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Use of Kendall's coefficient of concordance to assess agreement among observers of very high resolution imagery

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Ground-based vegetation monitoring methods are expensive, time-consuming and limited in sample size. Aerial imagery is appealing to managers because of the reduced time and expense and the increase in sample size. One challenge of aerial imagery is detecting differences among observers of the same imagery. Six observers analysed a set of 1-mm ground sample distance aerial imagery for graminoid species composition and important ground-cover characteristics. Kendall's coefficient of concordance (W) was used to measure agreement among observers. The group of six observers was concordant when assessed as a group. When each of the observers was assessed independently against the other five, lack of agreement was found for those graminoid species that were difficult to identify in the aerial images.

Keywords: 1-mm GSD imagery; grassland monitoring; rangeland monitoring; *SamplePoint*; very large scale aerial imagery

1. Introduction

Monitoring natural ecosystems has been the subject of a plethora of books, manuals and articles for many decades (e.g. Clements 1928, Levy and Madden 1933, Canfield 1941, 't Mannetje and Haydock 1963, Senay and Elliot 2000, Wang *et al*. 2004, Toevs *et al*. 2011). This is particularly true of public rangelands due to their vast area and federal mandates requiring vegetative monitoring. On-the-ground monitoring requiring the physical presence of professionals in the field is considered the standard for monitoring rangelands; however, the type of terrain, geographical area to be covered, number of professionals available, methods used and funding all limit the number of plots that can feasibly be monitored in one growing season by traditional methods (Owens *et al*. 1985, Pellant *et al*. 1999, West 1999, Booth and Tueller 2003, Forbis *et al*. 2007).

Aerial imagery is appealing to managers for a number of reasons. Firstly, the sample size (i.e. the number of plots) can be increased dramatically without incurring substantial additional expense. Secondly, images are a record of resource conditions

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that can be re-examined, whereas traditional non-imaging methods record field observations without a practical means of verification and exclude the possibility of re-sampling present conditions at a future date. However, the use of imaging methods to provide a means for data verification depends on the ability of observers to interpret images of resource conditions in the same way – that is, to have concordance.

Any type of monitoring, whether ground- or imagery-based, is not without disadvantages. There are many types of errors associated with monitoring (e.g. between years [Kennedy and Addison 1987], methods [Whitman and Siggiersson 1954, Kercher *et al*. 2003] and plot sizes [Klimeš 2003, Heywood and DeBacker 2007]). Our research focused on detecting differences among observers (Smith 1944, Bråkenhielm and Qinghong 1995, Booth *et al*. 2005, Vittoz and Guisan 2007).

Bråkenhielm and Qinghong (1995) and Vittoz and Guisan (2007) utilized paired *t*-tests to detect differences between observers, while Smith (1944) combined all observers and used an analysis of variance (ANOVA) to determine differences between the group of observers on different days. Booth *et al*. (2005) utilized an ANOVA with mean separation test to detect differences among observers. A mean separation test and Kappa statistic (a statistical measure of inter-rater agreement) can be appropriate analyses when n is small, but become cumbersome when n is large. Additionally, χ^2 tests have a low Type I error and are overly conservative when the number of observers is less than 20 (Legendre 2004, 2005).

Kendall's coefficient of concordance (W) is a measure that uses ranks to assess agreement between observers (Kendall and Babington Smith 1939) similar to Spearman's rank correlation coefficient[1] (1904). Our objective was to test the utility of Kendall's W for determining the level of agreement among six observers.

2. Methods

2.1. Study area

The imagery used in this study was collected in the Grand River National Grasslands (GRNG; lat. 45°55′ long. 102°32′) near Hettinger, ND. The study area is a typical mixed-grass prairie of the northern Great Plains of the central USA, characterized by western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve), blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth), prairie junegrass (*Koeleria macrantha* [Ledeb.] Schult.) and threadleaf sedge (*Carex filifolia* Nutt., Küchler 1964, Hansen 2008, USDA NRCS 2012). This area was heavily farmed during the first half of the twentieth century (Hansen 2008). Several non-native grasses are of concern in this area, including smooth brome (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.) and crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), which was generally selected for reseeding efforts and has populated abandoned fields (USDA NRCS 2012).

2.2. Imagery

True colour, digital, very large scale aerial (VLSA) images were collected between 15 July and 1 August 2007. These dates were selected to maximize the likelihood that the cool season graminoids would have inflorescence and warm season graminoids have sufficient growth to be identifiable in the imagery. Images were acquired by a sport aircraft (225 kg empty weight) at approximately 100 m above ground level and 23.5 m s^{-1} average ground speed (FAA 2004). A 16.7-megapixel Canon EOS 1DS

Mark II (Canon USA, Lake Success, NY, 4992 × 3328 pixels) configured with an 840-mm focal-length lens captured images with an average ground sample distance (GSD; a measure of digital image resolution) of approximately 1 mm and 3 × 4 m field of view. Booth and Cox (2008) and Moffet (2009) described the equipment and sampling methods.

A systematic grid of 100 software-generated points was overlaid on the images using the program *SamplePoint* (Booth *et al*. 2006). The points were marked by digital crosshairs having a nine-pixel array at the centre (Figure 1). Observers classified the centre pixel of the array as representing an individual species or ground cover, and the selection was automatically written to a comma separate value (CSV) file.

2.3. *Observers*

Six observers classified the same set of pixels for each image into one of the 11 ground-cover categories. The ground-cover categories were divided into three groups: biotic, abiotic and confounding. The biotic group included six graminoids which were common, and we felt were important indicator species in the study area. Those species were western wheatgrass, blue grama, needle and thread, sedge species (which included threadleaf sedge, needle leaf sedge {*Carex duriuscula* C.A. Mey.}

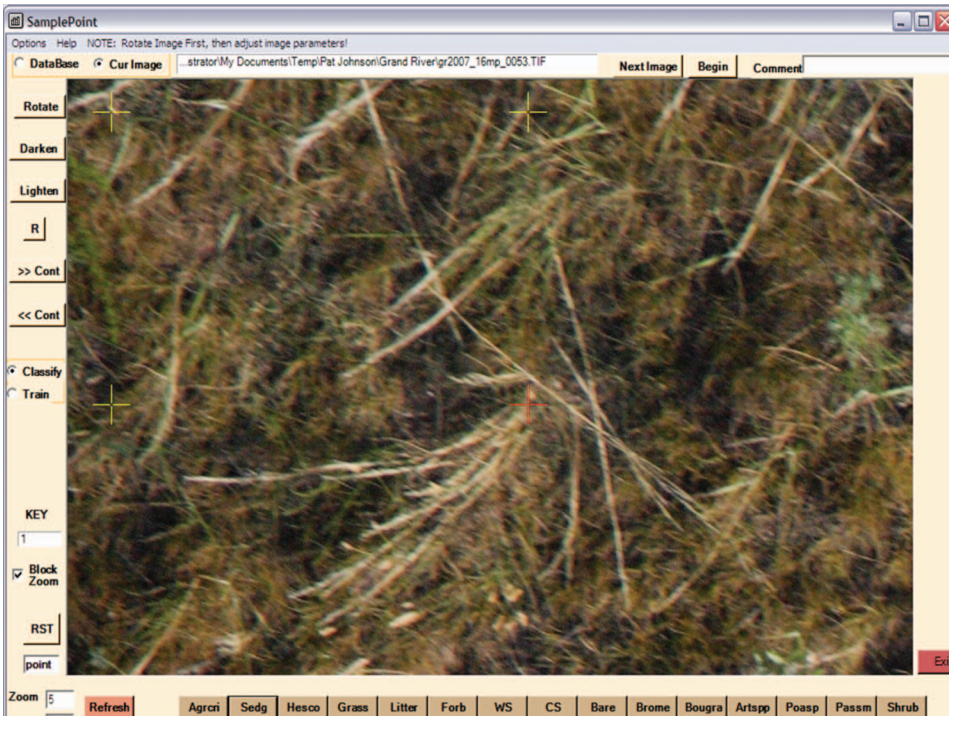

Figure 1. *SamplePoint* is a software program that generates a systematic grid of digital crosshairs on an image. The centre array of pixels of the crosshair is open and an observer classifies the contents of that array into user-defined categories. The red crosshair (in the centre of the image) is the active array being classified. The classification categories appear at the bottom of the screen, and when an observer clicks the button with the category of their choice, the selection is automatically written to a CSV file.

and sun sedge {*Carex inops* L.H. Bailey ssp. *heliophila* [Mack.] Crins}), bluegrass species (which included Kentucky bluegrass, Sandberg's bluegrass {*Poa secunda* J. Presl} and Canada bluegrass {*Poa compressa* L.}) and crested wheatgrass. The abiotic group included three ground-cover categories generally considered important indicators of ecological change (Booth and Cox 2008): bare ground (bare mineral soil), litter (which included senesced plant material, duff and dung) and rock. The confounding group included two variables which were confusing to observers: grass (in which a specific graminoids species could not be determined) and shadow.

The observers were all females of various ages that had a range of on-the-ground field experience in the study area (Table 1). We deliberately chose observers who had a range of experiences working with imagery, general field experience and study area-specific experience. All observers had at least 3 years of plant identification experience. Observers A, B and C were under 30 years of age and had at least 2 years of experience in the study area. Observers D, E and F were over 30 years of age and had 5 days or less experience in the study area.

2.4. Statistical analysis

Kendall's coefficient of concordance (W) was applied to observations from all observers for each ground-cover category independently. Kendall's W is calculated by Equation (1):

$$W = \frac{12S}{p^2(n^3 - n) - pT} \tag{1}$$

where S is the sum-of-squares from row sums of ranks R_i (Equation (2)), n is the number of objects, p is the number of judges and T is a correction factor for tied ranks (Equation (3); Siegel 1956, p. 234).

$$S' = \sum_{i=1}^{n} R_i^2 = SSR \tag{2}$$

$$T = \sum_{k=1}^{m} (t_k^3 - t_k) \tag{3}$$

where S is the sum-of-squares from row sums of ranks R_i, m is the number of groups and t_k is the number of tied ranks in each (k) of m groups (Siegel 1956, p. 234).

Table 1. Six observers classified a set of 146 one-millimetre GSD digital aerial images into 11 ground-cover categories. The observers were all female, ranged in age from 18 to 55 years of age and had various imagery, general field and study area-specific experience levels.

	Observer					
Characteristics and experiences	A	B	C	D	E	F
Gender	F	F	F	F	F	F
Age (years)	28	18	22	40	55	49
SamplePoint/VLSA imagery experience	2 years	7 days	7 days	3 years	7 days	8 years
General field experience (years)	8	3	4	20	20	30
Study area-specific experience	5 years	3 years	2 years	5 days	0 days	0 days

This calculation was completed using the software program *Kendall W* which automatically transforms ordinal scores from each observer into cardinal ranks (Legendre 2004, 2005). The overall null hypothesis of global concordance tested was that the six observers produced independent rankings for each ground-cover characteristic for all images (i.e. the six observers were not concordant with one another). When this global concordance hypothesis was rejected, we tested the *a posteriori* hypothesis of independent concordance that a specific observer produced a ground-cover characteristic ranking that was independent of the other five. The independent *a posteriori* concordance tests were run with $n = 146$ (number of images) and $p = 6$ (number of observers). Concordance analyses were run independently for each of the 11 ground-cover categories with 9999 permutations to test the contribution of individual observers to the global concordance (W). Permutation testing is a more robust test than the χ^2 test and results in more accurate Type I error (Legendre 2005). Perfect agreement is indicated by values of 1, while no agreement is indicated by values of 0.

3. Results

3.1. Global concordance (W)

The six observers were concordant with one another (null hypothesis #1 was rejected; $P = 0.001$). Global concordance (W) values among observers ranged from 0.34 (unidentifiable grass species) to 0.88 (sedge species; Table 2).

3.2. Individual concordance (Wj)

Within each of the ground-cover categories, observers were generally concordant with one another (null hypothesis #2 was rejected; $P \leq 0.05$). However, there are several exceptions in which individual observers were not concordant with the rest of

Table 2. Ordinal scores from the six observers of a set of 1-mm GSD digital aerial images. The scores were transformed into cardinal ranks and analysed for agreement using Kendall's coefficient of concordance (W). The null hypothesis, that is, the six observers were not concordant with each other, was rejected. All P values were significant at $\alpha = 0.001$.

Ground-cover category	W
Biotic	
Western wheatgrass[1]	0.43
Blue grama[2]	0.43
Needle and thread[3]	0.64
Sedge species[4]	0.88
Bluegrass species[5]	0.30
Crested wheatgrass[6]	0.86
Abiotic	
Bare ground	0.64
Litter	0.44
Rock	0.59
Confounding	
Grass[7]	0.34
Shadow	0.46

Notes: [1]*P. smithii* [Rydb.] A. Löve. [2]*B. gracilis* [Willd. ex Kunth] Lag. ex Griffiths. [3]*H. comata* [Trin. & Rupr.] Barkworth. [4]*C. filifolia* Nutt., *C. inops* L.H. Bailey ssp. *heliophila* [Mack.] Crins and *C. duriuscula* C.A. Mey. [5]*P. pratensis* L., *P. compressa* L. and *P. secunda* J. Presl. [6]*A. cristatum* [L.] Gaert. [7]Specific graminoid species could not be determined.

the observers (Table 3): western wheatgrass (observer F), blue grama (observer D), bluegrass species (observers E and F) and unidentifiable grass species (observers A, B and C).

4. Discussion

4.1. Global concordance (W)

The six observers in our trial were concordant with each other, meaning that when one observer had a high number of observations of a particular ground-cover category, there was a trend for all the observers to have high numbers for that category. This agreement was not always strong, however. For western wheatgrass and blue grama, the two dominant native grasses, the concordance was moderate to low ($W < 0.5$). Western wheatgrass occurs as a single-stemmed plant that does not always produce an inflorescence (Johnson and Larson 2007). The likelihood of a single-stemmed plant being represented by a sample point is much lower than for plants occurring as a bunch or clump (Brady *et al.* 1991). Blue grama typically has a moderately caespitose growth form but tends to occur underneath the canopy of other taller-statured plants (Larson and Johnson 2007). The two highest concordance values were for native sedge species and an introduced perennial bunchgrass, crested wheatgrass. There may be several reasons for this. Both the sedge species and crested wheatgrass have distinct colours, caespitose growth forms, tend to grow in relatively pure stands and are generally abundant in the prairie.

4.2. Individual concordance (Wj)

Individual observers were generally concordant when compared to the other five observers. Observer D lacked concordance in the blue grama category. As discussed

Table 3. Ordinal scores from the six observers of a set of 1-mm GSD digital aerial images. Scores were transformed into cardinal ranks and analysed for agreement using Kendall's coefficient of concordance (*Wj*). The null hypothesis, that is, an individual observer was not concordant with the other five, was rejected for most categories.

	Observer (*Wj*)					
Ground-cover category	A	B	C	D	E	F
Biotic						
Western wheatgrass	0.45**	0.49**	0.41**	0.39**	0.42**	0.17
Blue grama	0.50**	0.45**	0.48**	0.16	0.35**	0.25*
Needle and thread	0.69**	0.74**	0.65**	0.71**	0.58**	0.46**
Sedge species	0.86**	0.89**	0.86**	0.89**	0.88**	0.88**
Bluegrass species	0.34**	0.31**	0.28**	0.38**	0.26	0.23
Crested wheatgrass	0.84**	0.88**	0.86**	0.87**	0.87**	0.83**
Abiotic						
Bare ground	0.61**	0.66**	0.66**	0.64**	0.58**	0.71**
Litter	0.46**	0.39**	0.41**	0.46**	0.46**	0.44**
Rock	0.65**	0.69**	0.70**	0.56**	0.69**	0.56**
Confounding						
Grass	0.24	0.19	0.27	0.35**	0.39**	0.31**
Shadow	0.54**	0.27*	0.47**	0.47**	0.43**	0.50**

Notes: *Significant at $\alpha = 0.05$. **Significant at $\alpha = 0.01$.

in the previous section, blue grama may be difficult to correctly identify because it occurs under the canopy of taller-statured plants. Observer F lacked concordance in the western wheatgrass category. Western wheatgrass does not always produce an inflorescence and may be difficult to identify in imagery. Observers E and F both lacked concordance for bluegrass species. The most common bluegrass that occurs in GRNG is Kentucky bluegrass (*P. pratensis* L.). Kentucky bluegrass can be difficult to identify, even on the ground. This introduced grass is strongly rhizomatous, does not always produce inflorescence and has narrow leaves (3.2–6.4 mm) that tend to fold or curl (Johnson and Larson 2007, USDA NRCS 2012).

Observers A, B and C lacked concordance in the unidentifiable grass category. It may be that Observers A, B and C were simply able to identify more grasses. It could also be that Observers D, E and F, who lacked concordance in individual species categories, placed those points into the unidentifiable grass category.

4.3. Environment

The northern mixed-grass prairie has a relatively continuous cover of grass that has challenged individual species identification by remote sensing technologies for many years. This area is populated by both warm and cool season species which present phenological challenges for point-in-time monitoring (e.g. the way this imagery was used in this study). One of the advantages of aerial imagery is that additional sampling periods could be added throughout the growing season to address the phenological changes occurring on the landscape.

The prairie canopy is heterogeneous and complex, containing a mix of tall-, mid- and short-statured species. This complexity may add to the difficulty of identifying individual species by canopy point sampling. Additionally, the local environmental conditions of the GRNG made it difficult to get a quality set of imagery with the equipment used. Although wind speeds average 18 km h^{-1} (UNL 2011), summer

Figure 2. Imagery collected on the GRNG during the summer of 2007 was subject to considerable motion blur due to wind gusts up to 30 km h^{-1} that forced the sport aircraft to travel at higher speeds than preferable.

Figure 3. Imagery collected on the GRNG during the summer of 2007 was subject to a large number of shadows due to wind gusts up to 30 km h^{-1} during the midday that forced the sport aircraft to fly at non-optimum times of day, such as early morning and late afternoon.

winds are typically more variable and routinely gust up to 30 km h^{-1} (NDSU 2011) around the midday hours. Because of this phenomenon, the aircraft was flown faster than preferable and at non-optimum times, such as early morning and late afternoon. Thus, this set of imagery was subject to considerable motion blur (Figure 2) and a large number of shadows (Figure 3) which may have affected the analysis.

5. Conclusions

We suggest that if there are multiple observers viewing the same imagery, a test of agreement between the observers should be conducted. We caution that Kendall's W does not imply that any particular observer is correct or incorrect, simply whether observers agree or not. Additionally, Kendall's W should not be used to analyse data for which positive and negative correlations have equal importance (Legendre 2005). It should be noted, we were not trying to quantify the reasons that the observers were different, simply to detect differences among their observations of the same set of data. We conclude that Kendall's W is a simple and efficient technique that can be used to assess agreement among groups of observers, especially when evaluating aerial images.

Note

1. The difference between Spearman's rank correlation (r) and Kendall's coefficient of concordance (W) is that only two observers can be compared with Spearman's r and two or more observers can be compared with Kendall's W.

References

Brady, W.W., Cook, J.W., and Aldon, E.F., 1991. *A microplot method for updating loop frequency range trend data: theoretical considerations and a computer simulation*. Fort Collins, CO: USDA-Forest Service Rocky Mountain Forest and Range Experiment Station, RM-RP-295.

Bråkenhielm, S. and Qinghong, L., 1995. Comparison of field methods in vegetation monitoring. *Water, Air and Soil Pollution*, 79, 75–87.
Booth, D.T. and Cox, S.E., 2008. Image-based monitoring software to measure ecological change in rangelands. *Frontiers in Ecology and the Environment*, 6, 185–190.
Booth, D.T. and Tueller, P.T., 2003. Rangeland monitoring using remote sensing. *Arid Land Research and Management*, 17, 455–467.
Booth, D.T., Cox, S.E., and Johnson, D.E., 2005. Detection calibration and other factors influencing digital measurements of ground cover. *Rangeland Ecology and Management*, 58, 598–604.
Booth, D.T., Cox, S.E., and Berryman, R.D., 2006. Point sampling digital imagery with 'SamplePoint'. *Environmental Monitoring and Assessment*, 123, 97–108.
Canfield, R.H., 1941. Application of line interception method in sampling range vegetation. *Journal of Forestry*, 39, 388–394.
Clements, F.E., 1928. *Plant succession and indicators: a definitive edition of plant succession and plant indicators*. New York, NY: H.W. Wilson.
Federal Aviation Administration (FAA), 2004. Airworthiness certification of aircraft and related products. Order 8130.2F.
Forbis, T.A., *et al*., 2007. A method for landscape-scale assessment: application to Great Basin rangeland ecosystems. *Rangeland Ecology and Management*, 60, 209–217.
Hansen, K., 2008. *Plants of the Grand River National Grasslands: 2008*. USDA-Forest Service, Dakota Prairie Grasslands, internal report, 56 pp.
Heywood, J.S. and DeBacker, M.D., 2007. Optimal sampling designs for monitoring plant frequency. *Rangeland Ecology and Management*, 60, 426–434.
Kendall, M.G. and Babington Smith, B., 1939. The problem of *m* rankings. *The Annals of Mathematical Statistics*, 10, 275–287.
Kennedy, K.A. and Addison, P.A., 1987. Some considerations for the use of visual estimates of plant cover in biomonitoring. *Journal of Ecology*, 75, 151–157.
Kercher, S.M., Frieswyk, C.B., and Zedler, J.B., 2003. Estimates of sampling teams and estimation methods on the assessment of plant cover. *Journal of Vegetation Science*, 14, 899–906.
Klimeš, L., 2003. Scale-dependent variation in visual estimates of grassland plant cover. *Journal of Vegetation Science*, 14, 815–821.
Küchler, A.W., 1964. *Potential natural vegetation of the coterminous United States*. New York, NY: American Geographical Company.
Johnson, J.R. and Larson, G.E., 2007. *Grassland plants of South Dakota and the Northern Great Plains*. Revised ed. Brookings, SD: South Dakota State University, College of Agriculture and Biological Sciences, South Dakota Agricultural Experiment Station B566.
Larson, G.E. and Johnson, J.R., 2007. *Plants of the Black Hills and Bear Lodge Mountains*. 2nd ed. Brookings, SD: South Dakota State University, College of Agriculture and Biological Sciences, South Dakota Agricultural Experiment Station B732.
Legendre, P., 2004. *Kendall coefficient of concordance: global test and a posteriori tests of individual judges — program Kendall_W user's guide*. Département de sciences biologiques, Université de Montréal, 8 pp.
Legendre, P., 2005. Species associations: the Kendall coefficient of concordance revisited. *Journal of Agricultural, Biological and Environmental Statistics*, 10, 226–245.
Levy, E.B. and Madden, E.A., 1933. The point method of pasture analysis. *New Zealand Journal of Agriculture*, 46, 267–279.
Moffet, C.A., 2009. Agreement between measurements of shrub cover using ground-based methods and very large scale aerial imagery. *Rangeland Ecology and Management*, 62, 268–277.
North Dakota State University (NDSU), 2011. *North Dakota agricultural weather network*. Available from: http://ndawn.ndsu.nodak.edu/ [Accessed 2 May 2011].
Owens, M.K, Gardiner, H.G. and Norton, B.E., 1985. A photographic technique for repeated mapping of rangeland plant populations in permanent plots. *Journal of Range Management*, 38, 231–232.
Pellant, M., Shaver, P., and Spaeth, K. 1999. Field test of a prototype rangeland inventory procedure in the western USA. *In*: D. Eldridge and D. Freudenberger, eds. *People and rangelands: building the future. Proceedings of the VI International Rangeland Congress*, 19–23 July 1999. Townsville, Queensland, Australia: VI International Rangeland Congress, 766–767.

Senay, G.B. and Elliot, R.L., 2000. Combining AVHRR NDVI and landuse data to describe temporal and spatial dynamics of vegetation. *Forest Ecology and Management*, 28, 83–91.
Siegel, S., 1956. *Nonparametric statistics for the behavioral sciences*. New York, NY: McGraw Hill.
Smith, A.D., 1944. A study of the reliability of range vegetation estimates. *Ecology*, 25, 441–448.
Spearman, C., 1904. The proof and measurement of association between two things. *The American Journal of Psychology*, 15, 72–101.
't Mannetje, L. and Haydock, K.P., 1963. The dry-weight-rank method for botanical analysis of pasture. *Journal of the British Grassland Society*, 18, 268–275.
Toevs, G.R., *et al*., 2011. *Bureau of land management assessment, inventory, and monitoring strategy: for integrated renewable resources management*. Denver, CO: Bureau of Land Management, National Operations Center, BLM/WO/GI-11/014+1735.
United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS), 2012. *The PLANTS database*. Available from: http://plants.usda.gov [Accessed 20 March 2012].
University of Nebraska Lincoln (UNL), 2011. *High Plains Regional Climate Center*. Available from: http://www.hprcc.unl.edu/index.php [Accessed 14 January 2011].
Vittoz, P. and Guisan, A., 2007. How reliable is the monitoring of permanent vegetation plots? A test with multiple observers. *Journal of Vegetation Science*, 18, 413–422.
Wang, C., *et al*., 2004. Soil moisture estimation in a semiarid rangeland using ERS-2 and TM imagery. *Remote Sensing of Environment*, 90, 178–189.
West, N.E., 1999. Accounting for rangeland resources over entire landscapes. *In*: D. Eldridge and D. Freudenberger, eds. *People and rangelands: building the future. Proceedings of the VI International Rangeland Congress*, 19–23 July 1999. Townsville, Queensland, Australia: VI International Rangeland Congress, 726–736.
Whitman, W.C. and Siggiersson, E.I., 1954. Comparison of line interception and point contact methods in the analysis of mixed grass range vegetation. *Ecology*, 35, 432–436.