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Ground-truths or Ground-lies? : environmental sampling for remote sensing application exemplified by vegetation cover data

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Environmental sampling for remote sensing application exemplified by vegetation cover data

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0. Abstract

During time of fast development of computer and sensor technology, ground data sampling strategies have achieved diminished attention in many remote sensing studies. This paper discusses the importance of designing an appropriate sampling scheme of ground data collection for remote sensing applications. The difficulties of achieving a balance between the size and the error of the samples are identified. Different techniques of vegetation cover estimations are evaluated to illustrate parts of the proposed sampling design. The study indicates that traditional methods of ground data collection for remote sensing applications do not have to result in "ground lies". Determination of a reliable and appropriate sampling scheme for the ground data collection should be given a more attention when assuring accurate results in remote sensing studies.

Key words: ground data collection, ground truth, vegetation cover, remote sensing, sampling strategies

1. Introduction

Resource management is making increased use of Geographical Information Systems (GIS). This requires reliable and up-to-date information on the extent, distribution and use of natural resources in time and space. Remote sensing technology has emerged as a potentially powerful tool for providing information on natural resources at various spatial and temporal resolutions.

Integration of remote sensing data and GIS is facilitated by a number of developments. This includes software and hardware advances as well as price/capability ratios of GIS, the availability of high-resolution data in digital form, new developments in automated information extraction, and the use of GIS for spatial and dynamic modeling. What has been given less consideration is the accuracy of the input data when integrating data sources in a GIS. If incorrectly classified remotely sensed data is included in a database to be used for environmental modeling, the results will be uncontrolled error propagation throughout the study. The purpose of the geographical resource information processing is to improve environmental monitoring and management. This can only be achieved if the data are sufficiently reliable and error-free for the purpose for which they are required.

When using remotely sensed data the sources of errors may result from geometric errors, radiometric errors, a time lag between image acquisition and ground data collection and the actual methods of ground data collection, also referred to as ground truthing. Ground data is used both for calibration and the subsequent accuracy assessment of the classified image. Its quality is therefore of fundamental importance. Many researchers (e.g. Hord and Brooner 1976, Hay 1979, Justice and Townshend 1981, Curran and Williamson 1985, 1986, Congalton 1991, Zhou and Pilesjö 1996) have questioned the commonly used methods for collecting ground data, even indicating that inappropriate ground data collection easily may result in "ground lies". It seems that during time of fast computer technology and sensor development, sample design has achieved diminished attention in many remote sensing studies.

This paper aims to highlight the importance of ground data collection for remote sensing purposes, being aware of the difficulties of achieving a balance between the size and the error of the samples. An appropriate sampling scheme, which takes the spatial variation of the studied population, is discussed. To illustrate parts of the proposed sampling design an example of ground data collection for vegetation cover assessment in a semi-arid rangeland environment is presented. Different techniques of vegetation cover estimations are also compared.

2. Sampling design considerations

2.1 Importance of designing an appropriate sampling scheme

One of the strengths of remotely sensed data is that it represents a complete spatial population. When computer-derived classifications are used to produce ground cover maps they are generally based on ground data collected by the user from selected training areas. The accuracy of the thematic map depends on the user ability to extrapolate successfully from the training areas to the whole map area (Thomas and Allcock 1984). Usually the training data set makes up the first part of the collected ground data, whereas the remaining part is used for accuracy assessment of the classified image.

The sample design is a critical part of the image classification accuracy assessment. The standard form for reporting overall error for each class of the image classification is by the use of an error matrix. Error matrices represent the number of correctly mapped pixels by comparing ground data with corresponding results of computer assisted classification. Designing a poor sampling scheme can easily result in significant biases being introduced into the error matrix, which will then affect the classification accuracy (e.g. Richard 1993, Congalton 1991, Lunetta et. al. 1991).

To ensure that the ground data is representative for the spatial population, a suitable sample design has to be chosen. Curran and Williamson (1985) emphasize the importance of the representation of ground data, both at the scale of the image to ensure an adequate range of data for accuracy testing, and at the scale of the pixel to ensure spatial compatibility between ground

data and pixel resolution. Even if complete spatial coverage of a region is provided by remotely sensed imagery, each pixel of the images represents an integration of information, which is considered by this approach.

Designing a sample scheme include a number of consideration about the relations between study area, sample site and subplot (Figure 1), such as:

- the spatial distribution of sample sites within a study area

- the number of sample sites required within a study area

- the required size of the individual sample site

- the number of subplots required within one sample site

- the size of subplots within one sample site

These considerations will be further discussed under the following paragraphs. Other important considerations are available time and personnel.
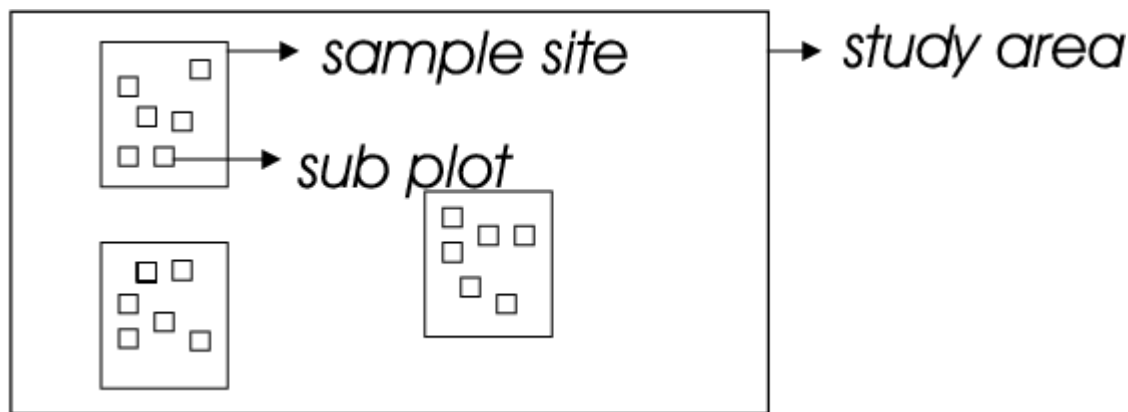

Figure 1. Sketch of the relations between the study area, sample site and subplot.

2.2 Spatial distribution of sample sites within a study area

When designing an appropriate sampling scheme for collecting ground data the primary consideration is the choice of the sample sites distribution. Each sample design must account for the area being studied and the cover type being classified.

Simple random sampling is a method of selecting the sample units out of the population, such that each element in the population has an equal chance of being selected (Cochran 1977). Simple random sampling tends to under-sample small but potentially important areas (Congalton 1988a, 1991). That problem can be overcome by using *stratified random sampling,* which is a sampling method in which the elements of the population are allocated into sub-populations (e.g. strata) before the sample is taken, and then each stratum is randomly sampled. This sampling approach can be used when specific information about certain sub-populations and increasing precision of the estimates for the entire population is desired (Cochran 1977, Clark and Hosking 1986). *Systematic sampling* is a method where the sample units (here pixels) are selected at some equal interval over time or space. The advantage of systematic sampling is the uniform spread of the sampled observations over the entire population (Cochran 1977). The major disadvantage, on the other hand, is that the selection procedure implies that each unit in the population does not

have an equal chance of being included in the sample. (Berry and Baker 1968). Systematic sampling can ether be random systematic or stratified systematic. A *random systematic sampling* design is when the population elements are arranged in some order. The first sample is randomly located and thereafter is each unit selected systematically from around that single sampled unit using a fixed interval (Clark and Hosking 1986). *Stratified systematic sampling* combines the advantage of randomization and stratification with the useful aspects of systematic sampling, while avoiding the possibilities of bias due to the presence of periodicity (Berry and Baker 1968). When dealing with very large areas where cost and time are of great concern sampling from a car can be a necessary choice. Some consider this sampling technique as a mixture of random and a systematic sampling (Helldén 1980). Disadvantages are though, limitation of the sampling to passable roads. Extensive classes that are not covered by roads, e.g. mountainous terrain, may then be under- or unsample. Land use and other human activities may also not be representative for the whole area.

Opinions vary greatly about choices of sample sites distributions and their conclusions include everything from simple random sampling to stratified systematic sampling (e.g. Rosenfield et. al. 1982, Fitzpatrick-Lins 1981, Ginevan 1979, Van Genderen et. al. 1977, 1978, Hord and Brooner 1976). After performing sampling simulations on three spatially diverse areas Congalton (1988a) came to the conclusion that simple random and stratified random sampling provided satisfactory results in all cases. But as mentioned above, simple random sampling tends to undersample small, but possibly important, areas. Therefore can stratified random sampling, where a minimum number of samples are selected from each stratum, provide a better choice according to Congalton (1988a).

Atkinson (1991, 1996) criticize the common sampling schemes reported in the literature of remote sensing, claiming that classical statistics are based on assumptions that do not hold for spatially dependent populations. He suggests that the best method to sample ground data within each pixel is an optimal sampling scheme based on spatial autocorrelation. Autocorrelation is directly applicable to error analysis and accuracy assessment of remotely sensed data because each pixel is a mutually exclusive unit and the property of interest is whether or not the pixel has been correctly classified (Congalton 1988b).

2.3 Number of sample sites in a study area

The use of few sample sites to characterize a spatially complex study area is a major source of error in remote sensing investigations (Curran and Williamson 1985). The number of sample sites required to characterize study area has been extensively discussed (e.g. Curran and Williamson, 1985, 1986, Hatfield et. al. 1985, Hay 1979, Van Genderen et al. 1978, Ginevan 1979, Hord and Brooner 1976, Thomas and Allcock, 1984). Curran and Williamson (1985) indicate that the number of sample sites within a study area is dependent upon the size of the training data set and the number of classes in the final analysis. They conclude that a larger sample size than 30 should be collected in remote sensing studies if sampling errors are to be kept low.

As discussed in section 2.1, the accuracy assessment of the classifications is done by using the other part of the data set and usually by applying an error matrix. Hay (1979), assuming a binomial distribution of the sampled data, illustrates that for a complete interpretation of the efficiency of the used classification a confidence interval for the accuracy should be given. If only 10 sample points of the produced map are checked and the result indicates that all ten determinations were correct the immediate reaction could be that the method is 100% correct.

However, according to a sampling theory the probability to get 100% correct result (e.g. 10/10) is only 0.9 if the true proportion correct is 0.99 and 0.20 if the true proportion is 0.85. On the other hand, the result 9/10 suggesting 90% correct might arise from a situation where the true proportions is much higher (99%) or much lower (85%). These are the figures if a 95% confidence level is chosen and will have to be recalculated if other confidence level is chosen. Hay (1979) concludes that any sample of less than 50 samples for each category would be an unsatisfactionary guide to true error rates.

Hord and Brooner (1976) outline the importance that the user understand that any accuracy estimate based on sampling requires confidence intervals which are dependent on the number of sample points selected per study area. Hord and Brooner tabulated the upper and lower accuracy limits at 95% confidence interval, using a normal distribution as an approximation to the binomial distribution. Their examples when using 50 and 100 samples respectively for checking land use maps are presented in table 1.

Table 1. Map accuracy upper and lower 95 % confidence limits as a function of the number of samples and the correct proportion for these samples (from Hord and Brooner 1976).

Number of samples	Correct proportion	Lower limit	Upper limit
50	80	0.6896	0.8876
50	90	0.7864	0.9565
50	99	0.9111	0.9990
100	80	0.7112	0.8666
100	90	0.8256	0.9448
100	99	0.9455	0.9982

Ginevan (1979) suggested the use of acceptance sampling together with the binomial probability function as a sound methodology for map accuracy validation. The technique, which requires a larger minimum sample, gives not only a low probability of accepting a map of low accuracy but gives as well a high probability of accepting a map of high accuracy.

Thomas and Allcock (1984) described another method for calculating the confidence intervals for mapping accuracy statements using the binomial distribution. Their method calculates confidence interval for a map's accuracy for sample of a size specified by the user. The calculation (eq. 1.) requires, though, a minimum number of samples greater than 50 and p greater than 0.1 so that an approximation to normal distribution can be done. The equation allows the user to calculate the lowest number of correctly classified pixels at a certain confidence level, or, the user will be x % sure that at least y % of the pixels in a study area have been correctly classified. Consequently, by increasing the level of confidence the minimum number of correctly classified pixels will be lower.

$$Q = (m - Ze_m) - Z(s + Ze_s) \tag{1}$$

where:

Q = minimum no. of correctly classified pixels at decided confidence level

$m = Np$

N = the number of samples taken

p = number of samples that have been correctly classified

Z = tabulated value for normal distribution (for 95 % confidence level set to 1.65)

$e_m = s/\sqrt{N}$

$s = \sqrt{(Npq)}$

$q = 1-p$

$e_s = s/\sqrt{(2N)}$

2.4 Size of each sample site

Justice and Townshend (1981) provided a formula to calculate the size of each sample site, in relation to the pixel size and the geometric accuracy of the imagery (eq. 2). The size of the pixel determines the geometric resolution and varies between different satellite sensors and has a large influence on the size of the sample site, as can be seen in the given examples below.

$$A = (P(1+2G))^2 \tag{2}$$

where:

A = area to be sampled

P = pixel size

G = geometric accuracy of the image (in number of pixels)

Hypothetical examples with different sensors and geometric accuracy (eq. 2):

P=80m (Landsat MSS)	G = 2.0 pixels:	A = 400x400m
	G = 0.5 pixels:	A = 160x160m
P=30m (Landsat TM)	G = 2.0 pixels:	A = 150x150m
	G = 0.5 pixels:	A = 60x60m
P=10m (SPOT-Pan)	G = 2.0 pixels:	A = 50x50m
	G = 0.5 pixels:	A = 20x20m

2.5 Number of subplots within one sample site

The number of subplots per sample site is mainly dependent upon the area to be sampled and its spatial variability. In order to determine the spatial variability of a sample site, the standard deviation of a number of spatially random measurements may be used to calculate the relationship between accuracy and number of samples (eq. 3) (Rao and Ulaby 1977). The required degree of accuracy ($\pm$ a) should be set according to the study, quality of the remotely sensed data, etc.

$$N_s = (\sigma_s t/a)^2 \qquad (3)$$

where:

N_s = number of subplots

σ_s = standard deviation of measured values

t = tabulated student's t (n-1)

a = required degree of accuracy in units from true population mean

The calculation assumes that the data are normally distributed, and that the sample size used for extraction of the t-value (Student's t) in a pilot study (see example in section 3.3) is in the same range as the sample calculated number of subplots. Degrees of freedom for the t-value are calculated from (n - 1) where n is the number of samples used in the pilot study.

Hypothetical examples with different required accuracy (eq. 3):

$t_{(n=10)} = 2.3$	$\sigma_s = 0.19$	a=10	$N_s = 19$
$t_{(n=10)} = 2.3$	$\sigma_s = 0.19$	a=20	$N_s = 5$

From the above examples it is obvious that the number of subplots may vary considerably with the level of required accuracy.

2.6 Size of subplots within one sample site

The size of the subplot should be chosen according to the nature of the studied parameter and the applied sampling technique. If the studied parameter is highly variable, the subplot could be made smaller and then a larger number will be required. If, however, the parameter is more homogeneous fewer but larger subplots will be more efficient. The applied sampling technique may decide the size of the subplot.

The main considerations of the above review (section 2.3-2.6) on sampling designs for remote sensing applications are summarized in the following flow scheme (Figure 2).
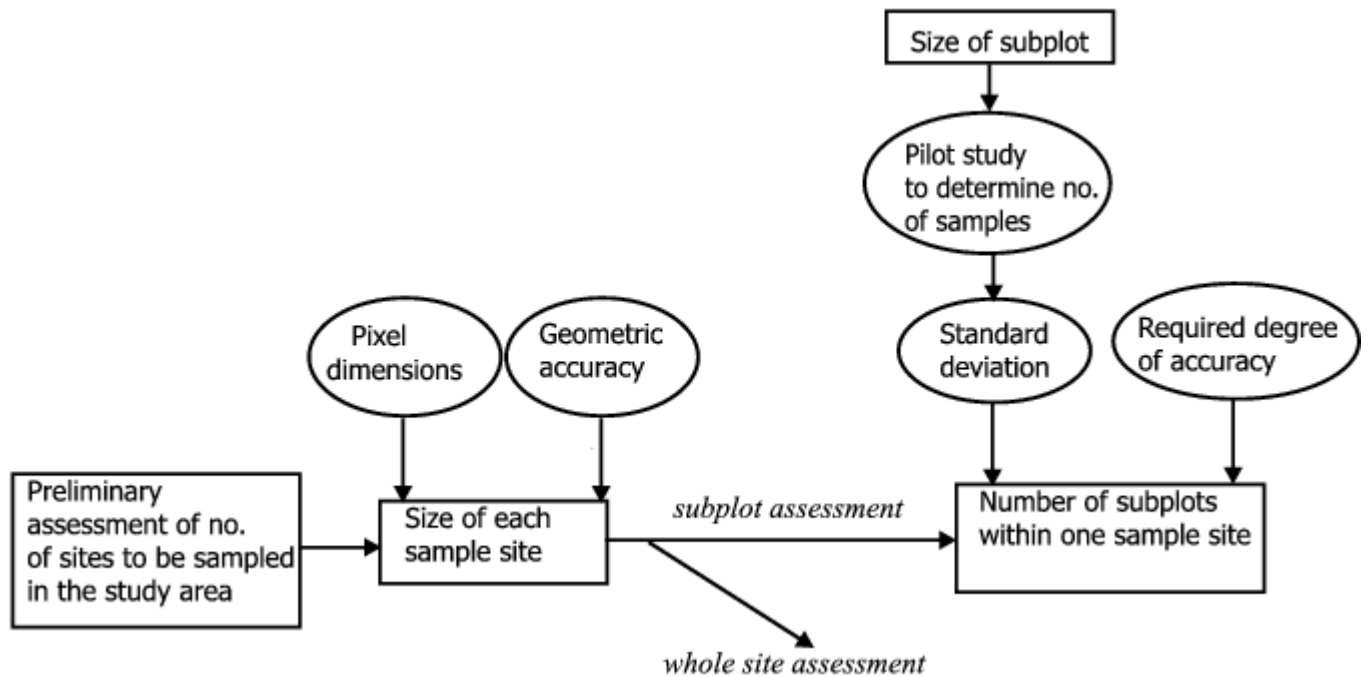

Figure 2. Flow scheme for the collection of ground data. Boxes illustrate the main consideration steps when designing a sampling scheme.

3. Vegetation cover data as an example of ground data collection

3.1 Relationship between vegetation and remote sensing data

In rangeland management and land degradation studies**,** image processing of satellite data may potentially provide quantitative data on vegetation cover and related parameters, e.g. wet and dry biomass. The various methods for estimating vegetation cover were already outlined in some of the early ecological publications dealing with vegetation cover (Arrhenius 1921, 1923). The most common sampling techniques include visual estimation, quadrants, line intercept and point-centered quadrate (Küchler and Zonneveld 1988).

3.2 Case study

To illustrate the proposed sampling scheme and compare different ground cover estimation techniques a field study was performed in a semi arid rangeland environment located near Sidi BouZid in central Tunisia, North Africa (E 35° 00', N 9° 30'). Four sites with sparse vegetation, dominated by small bushes, perennial herbs and grasses were used. These sites are representative for the variety of rangeland in the area (Figure 3). A scenario of Landsat TM data with the geometric correction of 0.5 pixels was chosen as an example, which gave a sample site size of 3600m^2 or 60x60m (eq. 2). To compare the site level data with the data from subplot level, the subplot level data were aggregated into the site level by averaging the subplots of each site. Different ground cover estimation techniques were tested: visual estimations both on site and subplot levels, a line intercept, a quadrant and image analysis of ground photographs.

Figure 3. Overview of site 3. Salt tolerant bushes and herbs dominate the site.

3.3 Pilot study

Prior to the field study a pilot study was undertaken to statistically calculate the number of samples needed for characterizing the different sites. The subplot area was set to 2x2m due to the applied photograph technique. The required number of samples for the pilot study was set to 10. Within each site 10 subplots were randomly located and vegetation cover determined by using quickly applied quadrant. This gave a t-value = 2.3. The standard deviation for the 10 subplots was calculated (table 2) and the required degree of accuracy was set to ± 10%, which means that a deviation from the truth in vegetation cover by this amount is accepted. The required number of subplots (N_s) for the site was calculated (eq. 3) (Table 2).

Table 2. The standard deviations in the pilot studies and calculated numbers of subplots.

	site 1	*site 2*	*site 3*	*site 4*
Standard deviation	0.073	0.035	0.189	0.090
Required number of subplots (eq. 1)	2	1	19	5
Used number of subplots (eq. 1)	5	5	19	5

As can be seen in table 2, the number of required subplots differs widely between the sites due to different structure and cover of the vegetation in each site. To be able to compare the cover techniques at the different sites the number of subplots were increased in site 1 and 2 to the minimum number of 5.

3.4 Applied vegetation cover techniques

Three observers were used to make a visual estimation both on site level and subplot level. The estimations were made independently by the observers to compare the errors between observers. A line intercept technique was applied on a sample site level to the four 60x60m sites. Two crossing 60m measuring tapes were applied. The total length of interception for vegetation and for the bare areas was calculated as percentage of the total length of the tape. A quadrant technique was used at subplot level to assess the overall vegetation cover. A 1x1m wooden square was divided into 25 quadrant units (20x20cm). By applying the wooden square four times at each 2x2m subplot area, every quadrant in the square represented 1%. The final technique applied was using a remotely controlled camera to photograph each subplot. A camera stand with a height of three meters was constructed to cover an area of 2x2m with a 28mm-focus length. The choice of a normal camera instead of digital camera was made due to the advantage of better picture resolution. The camera was mounted and put in a horizontal position and pictures were taken of each 2x2m subplot. The 28mm-focus length was considered to give only minor distortions, which could be neglected in this case. The scanned photos were visually interpreted using PCI ImageWorks software. This was done by drawing vectors around the vegetation and calculating the area (Figure 4).
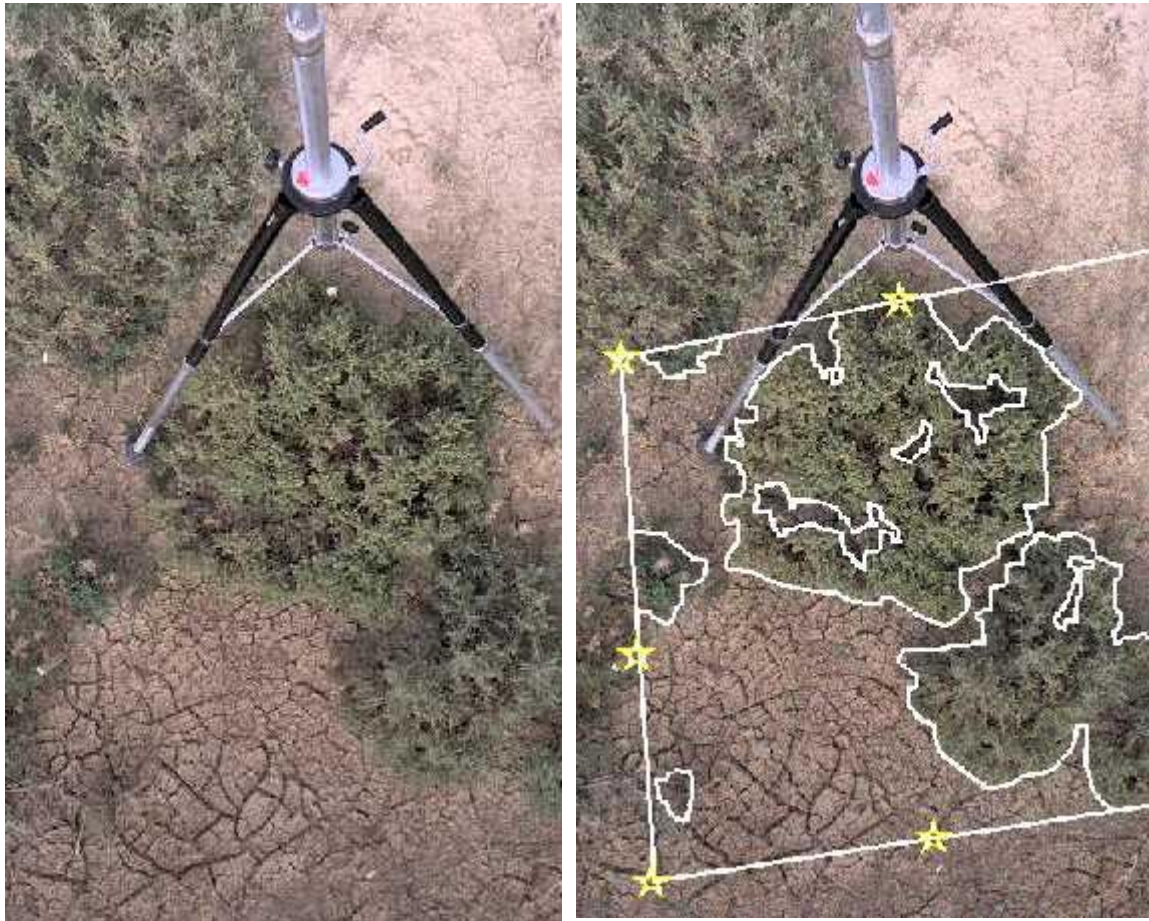

Figure 4. Photos of one of the plots at site 3. The camera is at a height of 3 m and the 8 wooden sticks (marked with stars in the photo) are the boarders for the 2x2 m square. The vectors around the vegetation, which were used to calculate the vegetation, are shown on the right photo.

3.5 Results and discussion

The line intercept technique was found to be a easy applied to measure the rangeland vegetative cover. At site three, however, some sparsely growing vegetation provided difficulties as the size of the individual plants were to small for cover estimation. The quadrant technique was straightforward as well; after gaining some experience the inter observer difference decreased and the vegetation cover was quickly estimated by the three observers. The photo technique however, was found to be a time consuming method: e.g. fieldwork, interpretation and analysis, as well as expensive: e.g. stand, camera and film development. In this study a colour film was used, which made the interpretation of the different plots easier than if they had been in black and white. Problems with interpretations of the photos were the vegetation shadows, which probably caused an over estimation of the vegetative cover; similarities in colour between dry vegetation and soil; and sparsely standing plants with tiny ground cover area.

The comparisons of the applied techniques are shown in table 3. A unexpected result was the high correspondence between the visual site observation and the techniques considered more exact as the quadrant and photograph technique. More site level observations, however, would have been preferred to confirm this result.

Table 3. Comparison of the different ground data collection techniques. (x = missing value).

	Technique	Site 1 (%)	Site 2 (%)	Site 3 (%)	Site 4 (%)
Site level	**Visual: Obs. 1**	20	5	50	20
	Visual: Obs. 2	20	3	60	17
	Visual: Obs. 3	17	8	40	16
	Average visual	19	5	30	18
	Line intercept	30	5	51	23
Subpl. level	**Visual: Obs. 1**	19	6	20	14
	Visual: Obs. 2	25	5	23	15
	Visual: Obs. 3	21	6	23	14
	Average visual	22	6	22	14
	Quadrant	20	6	24	15
	Photo	19	6	27	x
	Average	21	6	31	17
	CV* (%)	18	23	55	18

*CV, Coefficient of variation

The largest difference between the techniques appeared at site 3, which gave the coefficient of variation from the average as high as 55% (table 3). The vegetation type at site 3 is considered as

the main factor for the large differences between its site and subplot levels. Higher values of the line intercept method at site 1 and 4 are more difficult to explain. The problem of data aggregation from subplot to site level was also found by Zhou and Pilesjö (1996).

The correlation coefficients between different techniques at the subplot level (table 4) shows that all techniques performed at the subplot level have high correlation to each other. The highest correlation is obtained between the quadrant technique and the three observers.

Table 4. Correlation coefficients between different methods and observers at subplot level

Technique	Quadrant	Photo	Obs. 1	Obs. 2	Obs. 3
Quadrant	1				
Photo	0.938	1			
Obs. 1	0.951	0.895	1		
Obs. 2	0.947	0.868	0.951	1	
Obs. 3	0.943	0.878	0.919	0.934	1

n = 29. All significant at the 0.001 level.

4. Conclusion

The accuracy of remotely sensed data is highly dependent on the designed sampling scheme used for the collection of ground data. The most important steps when designing a sampling scheme for collecting ground data can be summarized as follows:

- A stratified random sampling scheme is suggested as the best choice in most situations.

- The number of samples within each category of interest ought to be at least 50 if no prior probabilities are available. Confidence intervals for the accuracy assessment should be presented along with error matrices.

- The area of each sample site should be governed by the pixel size of the sensor and the geometric accuracy of the satellite image.

- When using a subplot assessment a pilot study should be used to give the number of plots to be sampled in order to achieve a given accuracy. The size of the subplot should be based on the homogeneity of the studied parameter and the applied sampling technique.

Comparisons of different techniques for vegetation cover estimations in a semi-arid rangeland environment resulted in high correlation between the different evaluated techniques at subplot level (e.g. visual estimations, quadrant and photograph). At site level the vegetation cover from line intercept were overestimated compared to the subplots at several sites. Even though the samples were few on site level, it is indicated that the line intercept method gave higher values than the aggregated subplot measurements. The visual estimations are indicated to be within the range of acceptable error compared to the other techniques.

The alternative of taking photographs of the subplots did not prove to add any higher accuracy to the estimations. The technique per se functioned well in field and colour film, as well as the use

of a digital photo-CD, proved to be a good choice. However, the photograph technique is time consuming, expensive and the equipment is sensitive and heavy to carry around. As the interpretation of the photos involved some difficulties, using a quadrant is indicated to be both the easiest and most accurate method in the studied type of environment.

When collecting vegetation cover data it is recommended to combine the quadrant method (pilot study) and visual method in carefully outlined sites. When skills of the fieldworkers have increased through using the quadrant the visual method can be used if the type of vegetation is familiar and the whole site is taken into consideration. If several field workers are involved their concordance ought to be checked regularly. If this can not be done or if the field workers are inexperienced the need for a more subjective method increases and the photographs of the subplot should be considered. The study indicates that traditional methods of ground data collection for remote sensing applications do not have to result in "ground lies". Determination of a reliable and appropriate sampling scheme for the ground data collection should, however, be given more attention when assuring accurate results in remote sensing studies.

5. Acknowledgements

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