites, nest areas, and random locations.

	Years	Nest Success (%)	Sagebrush Cover at Nest Site (%)	Sagebrush Cover in Nest Area (%)	Sagebrush Cover at Random Locations (%)
Aldridge and Brigham 2002	1998-1999	46	31.9		15.7
Apa 1998	1989	55	22.0	13.8	16.8
Apa 1998	1990	60	18.8	17.8	19.4
Apa 1998	1991	33	16.7	13.3	15.7
Connelly et al. 1991	1987-1989	52	25.0		18.2
Fischer 1994 (Preburn)	1987-1989	52			
Fischer 1994 (Postburn)	1990-1992	43			
Gregg 1991 (Hart Mountain)	1989-1990	24			
Gregg 1991 (Jackass Creek)	1989-1990	12			
Heath et al. 1997	1994-1996	33	24.5	20.8	19.8
Holloran 1999	1997	52	24.9		19.5
Holloran 1999	1998	67	25.2		21.3
Klebenow 1969	1965-1966	67	14.1		12.5
Klott et al. 1993	1993	24			
Lyon 2000	1998-1999	50	25.6		27.0
Popham and Gutierrez 2003	1998-2000	40	14.5		15.0
Sveum et al. 1998	1992	31			
Sveum et al. 1998	1993	47			
Wakkinen 1990	1987-1988	60	21.5	20.4	21.6

Table 2f. Nest success and total shrub cover at nest sites, nest areas, and random locations.

	Years	Nest Success (%)	Total Shrub Cover at Nest Site (%)	Total Shrub Cover in Nest Areas (%)	Total Shrub Cover at Random Locations (%)
Aldridge and Brigham 2002	1998-1999	46	39.3		17.4
Apa 1998	1989	55	37.5	24.3	21.1
Apa 1998	1990	60	35.6	29.8	30.1
Apa 1998	1991	33	34.2	30.8	24.8
Connelly et al. 1991	1987-1989	52	24.0		26.5
Fischer 1994 (Preburn)	1987-1989	52	29.0	26.7	27.6
Fischer 1994 (Postburn)	1990-1992	43	18.2	17.5	16.5
Gregg 1991 (Hart Mountain)	1989-1990	24	52.3	29.0	35.3
Gregg 1991 (Jackass Creek)	1989-1990	12	55.1	27.2	26.5
Heath et al. 1997	1994-1996	33	29.6	25.4	24.7
Holloran 1999	1997	52	29.7		23.8
Holloran 1999	1998	67	30.7		24.9
Klebenow 1969	1965-1966	67	18.4		14.4
Klott et al. 1993	1993	24	23.3		20.3
Lyon 2000	1998-1999	50	38.1		35.2
Popham and Gutierrez 2003	1998-2000	40	20.0		20.0
Sveum et al. 1998	1992	31	51.0		6.0
Sveum et al. 1998	1993	47	59.0		7.0
Wakkinen 1990	1987-1988	60	28.9	26.7	27.8

Table 3. Methods different studies used to measure grass height for studies cited in the WAFWA guidelines.

Study	Method
Aldridge and Brigham 2002	Not defined, reported only as “grass height”
Apa 1998	Not defined, reported only as “grass height”
Connelly et al. 1998	Not defined, reported only as “grass height”
Fischer 1994	Not defined, reported only as “grass height”
Gregg 1991	Not defined, reported only as “grass height”
Gregg et al. 1994	Droop height, excluding flower stalks
Heath et al. 1997	Not defined, reported only as “grass height”
Holloran 1999	Not defined, reported only as “grass height”
Klott et al. 1993	Not defined, reported only as “grass height”
Lyon 2000	Not defined, reported only as “grass height”
Pope and Gutierrez 2003	Droop height, excluding flower stalks
Sveum et al. 1998	Droop height, excluding flower stalks
Wakkinen 1990	Not defined, reported only as “grass height”

Numerous studies, but not all, reported both herbaceous and shrub attributes at successful and unsuccessful nests, or successful and predated nests (Tables 4a and 4b). No studies measured the entire suite of potential vegetation attributes. For grass height, only one study found statistically significant differences ($P \leq 0.10$) at successful and unsuccessful nests. More often than not, grass height was the same or taller at unsuccessful nests than at successful nests (Table 4a).

Grass cover was more at unsuccessful nests in 45% of the studies (Table 4a). Only two studies had large differences in cover between successful and unsuccessful nests. Aldridge and Brigham (2002) found 9.0% more cover at unsuccessful nests, while Gregg (1991; see also Gregg et al. 1994) had 11% more cover at successful nests. In over half the studies, the difference in grass cover between successful and unsuccessful nests was 2% or less.

Only one study had a statistically significant difference in forb cover between successful and unsuccessful nests (Table 4a). The numeric difference was very small (0.4%); thus, the statistically significant difference is probably biologically insignificant. Two other studies (Sveum et al. 1998, 1992 data; Aldridge and Brigham 2002) had no statistically significant differences for forb cover at successful and unsuccessful nests, but relatively large numeric differences (5-8%). The lack of statistical significance in these two studies should not be interpreted to mean a lack of biological significance. The biological importance of forbs for nest success cannot be derived from this subset of studies.

Some authors have stated that residual herbaceous height and cover are important for nesting sage grouse (Gregg et al. 1994, Holloran 1999). Data are very limited. Only three studies measured these attributes at successful and unsuccessful nests (Table 4a). Heath et al. (1997) found statistically significant differences ($P \leq 0.05$) for residual grass height and residual grass cover, but the absolute difference was relatively small (Table 4a). At unsuccessful nests mean residual grass height was 1.9 cm shorter, and mean residual grass cover was 1.3% less. Total herbaceous cover (i.e., live and dead), however, was almost identical at the successful and unsuccessful nests. Sveum et al. (1998) found significantly more residual cover at successful nests one year, but not another (Table 4a). Nest success was highest in 1993, the year with substantially less residual herbaceous cover and a small difference in residual cover between successful and unsuccessful nests. Sveum et al. (1998) found substantially more total herbaceous cover (residual + live) at nest sites (successful and unsuccessful) than did Holloran (1999), but substantially lower nest success rates (Tables 2a and 4a). Gregg et al. (1994) state that tall residual grass cover was significantly greater ($P<0.001$) at nonpredated nest sites than in areas surrounding predated nests, but present no data (for grass height) to show if actual differences were large or small. Data for residual grass height, residual grass cover, and residual cover at successful and unsuccessful nests does not follow a consistent pattern, with respect to nest success. At this time, data are too few and/or too varied to provide a definitive interpretation about the biological importance of residual herbaceous height and cover for nesting sage grouse. While residual herbaceous height and cover are intuitively important for nesting sage grouse there is a lack of robust scientific evidence to document its importance. It may be important in specific situations and unimportant in others. If so, ecologists must identify those situations when residual herbaceous height and cover are important and those situations when it is not.

Sagebrush cover was very similar at both successful and unsuccessful nests (Table 4b). There were no statistically significant differences, and the small actual difference between paired successful and unsuccessful nests indicates little biological significance. Total cover from shrubs, at successful and unsuccessful nests, typically was within 2 to 5% of one another and usually exceeded 20% total shrub cover. Total shrub cover at successful and unsuccessful nests did not have a statistically significant difference in most studies (Table 4b). The one study with a statistically significant difference probably was not biologically significant for two reasons. First, unsuccessful nests had slightly more total shrub cover. Second, cover from shrubs, although much less than in the other studies, was adequate for 43% nest success. Few studies reported total shrub cover in the nest area at successful and unsuccessful nests (Table 4b).

Table 4a. Comparison of herbaceous vegetation characteristics at successful and unsuccessful nests for studies used to develop the WAFWA herbaceous height and cover guidelines for sage grouse habitat. Two additional studies published since publication of the WAFWA guidelines are included. Blank spaces indicate data either was not recorded or reported. Studies in Table 2 not listed here did not report data for both successful and unsuccessful nests. Paired values with bold typeface were significantly different at P≤0.10. Paired values with italic typeface did not have statistical significance reported. Paired values with normal typeface were not statistically different at P≤0.10. Residual cover refers to herbaceous material that remains from the previous year (growing season).

Study	Nest Success	Height (cm)	Grass Cover (%)	Grass Height (cm)	Forb Cover (%)	Forb Grass Height (cm)	Residual Grass Cover (%)	Residual Cover (%)	Residual Cover (%)
Aldridge & Brigham 2002	Successful	37.0	26.8	20.1	11.1				
	Unsuccessful	25.3	36.7	11.2	6.0				
Fischer 1994									
(Pre-burn)	Successful	19.5	7.7						
	Unsuccessful	20.4	6.8						
(Post-burn)	Successful	21.4	27.9		5.0				
	Unsuccessful	22.7	31.4		3.8				
Gregg 1991	Successful		24.0		8.0				
	Unsuccessful		13.0		10.0				
Gregg et al. 1994[a]	Non-Predated		*24.0*		8.0				
	Predated		*11.0*		9.0				
Heath et al. 1997	Successful	14.7	8.1		2.6	9.2	3.2		*11.3*
	Unsuccessful	14.9	9.2		2.2	7.3	1.9		*11.1*
Holloran 1999	Successful	18.6	5.1		7.6	12.0	2.6		*15.3*
	Unsuccessful	18.6	4.2		6.9	11.9	2.3		*13.4*
Popham and Gutierrez 2003	Successful	22.1	14.0						
	Unsuccessful	24.2	11.0						
Sveum et al. 1998									
1992	Successful		32.0[b]		18.0			19.0	*69.0*
	Predated		33.0		10.0			5.0	*48.0*
1993	Successful		43.0[c]		19.0			5.0	*67.0*
	Predated		45.0		22.0			3.0	*70.0*
Wakkinen 1990	Successful		19.0		7.0				
	Unsuccessful		16.5		5.0				

a. Data reported for predated nests only, not all unsuccessful nests.
b. Cover from tall grasses (defined as ≥18 cm by the authors) was 24% at successful nests and 26% at predated nests. Non Significant at P≤0.10
c. Cover from tall grasses was 29% at successful nests and 24% at predated nests. Non Significant at P≤ 0.10

Table 4b. Comparison of sagebrush and shrub cover at successful and unsuccessful nests for studies used to develop the WAFWA herbaceous height and cover guidelines for sage grouse habitat. Two additional studies published since the WAFWA guidelines were printed are included. Blank spaces indicate data either was not recorded or reported. Studies in Table 2 not listed here did not report data for both successful and unsuccessful nests. Paired values with bold typeface were significantly different at P≤0.10. Paired values with italic typeface did not have statistical significance reported. Paired values with normal typeface were not statistically different at P≤0.10.

Study	Nest Success	Sagebrush Cover at Nest (%)	Total Shrub Cover at Nest (%)	Total Shrub cover in Nest Area (%)
Aldridge and Brigham 2002	Successful	32.9	41.8	
	Unsuccessful	31.0	37.0	
Fischer 1994				
(Pre-burn)	Successful		29.7	
	Unsuccessful		28.3	
(Post-burn)	Successful		16.9	
	Unsuccessful		18.8	
Gregg 1991	Successful		*56.0*	*31.0*
	Unsuccessful		*53.0*	*26.0*
Gregg et al. 1994[a]	Successful		*56.0*	*31.0*
	Predated		*52.0*	*28.0*
Heath et al. 1997	Successful	24.8	29.7	
	Unsuccessful	24.3	29.6	
Holloran 1999	Successful	25.0	30.8	
	Unsuccessful	25.2	29.5	
Popham and Gutierrez 2003	Successful	13.0	19.0	
	Unsuccessful	16.0	21.0	
Sveum et al. 1998				
1992	Successful		46.0	22.0
	Predated		50.0	27.0
1993	Successful		60.0	19.0
	Predated		58.0	17.0
Wakkinen 1990	Successful	21.6	30.0	
	Unsuccessful	20.8	27.3	

a. Data reported for predated nests only, not all unsuccessful nests.

Relationships Between Nest Success and Herbaceous Vegetation Attributes

It is intuitive that some amount of herbaceous vegetation is important for nest success of sage grouse. Herbaceous height and cover are necessary for hiding cover from predators and thermal cover during spring snow and rain events. At the minimum, forbs are critical for meeting the dietary needs of hens (Barnett and Crawford 1994). The question is: how much herbaceous height and cover are necessary, and do taller herbaceous species and/or more herbaceous cover result in higher nest success rates? If herbaceous height and cover are critical independent variables that significantly influence sage grouse nest success, one or more of the vegetation attributes should have significant positive relationships with nest success. Also, if a specific value (e.g., 18 cm tall grasses, or 25% cover) is important one may expect a curvilinear relationship, with the slope of the line changing at the critical value.

No statistically significant linear relationships (defined as $P \leq 0.10$) were found when simple linear regressions were developed between nest success and the following vegetation attributes: grass height at the nest, grass cover at the nest, forb cover at the nest, live grass and forb cover at the nest, and sagebrush cover at the nest (Figures 1a-1e). R-squared values were very small (0.004 to 0.012), and the P-values ranged from $P \leq 0.709$ to 0.91. Slight negative relationships were found between nest success and grass height at the nest, grass cover at the nest and sagebrush canopy cover at the nest (Figures 1a, 1b, and 1e). Forb cover at the nest and live grass and forb cover at the nest were the only herbaceous attributes with slight positive relationships with nest success, but the relationships were not strong (Figures 1c and 1d). For each linear relationship there was substantial scatter of the data points around the regression line. The slight positive and negative relationships for the fore-mentioned attributes should not be over interpreted. For forb cover (Figure 1c) the removal of one data point, which appears to be an outlier, would result in a more positive relationship with nest success. The relationship, however, is still not statistically significant ($P \leq 0.22$) and has low predictive potential (R^2=0.15). The shallow slope of the other regression lines (Figures 1a, 1b, 1d, and 1e) suggests that the regression coefficient could change its sign (e.g., positive to negative) with the addition of only one or two data points. The magnitude of the slope, however, is unlikely to change substantially. Regression lines with shallow slopes typically indicate variables with low predictive potential. Regression lines with steeper slopes usually indicate variables with better predictive potential.

There were no statistically significant relationships between nest success and grass height in the nest area, grass cover in the nest area, forb cover in the nest area, live grass and forb cover in the nest area, sagebrush canopy cover in the nest area, and total shrub cover in the nest area. The P-values ranged from 0.4915 to 0.9404. The R^2 values ranged from 0.07 to 0.0007. All regression equations for vegetation variables measured in the nest area had substantially smaller sample sizes (degrees of freedom ranged from 4 to 10) than equations with vegetation data from nest sites (degrees of freedom ranged from 10 to 17). Results from the simple linear regression analysis indicate that herbaceous height and cover and sagebrush cover are poor individual indicators of nesting habitat quality, at least when analyzed independent of one another. Sage grouse planning and monitoring programs should not use these attributes individually to assess or monitor habitat quality (i.e., the potential for successful nests) for nesting sage grouse.

The lack of any statistical significance between nest success and sagebrush cover (Figure 1e) should not be interpreted to mean sagebrush cover is unimportant. Sage grouse require sagebrush to survive. A logical inference is that once sufficient sagebrush cover is present for nesting to occur and be successful, other factors influence nest success more than sagebrush cover.

There was a better linear relationship between nest success and total shrub cover (Figure 1f). The statistical significance was $P \leq 0.09$; however, the relatively low R^2 and the wide scatter of data points around the regression line strongly suggest that one or more additional factors influence nest success. The negative relationship indicates that nest success will decline as total shrub cover increases. The decline in nest success may not be from increased shrub cover per se, but from a corresponding loss of the herbaceous component.

Multiple regression analysis between nest success, sagebrush cover, and a suite of herbaceous attributes found no statistically significant relationships (Table 5a). The P-value was lowest (i.e., approached statistical significance) with grass height in the nest area ($P<0.275$). The equation predicts that as sagebrush cover and grass height increase nest success will decline. Each 1% increase in grass height would result in a 4.4% decline in nest success, given the same cover from sagebrush. This result must be viewed (and used) cautiously for at least two reasons. First, the sample size was very small (5 data points). As sample size declines, the global applicability of the relationship declines. Second, sagebrush cover at the nest and grass height were highly correlated with one-another (VIF=14). Collinearity renders the individual regression coefficients unreliable, but does not change the equation's predictive ability. The respective influence of sagebrush cover and/or grass height may be more or less than shown in Table 5. The relationship between nest success, sagebrush cover at the nest site, and grass height at the nest site had twice as many samples as did data for the nest area, and found a much lower significance level ($P \leq 0.661$) and a very poor correlation coefficient (Adjusted R^2 = -0.14).

Predictive relationships between nest success, sagebrush cover at the nest, and herbaceous attributes at the nest generally were best (but not statistically significant) when forb cover was included in the equations (Table 5a). None of these relationships had problems with collinearity. The addition of grass height as a third variable resulted in a lower P-value, but grass height only improved the relationships if forb cover was included in the equation. This indicates that forb cover is the more important herbaceous attribute. None of the regression equations had particularly good predictive power, based on their adjusted R^2 values. Adjusted R^2 is more appropriate to use than R^2 because adjusted R^2 only increases when the new variables add to the equation's predictive ability. Additional variables can increase R^2 even when they have no real predictive ability (Analytical Software 2000, Dallal 2003).

The individual P-values for each variable in each regression equation also indicate that forbs may be a biologically significant variable that improves nest success (Table 5a). Four equations included a measure of forb cover and grass height, respectively. In those equations, the range in P-values for forb cover was from 0.10 to 0.23, with three values $\leq$ 0.14. The range in P-values for grass height ranged from 0.14 to 0.60. The consistently lower P-values for forb cover, and their narrower range, indicates forb cover has a stronger influence on nest success than does herbaceous height. The P-values for grass cover were generally larger than those for grass height, which indicates it has the least predictive ability for nest success.

The regression coefficient for forb cover was always positive and ranged from 2.42 to 3.82 (Table 5a). This indicates that each one percent increase in forb cover predicts a corresponding increase in nest success of 2.42 to 3.82 percent, provided the other variables remain constant. The regression coefficient for grass height was always negative (Table 5a), ranging from -0.38 to -4.44. This indicates that nest success will decline as grass height increases. The potential decline is from less than one percent to over four percent for each centimeter increase in grass height, other variables remaining constant. The effect of grass cover was positive or negative depending on the specific variables included in the equation (Table 5a).

Multiple regression analysis between nest success, total shrub cover, and a suite of herbaceous attributes, at both nest sites and nest areas, found four statistically significant ($P<0.10$) relationships (Table 5b). The equation that best predicts (i.e., has the highest adjusted R^2) nest success includes two variables, total shrub cover at the nest site and forb cover in the nest area. The common herbaceous attribute in all four statistically significant equations was percent forb cover at either the nest site or nest area. Grass height entered only one of the four equations but did not decrease the P-value (i.e., improve statistical significance) or increase the adjusted R^2 (i.e., improve the predictive ability of the equation). The P-value for the relationship between nest success, total shrub cover at the nest site, and forb cover at the nest site declined from 0.049 to 0.08 when grass height was added to the equation. Similarly, the adjusted R^2 went from 0.70 to 0.48. These results strongly support previous conclusions that forbs are biologically more important for sage grouse, than is herbaceous height.

Several other statistics support the conclusion that forbs are the most important herbaceous attribute for nest success. Forb cover was a component of seven regression equations in Table 5b. In six of those equations the individual P-value for the forb component ranged from 0.00 to 0.05. The only equation with a larger P-value (0.14) had a very small sample size (df=4). The P-values for grass height ranged from 0.13 to 0.53. The P-values for grass height only approached 0.13 when forb cover was included in the equation. This strongly suggests that forb cover takes strong precedence over grass height for determining nest success. The individual P-values for grass cover ranged from 0.41 to 0.85, with only one value less than 0.62. This strongly suggests grass cover has little predictive value for nest success.

When nest success was regressed with total shrub cover and one or more of the herbaceous variables, the regression coefficients for forb cover were always positive. For grass height the regression coefficients were always negative (Table 5b). The range of the regression coefficients for forb cover was from 2.9 to 5.17, compared to -0.39 to -0.83 for grass height. This indicates that for each 1% increase in forb cover, nest success will increase about 3 to 5%, provided the other variables remain constant. For each 1 cm increase in grass height, nest success will decrease up to 0.83%, provided all other variables remain constant. These results suggest a stronger positive biological influence for nest success from forb cover than from herbaceous height. This result should not be interpreted to mean perennial grasses are unimportant for sage grouse. A good component of perennial herbaceous species (particularly grasses) is required to maintain ecological resilience of sagebrush communities following fire and/or other disturbances that remove the shrub canopy. A reasonable inference is that sage grouse are better served by an abundance of perennial grasses in the plant community, than by grasses with a specific mean height.

Results from the simple regression analysis strongly indicate that no single vegetation attribute should be used to assess or monitor vegetation in sage grouse nesting habitat. All of the variables at both nest sites and nest areas had poor to marginal (total shrub cover at nest site) predictive relationships with nest success. Results from the multiple regression analysis indicate that total shrub cover and forb cover (nest site and nest area) are the two variables that best predict nest success. Sagebrush undoubtedly must be part of the total shrub component, but once sufficient amounts of sagebrush are available to permit successful nesting other vegetation attributes apparently have a better relationship with nest success.

It remains unclear how the specific values identified in the WAFWA guidelines were developed. None of the data analyzed shows clear (defined) changes in nest success at or near any of the values identified in the WAFWA guidelines. This analysis, however, does provide some indirect support for the sagebrush cover guideline of 10-25% canopy cover. Although no relationship was found between nest success and sagebrush cover, there was a weak relationship between nest success and total shrub cover at the nest site (Figure 1f). This relationship predicts that nest success will fall below 40% when total shrub cover at nest sites reaches 40 to 45%. Some data points for shrub cover at the nest site are biased high, compared to the surrounding area, because line transects used to measure shrub cover at the nest site always originated from the center of the nest, which is almost always under a shrub. Some studies used transects only 1 m long, while other studies used longer transects (typically 5 to 20 m long). Cover values obtained from short transects centered directly over a shrub will be much larger than cover values recorded on longer transects. It is likely that nest success begins to decline when total shrub cover for the general area is between 25 and 40%; however, there are insufficient data to determine a specific upper “threshold” cover value for all sagebrush sites. The WAFWA guidelines’ recommendation that local knowledge and conditions be incorporated into management decisions is very appropriate.

The results of the analyses in this paper strongly suggest that use of the specific herbaceous height and cover values in the WAFWA guidelines as minimum standards for habitat structure across the entire distribution of sage grouse is inappropriate. The WAFWA guidelines do not recommend this approach; however, individuals involved with local planning efforts have attempted to transform the guidelines into minimum standards for assessing and/or monitoring sage grouse habitat. There is no statistical or biological evidence to support global minimum values for any herbaceous attribute, or for shrub cover.

It is questionable whether the WAFWA guidelines should have included specific height and cover values for herbaceous variables. The inclusion of discrete values unintentionally converts the guidelines into minimum standards. Good nest success can be found across a broad range of herbaceous height and cover values, as can poor nest success (Tables 2a-2f). Also, these herbaceous variables interact with total shrub cover at nest sites and undoubtedly other unmeasured/unknown factors (e.g., size and shape of habitat patches, size and shape of sagebrush canopies, and distance from water) to influence nest success. How these unknown factors interact with herbaceous height and cover needs to be identified through well-controlled long-term research. The WAFWA guidelines would have been less contentious, and probably more accurate, if they had not included specific numeric values. A guideline by definition is an instruction about the best way to do or accomplish something. A standard refers to a minimum level of quality that is acceptable. For herbaceous height, a reasonable guideline would have been that ecological sites should be managed to increase or maintain those desired perennial grass species that produce taller and/or denser leaves. Once the WAFWA guidelines published the specific value of 18 cm, the value became a standard, whether intended as such or not. Standards are discrete entities, while guidelines provide broad direction.

This analysis found that nest success declined slightly with increasing grass height but the relationship is so poor it is probably meaningless. There is no evidence of any relationship between perennial grass cover and nest success. Perennial grasses are necessary to maintain site resilience following disturbance; however, there is no evidence that nesting sage grouse need a specific amount to have good nest success. When grass cover (or abundance) is adequate to maintain site resilience, any additional grass cover (or height) is unlikely to provide significant additional benefits to nesting sage grouse. The important habitat management question becomes, what amount of perennial grass cover, or what density of perennial grass plants, is necessary to maintain site resilience for the different ecological sites that inhabit a landscape.

The WAFWA guideline for 10% cover from forbs seems reasonable, but only if placed in the context of site potential. Ten percent cover is reasonable provided the ecological sites and the successional stage on the ecological sites can regularly produce ≥10% forb cover. Locations that lack an intrinsic potential to produce 10% forb on a regular basis, probably are not good quality (i.e., reliable) nesting habitat and never will be. In Nevada, this probably includes most Wyoming sagebrush ecological sites, and particularly those whose successional state has high canopy cover from sagebrush. In Nevada, most of the area inhabited by Wyoming sagebrush is part of the sagebrush semi-desert (West 1983a). Annual and spring precipitation is less in Nevada's sagebrush semi-desert than in the sagebrush steppe (Schultz and McAdoo 2002). The sagebrush semi-desert also has more variation in precipitation between years than does the sagebrush steppe (West 1983a, West 1983b). Less annual and spring precipitation, combined with more variation in precipitation suggests that Wyoming sagebrush sites in Nevada have a highly variable forb component between years. The quality of nesting habitat on most of Nevada's Wyoming sagebrush rangelands probably is inconsistent, unless there is a very heterogeneous patchwork of successional stages, at relatively small spatial scales. Forb production generally is much more reliable on higher elevation mountain sagebrush sites, particularly at the high end of the range for sagebrush cover.

Are the Data Adequate?

Two important questions are: 1) are there sufficient data to permit an analysis between nest success and herbaceous vegetation attributes; and 2) were the methodologies in previous studies used appropriately and/or applied consistently? Regardless of how much data are available some always believe additional data provides more information and better answers. This generally is true when data points are few and less true as replication and sample size increase. Tables 2a-2f identify 19 data points for nest success and at least 14 corresponding data points at nest sites for grass height, grass cover, forb cover, live grass and forb cover, and total shrub cover. A similar number of data points are available for vegetation attributes at random locations, but generally fewer for nest areas. These data are from studies across a wide variety of habitat occupied by sage grouse. Given the spatial and temporal range of the studies analyzed, the relatively large number of studies, and the wide spread of the data points (Figures 1a-1f) it appears there are an adequate amount of data to determine if there are global relationships between nest success and grass height, grass cover, forb cover, live grass and forb cover, or total shrub cover at nest sites. There is no evidence that if twenty additional studies were conducted, with the individual study sites randomly selected, the data points would have a substantially different distribution and change the relationships (or lack thereof) found in the analyses presented in this paper.

There are fewer data points for nest success and sagebrush cover at the nest (n=11). Additional data points for only sagebrush cover are unlikely to improve our fundamental knowledge about relationships between nest success and sagebrush. Biologists have clearly demonstrated that sage grouse require sagebrush to survive. Once sufficient sagebrush cover is present to permit nesting and provide for successful nests, other vegetative and non-vegetative factors appear to have a greater influence on nest success rates.

This analysis indicates a need to ensure that studies about nest success collect the same suite of data. The multiple regression results (Tables 5a and 5b) clearly show that the addition of variables to each regression analysis rapidly results in fewer data points included in the analysis (i.e., fewer degrees of freedom). As the number of data points decline there is an increased risk that the statistical result does not accurately portray conditions across the broad region (and conditions) inhabited by sage grouse. The number of data points necessary to determine if relationships exist between nest success and two or more herbaceous attributes is unknown, but having 19 data points for each attribute would have resulted in a stronger analysis (and conclusions) than when only 5 or 6 data points were available.

Table 3 illustrates a potential problem with data quality. Only three studies defined specifically how they measured grass height. Ironically data from two of these studies were not used in any regression analysis because the values reported were not average height but percent cover of grasses above a minimum height (18 cm). It is quite probable that one or more of the remaining studies measured height differently than in the other studies. The data points in Figure 1a may be comparing apples and oranges because different studies used different measurement techniques. This condition may change the predictability of the relationship. It could be better or worse.

A similar situation occurs with how shrub cover data were collected at the nest site. All of the studies analyzed in this paper defined the nest site as an area centered over the nest. It was as small as 3.14 m^2 (Sveum et al. 1998) and as large as 1,256 m^2 (Apa 1998 and several other studies). Since the nest was almost always located under a shrub, small nest areas will have cover biased high compared to studies that defined nest sites as larger areas.

Conclusions

- Authors of the WAFWA guidelines did not adequately analyze all of the studies they cited (used) in their development of herbaceous height and cover guidelines. Existing data do not support the specific values listed for height and cover in the guidelines. Simple linear regression analysis of data from 13 studies indicates there is no relationship between nest success and any single measurement of herbaceous height and/or cover.
- The poor relationship between nest success and any single herbaceous attribute indicates it is inappropriate to use one or more of the herbaceous vegetation measurements discussed in this paper (or the WAFWA guidelines) as the sole or primary monitoring criteria for adjusting other land uses (primarily livestock grazing) in sage grouse nesting habitat.
- The multiple regression analyses indicate that forb cover has good relationships with nest success for sage grouse. The relationship, however, has a strong interaction with total shrub cover. Any monitoring or assessment measurement that uses only forb cover will provide little information about the overall quality of the habitat for nesting sage grouse, particularly with respect to nest success. As previously noted, forb cover as a stand alone variable has a poor relationship with nest success.
- There was no evidence from the multiple regression analyses that grass height or grass cover had strong, positive, relationships with nest success. Grass height was a variable in only one statistically significant regression equation, and it had a slightly negative relationship with nest success. The P-value for grass height approached significance only when forb cover was included in the regression equation, and forb cover had a substantially smaller P-value than did grass height (Table 5b). If perennial grass species are abundant enough to maintain site resilience following disturbance, nesting sage grouse appear to receive little if any additional benefit from having more grass cover or taller grass height.
- The WAFWA guidelines define how to measure herbaceous vegetation height (i.e., droop height) differently than the original studies that defined the measurement. Methodology for this and other attributes needs to be reasonably consistent for results (and their important concepts) to be extrapolated beyond the area studied.
- Most studies that measured herbaceous plant height did not define their methodology. This makes their measurement non-repeatable and interpretation of their height data subject to substantial error.
- Residual herbaceous height and cover have been poorly documented with respect to nest success. Its role, if any, needs clarification. The studies analyzed in this paper measured herbaceous height and cover at the end of the nesting period, not at the beginning or middle. Current year herbaceous growth may or may not have started at the time of nest initiation, and undoubtedly did not have a constant rate of leaf elongation during the incubation period. If residual height is taller than new growth at nest initiation,

the duration that residual height exceeds new growth may have an important influence for nest success. There is no evidence this has been studied.

- The lack of a clear relationship between nest success and herbaceous height and/or cover does not mean these structural attributes are unimportant and should be completely discounted. It is intuitive that a ground nesting species, subject to ground and aerial predators, receive some benefit from tall and abundant herbaceous species. Results from this analysis indicate that biologists have a poor understanding about how herbaceous vegetation structure interacts with other environmental and ecological variables, and their collective influence for nest success. Research needs to identify these interactions, understand their annual fluctuations, and learn how they affect short and long-term population dynamics of sage grouse.
- The guidelines should be interpreted strictly as guidelines. The WAFWA guidelines would have been less controversial, and probably more accurate, if they had avoided specific values, but rather stated that understory perennial vegetation should be managed to promote species that produce tall and abundant perennial leaf growth. A similar conclusion was drawn by Gregg (1991). Tall growing perennial herbaceous plants should provide better concealment when the base of the shrub canopy is routinely elevated above ground level. Abundant (i.e., dense, multilayered) leaves should provide better horizontal screening cover than sparsely leaved plants.
- Sage grouse are often described as a landscape level species. They typically use different components of the landscape to meet seasonal needs, but most or all of the sagebrush landscape during the course of the year. There has been substantial research focused at nest sites and nest areas, which are mere points on the landscape. Little, if any, work has integrated these point data with large scale habitat and environmental information. It is unlikely that ecological problems associated with a landscape level species will be understood sufficient enough to improve the management of sage grouse and their habitat by focusing most energy and research at point scales.
- Ecologists need to better understand the role of forbs for nest success, and the potential for individual ecological sites and their various successional stages to produce ample and reliable amounts of forbs. This requires a better understanding of patch dynamics (internal and between patch) at the landscape scale and across time. That is, does a landscape have a high or low intrinsic potential to produce abundant forbs, and is this potential widespread, or restricted to specific locations?

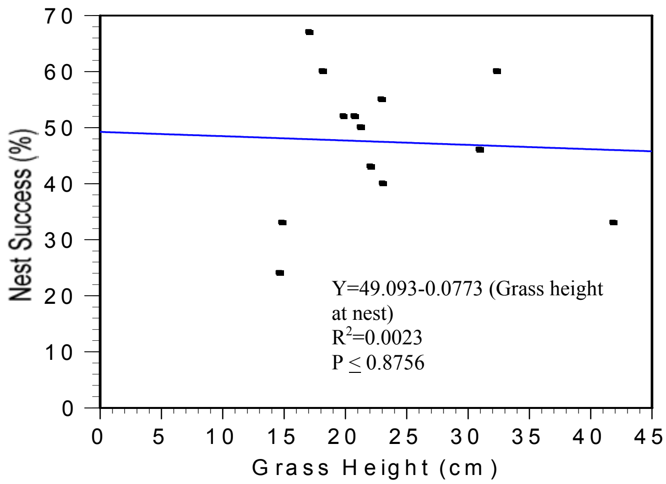

Figure 1a. Relationship between nest success and the mean height of live grass plants at the nest site.

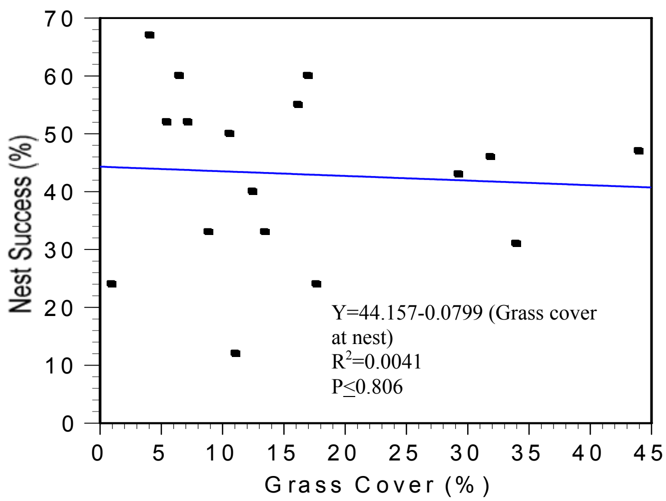

Figure 1b. Relationship between nest success and mean canopy cover for live grass plants at the nest site.

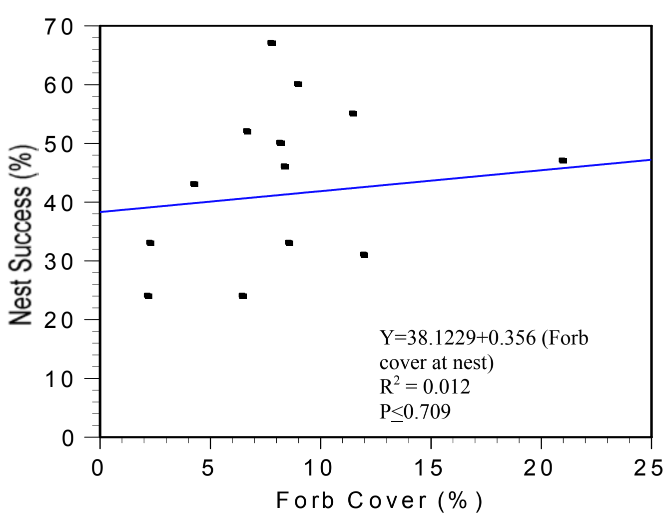

Figure 1c. Relationship between nest success and mean forb canopy cover at the nest site.

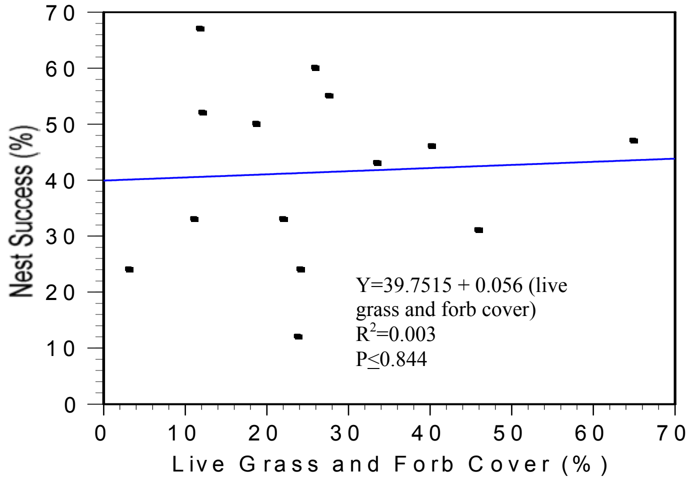

Figure 1d. Relationship between nest success and mean canopy cover for live grass and forbs at the nest site.

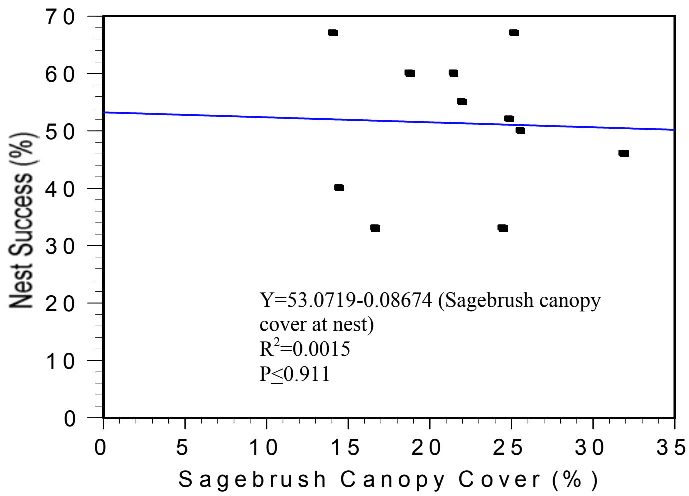

Figure 1e. Relationship between nest success and mean sagebrush canopy cover at the nest site.

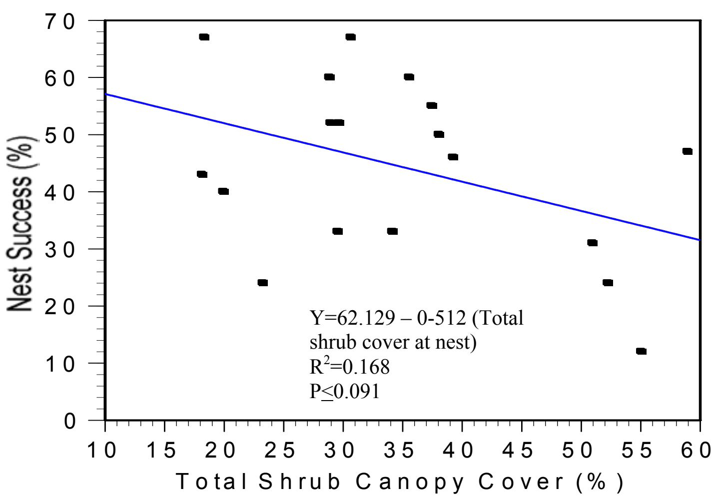

Figure 1f. Relationship between nest success and mean total shrub canopy cover at nest site.

Table 5a. Results of multiple regression analysis for nest success (dependent variable), sagebrush cover at nest sites, and various herbaceous attributes. Regression equations with three or fewer degrees of freedom are not shown.

Dependent/ Independent Variables	R^2	Adjusted R^2	F	P	Coefficient	SE	P
Nest Success (df=9)	0.11	-0.14	0.44	0.661	52.2910	26.302	0.0871
Sagebrush Cover at Nest					0.2938	0.8582	0.7421
Grass Height at Nest					-0.3824	0.5191	0.4852
Nest Success (df=4)[a]	0.73	0.45	2.64	0.275	458.021	181.60	0.1278
Sagebrush Cover at Nest					-14.584	6.5614	0.1563
Grass Height at Nest Area					-4.4415	1.9321	0.1483
Nest Success (df=9)	0.13	-0.12	0.53	0.609	39.5856	18.746	0.0726
Sagebrush Cover at Nest					0.69792	0.8529	0.4402
Grass Cover at Nest					-0.4523	0.5328	0.4240
Nest Success (df=4)	0.08	-0.82	0.10	0.910	-12.952	153.71	0.9405
Sagebrush Cover at Nest					1.8442	5.5257	0.7593
Grass Cover at Nest Area					2.0405	4.5933	0.7003
Nest Success (df=7)	0.28	-0.01	0.97	0.442	16.9831	30.3090	0.5994
Sagebrush Cover at Nest					0.5711	1.0042	0.5942
Forb Cover at Nest					2.4298	1.7862	0.2318
Nest Success (df=7)	0.01	-0.38	0.04	0.964	43.2863	28.0927	0.1840
Sagebrush Cover at Nest					0.3154	1.1826	0.8004
Live Grass/Forb Cover at Nest					-0.0593	0.5478	0.9180
Nest Success (df=7)	0.56	0.24	1.73	0.299	45.1152	31.5511	0.2260
Sagebrush Cover at Nest					-0.0683	0.9577	0.9466
Grass Height at Nest					-0.8782	0.5124	0.1807
Forb Cover at Nest					3.6123	1.71537	0.1030
Nest Success (df=7)	0.55	0.21	1.63	0.317	1.7545	28.5311	0.9539
Sagebrush Cover at Nest					1.2701	0.9955	0.2711
Grass Cover at Nest					-0.8561	0.5524	0.1961
Forb Cover at Nest					3.3734	1.7887	0.1052
Nest Success (df=7)	0.59	0.05	10.9	0.490	26.4793	53.5673	0.6550
Sagebrush Cover at Nest					0.5362	1.6904	0.7718
Grass Cover at Nest					-0.4391	0.9512	0.6758
Forb Cover at Nest					3.8260	1.9691	0.1473
Grass Height at Nest					-0.5402	0.9499	0.6093

a. Dependent variables have high collinearity (i.e., highly correlated to one another). Reliable estimates of the individual regression coefficients could not be determined.

Table 5b. Results of multiple regression analysis for nest success (dependent variable), total shrub cover at nest sites, and various herbaceous attributes. Statistically significant (P<0.10) equations have a bold typeface.

Dependent/ Independent Variables	R^2	Adjusted R^2	F	P	Coefficient	SE	P
Nest Success (df=12)	0.18	0.01	1.07	0.379	30.5723	16.9331	0.1011
Total Shrub Cover at Nest					0.8499	0.5845	0.1766
Grass Height at Nest					-0.3908	0.5077	0.4592
Nest Success (df=6)	0.15	-0.27	0.36	0.719	39.1763	26.8932	0.2189
Total Shrub Cover at Nest					0.6439	0.9039	0.5156
Grass Height at Nest Area					-0.4619	0.6773	0.5327
Nest Success (df=16)	0.12	-0.00	0.98	0.399	57.9034	11.7150	0.0002
Total Shrub Cover at Nest					-0.4974	0.3609	0.1897
Grass Cover at Nest					0.1802	0.3639	0.6282
Nest Success (df=10)	0.26	0.07	1.41	0.299	61.8291	15.2369	0.0036
Total Shrub Cover at Nest					-0.6399	0.3813	0.1318
Grass Cover at Nest Area					0.2482	0.5201	0.6460
Nest Success (df=13)	0.42	0.31	4.00	0.049	65.6236	12.2782	0.0002
Total Shrub Cover at Nest					-1.3197	0.4737	0.0177
Forb Cover at Nest					2.9884	1.2025	0.0303
Nest Success (df=8)	0.78	0.70	10.53	0.011	62.0096	9.4356	0.0006
Total Shrub Cover at Nest					-1.4634	0.3299	0.0044
Forb Cover at Nest Area					3.8284	0.9253	0.0061
Nest Success (df=13)	0.19	0.05	1.33	0.303	58.1761	13.873	0.0015
Total Shrub Cover at Nest					-0.7098	0.4385	0.1338
Live Grass and Forb Cover at Nest					0.3859	0.4385	0.2682
Nest Success (df=8)	0.37	0.16	1.77	0.249	48.4634	16.3038	0.0249
Total Shrub Cover at Nest					-0.6772	0.3999	0.1413
Live Grass and Forb Cover at Nest					0.6151	0.4198	0.1932
Nest Success (df=12)	0.18	-0.09	0.66	0.599	30.4763	17.8215	0.1214
Total Shrub Cover at Nest					0.8603	0.6174	0.1969
Grass Cover at Nest					0.0888	0.4732	0.8552
Grass Height at Nest					-0.4488	0.6170	0.4855

Table 5b (continued).

Nest Success (df=6)	0.21	-0.57	0.27	0.844	21.4010	47.6179	0.6836
Total Shrub Cover at Nest					1.1680	1.4869	0.4889
Grass Cover Nest Area					0.5875	1.2242	0.6641
Grass Height at Nest Area					-0.7198	0.9255	0.4935
Nest Success (df=9)[a]	0.65	0.38	2.35	0.187	45.5006	19.1505	0.0635
Total Shrub Cover at Nest					-0.4745	0.8157	0.5860
Grass Cover at Nest					0.0834	0.3954	0.8412
Grass Height at Nest					-0.8297	0.5421	0.1864
Forb Cover at Nest					5.0000	1.9564	0.0509
Nest Success (df=13)[a]	0.42	0.25	2.45	0.124	65.9158	12.9108	0.0005
Total Shrubs Cover at Nest					- 1.3210	0.4956	0.0237
Forb Cover at Nest					3.1311	1.4094	0.0506
Grass Cover at Nest					-0.0847	0.3769	0.8267
Nest Success (df=8)	0.81	0.69	7.06	0.030	67.3497	11.2898	0.0019
Total Shrub Cover at Nest					-1.5754	0.3579	0.0070
Forb Cover at Nest Area					4.4217	1.1499	0.0121
Grass Cover at Nest Area					-0.3410	0.3801	0.4108
Nest Success (df=9)	0.65	0.48	3.72	0.080	46.0853	17.3748	0.0379
Total Shrub Cover at Nest					-0.5029	0.73766	0.5208
Forb Cover at Nest					5.0466	1.7824	0.0299
Grass Height at Nest					-0.7819	0.4514	0.1340
Nest Success (df=4)	0.96	0.83	7.44	0.262	53.1208	12.3242	0.1451
Total Shrub Cover at Nest					-0.8681	0.5020	0.3338
Forb Cover at Nest Area					5.1789	1.2024	0.1452
Grass Height at Nest Area					-0.7193	0.2973	0.2495

a. Insufficient data to conduct same analysis for same herbaceous attributes using data for nest area.

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