MONITORING VEGETATION CHANGE IN THE OWENS VALLEY

A Review of Concepts and Principles

Prepared by

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EXECUTIVE SUMMARY

Understanding the complex issue of vegetation change in the Owens Valley is important to both the Los Angeles Department of Water and Power (LADWP) and the Inyo County Water Department (ICWD). A pre-requisite to understanding vegetation change is monitoring vegetation change. It is difficult to determine why something has happened if we do not know what has happened. The purpose of this paper is to address some of the issues involved in developing an effective vegetation monitoring program. More specifically, this paper 1) presents basic concepts related to the process of vegetation sampling and monitoring, 2) evaluates the techniques currently being used to sample vegetation change in the Owens Valley, and 3) uses vegetation data collected by ICWD to illustrate these concepts and techniques.

Monitoring vegetation change is the process of recording changes in the relative amounts of plant species over time. It is not practical to measure changes in every plant at every location. Instead, vegetation monitoring is based on sampling. Because we rely on samples rather than on measurements of the entire population, it is critical that the samples are selected properly and the resulting data are interpreted correctly. If not, the conclusions reached based on these samples will be flawed.

Sampling is based on statistics. Therefore, a valid vegetation monitoring program must incorporate basic statistical concepts. Sample parameters such as the sample mean, the sample variance, and confidence intervals around the sample mean are estimates of the true values for the population. Because they are only estimates, there is a certain probability associated with conclusions that should be drawn from their use. The sample mean is a point (single value) estimate of a variable. As the variability associated with the sample increases, the confidence we should place in how representative that estimate is of the values of the observations in the sample decreases.

Vegetation monitoring is vegetation sampling for the purpose of detecting changes over time. To do so, the area to be monitored and the vegetation attribute to be sampled must be defined. The area to be sampled should be as homogeneous (uniform) as possible. Otherwise, the samples taken will not accurately represent the entire area. Vegetation has many attributes that can be sampled, and no one attribute is best for all purposes. Therefore, care should be taken in this selection.

Data collection can begin once the area and attribute to be sampled have been defined. Data collection begins with the location of the sampling units. Most often, the initial location of sampling units should be random. Thereafter, data collection over time should be from these same locations. Otherwise, spatial variability (differences in sample values resulting from differences in location) is included in the data and can be easily confused with temporal variability (change over time). The more heterogeneous (mixed) the sample unit, the more of a potential problem spatial variability becomes.

In 1984-87, LADWP mapped the vegetation on the lands they owned in the Owens Valley. The sample units they used were parcels. LADWP sampled the vegetation on 1,700 of these parcels which supported native vegetation. These data are the baseline vegetation data. In 1991, ICWD began sampling the vegetation on some of these parcels and has continued this sampling each year since. The number of parcels sampled by ICWD varies each year, but has averaged about 70 per year.

Green Book (1990) is the technical document agreed to by LADWP and ICWD for vegetation monitoring. The line-point transect method is the technique specified by Green Book (1990) for vegetation monitoring. This technique is a widely-used and accepted method of sampling vegetation cover. Like all sampling techniques, the method has limitations. Research studies, under highly-controlled conditions, have shown that the maximum accuracy of the method for sampling the vegetation of arid and semiarid shrublands and grasslands is 2-3 percentage points. Under most field conditions, the accuracy is probably less. Factors contributing to the reduced accuracy include improper implementation by field crews, climatic conditions, sampling bias, and spatial heterogeneity.

Spatial heterogeneity is a major potential source of variability in vegetation monitoring data in the Owens Valley whenever transect locations are re-randomized each year. Several examples are presented using annual vegetation data collected from parcels in the Owens Valley. These examples suggest that the annual vegetation data collected by ICWD may contain more than 15% error because of spatial heterogeneity not being accounted for.

ICWD has collected vegetation data on 137 parcels since 1991, or about 8% of the parcels supporting native vegetation. Of these 137 parcels, data have been collected each year since 1991 on 18. These 18 parcels represent areas that have been subjected to groundwater pumping (wellfield) and areas that have not been subjected to groundwater pumping (control). Total perennial cover, based on sample means, has fluctuated annually on all 18 parcels. Cover values have increased in some years on all 18 parcels and have decreased in some years on all 18 parcels. This is true of both wellfield and control parcels. Overall, sampled total perennial cover increased on the control parcels (not subjected to groundwater pumping) from an average of 16% in 1991 to 25% in 2003. The same increase was manifested on the wellfield parcels (16% in 1991 and 24% in 2003). The annual fluctuations in sampled total perennial cover on these 18 parcels are consistent with annual fluctuations in vegetation in similar ecological regions of the western United States. In addition, half of the reported annual changes were less than the accuracy limitations of the sampling methodology.

Vegetation change on four parcels, as indicated by the ICWD data, was used to illustrate the sampling concepts developed in this paper. These data include both total perennial cover and cover of grasses and cover of shrubs. These data illustrate that different conclusions can be reached depending on whether total perennial cover or cover by lifeform (grasses, shrubs) are used. These data also illustrate the statistical concept of significant differences between means and the importance of accounting for variability in a sample.

Perhaps the most important concept presented in this paper and supported by the data collected by ICWD is that vegetation is dynamic. Vegetation change over time is a natural process that is caused by a variety of factors. The second most important concept illustrated by these data is that care must be taken in how these types of vegetation monitoring data are interpreted. Statistical variability, limitations of sampling techniques, and influence of spatial variation must be taken into account if proper interpretations are to be made. It should always be remembered that sampling produces estimates of the true population values. The better the sampling technique, the more detailed the statistical analysis, the more refined the sampling design, the better the estimates. But they remain estimates.

Vegetation change is taking place in the Owens Valley. That should not be surprising. Vegetation is not static. Determining the causes of vegetation change is much more challenging than determining that change is taking place. Many factors are involved, and each has its role.

MONITORING VEGETATION CHANGE IN THE OWENS VALLEY

INTRODUCTION

Understanding vegetation change in the Owens Valley is important to both the Los Angeles Department of Water and Power (LADWP) and the Inyo County Water Department (ICWD). Vegetation change is a complex ecological process. Likewise, understanding these changes is also a complex process. Addressing all of the issues involved in understanding the causes of vegetation change is beyond the scope of this paper. The purpose of this paper is to begin addressing this complex subject by defining some basic concepts and then addressing how vegetation change can be studied.

This paper is divided into three sections, each section presenting information relative to fulfilling this purpose. The first section presents general concepts associated with monitoring vegetation change. These concepts are important both in understanding vegetation change and in designing monitoring programs to study these changes. The second section reviews vegetation sampling methodologies, particularly those used by LADWP and ICWD in the Owens Valley. The purpose of this section is to better understand the usefulness and the limitations of these methods. The last section of this paper illustrates the concepts presented in the first two sections by using some Owens Valley examples from the vegetation monitoring data collected by ICWD. It is not the purpose of this paper to address the causes of these vegetation changes. Causes of vegetation change will be the subject matter of subsequent papers in this series. The purpose of this paper is to focus on how these vegetation changes should be measured.

SECTION 1. BASIC CONCEPTS

If our goal is to study vegetation change in the Owens Valley, our first step should be to define the subject of our study. What do we mean by vegetation? Vegetation obviously has to do with plants. But, for our purposes, it is not all plants that we are interested in studying. For purposes of vegetation monitoring in the Owens Valley, vegetation is largely focused on native species of plants, or non-native plants that affect native species. But it is even more specific than that. Vegetation is the sum total of plants covering a specified area (Weaver and Clements 1938, Billings 1970, Vankat 1979). Stated slightly differently, vegetation is the "plant life considered in mass" (Daubenmire 1978). Vegetation, what we are trying to study, therefore is more than just the presence or absence of a given plant species. Vegetation relates to the combinations of various species, the relative amounts of each species within specified areas, and the arrangement of these species.

We have now stated what the subject of our study is: the combination of native plants covering specified areas of the Owens Valley. However, this definition illustrates one of the major challenges in studying vegetation change. What, specifically, about the change in vegetation are we are interested in measuring? We will address this challenge in much more detail later in this paper, but at this point we will present the general concept.

Vegetation is the combination of plants, both individuals and species, within a defined area. There are many types of changes that can take place. The plants can become taller. There can be more of them. They can cover more area. They can produce more stems, leaves, or seeds. All of these attributes, and many others, can be measured for the vegetation as a whole. And measuring these attributes for the vegetation as a whole is convenient because it results in single values for each variable, e.g., the maximum height of the vegetation or the total number of plants within the area. But each of these variables can also be measured for the individual species that comprise the vegetation. And very often we might have increases in some species and decreases in others. For example, we might have an increase in cover of shrubs and a decrease in cover of grasses, but total cover of the vegetation might remain about the same. Or total cover may increase, but it is because one or two species are increasing while the others are decreasing. In both cases, our conclusions based on changes in the overall vegetation will be different than our conclusions based on changes in individual species. Which would be the right conclusions and which would be the wrong conclusions? Which was right and which was wrong would depend on our perspective. Ecologically, both would be correct.

The first step in this paper was to define vegetation, the subject of our study. The second step will be to address the question of why we might want to monitor vegetation change. There are many possible reasons, and these reasons may themselves change over time. No matter what our purpose is, we should always distinguish between 1) what the data indicate is happening and 2) how we wish to use that information. There are two parts to "how we wish to use that information." In our Introduction, we stated that it is not the purpose of this paper to address causes of vegetation change in the Owens Valley. However, this issue is one part of "how we wish to use that information." And it is a valid use of the information.. In fact, it is most often the scientific reason for having a vegetation monitoring program. The second part of "how we wish to use that information" is equally common, but much less scientific. This second part is to place a value judgement on the changes.

A common aspect of human nature is to place value judgements on things. We often tend to view things as being either right or wrong, good or bad. In nature, these judgments lose much of their meaning. Many Americans would view the large-scale destruction of a forest by human activities as bad. But when it happens because of a volcanic eruption, somehow it is different. A generation ago, forest fires were considered to be bad, even if they were started by lightning. Now we have a different view ecologically. Some forest fires are "good." Most of us who have lived all our lives in the West consider droughts to be bad. And yet they are part of the cycle of nature.

In the plant world, in the world of vegetation, change is driven by stress. Stress is a natural part of the life of plants, just as it is in the life of animals. "Plants in natural environments are subject to changing multiple stresses during their annual growth cycles. … In virtually all natural environments, plants are subjected to conditions that reduce their potential growth …" (Mooney et al. 1991). Some types of stress, e.g., moderate water stress under some circumstances, can increase the quantity and quality of some plant products (Kramer 1969:372). Grazing of grasses by livestock can remove significant amounts of leaf tissue from the grasses. Some people believe that this is harmful to the plants. However, numerous studies have shown that light- to moderate-grazing by livestock often results in greater production of both above- and belowground biomass by the grasses over time (Albertson et al. 1953, Stoddart et al. 1975, Milchunas and Lauenroth 1993, Boyd and Svejcar 2004, Loeser et al. 2004). Therefore, from the standpoint of productivity, proper livestock grazing can be beneficial to grasses. For decades, fire was viewed as a harmful environmental factor. Now, it is known to be critical to the maintenance of vigorous stands of prairie vegetation (Stoddart et al. 1975) and many forest vegetation types (Gallant et al. 2003).

A complicating factor in determining beneficial or detrimental effects of environmental stress on vegetation is deferential responses by species. A given environmental stress often results in very different responses by different species in the same location. The net result of the stress may therefore benefit one species while being detrimental to another. Under such circumstances, how does one decide whether or not the vegetation has been harmed, since one species of the vegetation increased and one species decreased? Fire provides a good example of this phenomenon. Fire often increases herbaceous species such as grasses and decreases woody species such as shrubs (Humphrey 1962, Daubenmire 1978, Scifres 1980, Scholes and Archer 1997, Gallant et al. 2003). The Great Basin is a term used for the region between the Sierra Nevada and Cascades on the west and the Rocky Mountains on the east, and north of the hot deserts of the southwestern United States (Stoddart et al. 1975:40; Vankat 1979:187). In the Great Basin, fire decreases big sagebrush (Artemisia tridentata) and increases perennial grasses (Daubenmire 1967, 1988; Stoddart et al. 1975). In this case, has the vegetation been harmed? With fire there is less sagebrush and more grass. Without fire, there is more sagebrush and less grass. Likewise, in montane forests in the western United States, fire favors aspen (Populus tremuloides) over conifers, and the maintenance of aspen populations are largely dependent on recurring disturbances (Gallant et al. 2003, Kulakowski 2004). With fire, aspen is favored. Without fire, conifers are favored.

In both cases with fire, there is no reason for one state of the vegetation to be considered "better" or more "natural" than the other. Under natural conditions, the landscape consists of a mosaic of both types of vegetation. There are patches with more sagebrush and less grass mixed with patches where there are more grass and less sagebrush. Over time, the grassy areas will become less grassy because of an increase in sagebrush. Then another fire will occur and the sagebrush will be reduced and grasses will increase for a period of time. In the mountains, there are groves of aspen, interspersed with stands of conifers. Without fire or some other disturbance, the conifers will eventually replace the aspen.

Vegetation change must be considered in the context of the natural process of change. In nature, vegetation does not remain static. It is dynamic and this change is a natural process. From a land management standpoint, some of these potential changes may be desirable and some may be undesirable. Therefore, for a wide variety of reasons, it is important to be able to evaluate these changes on the basis of our management criteria (Glenn-Lewin et al. 1992). However, before we can evaluate the desirability of the changes, we must first be able to determine what the changes are. We must be able to monitor vegetation change if we are going to attempt to direct the change.

Vegetation Sampling

Vegetation monitoring is based on sampling. This is true because we cannot measure every plant and every piece of the landscape (Daubenmire 1968). Therefore, we measure parts of the entire population. These subsets become our sample populations. We then make our judgements based on the data we collect from these sample populations, even though we are interested in the entire population, not just the sample populations. Because of our reliance on these samples, it becomes critical that the samples are selected properly. If they are not, then the conclusions we may reach based on the samples and then apply to the vegetation as a whole may be flawed. In such cases, even if the conclusions are true for the sample population, they may not be true for the vegetation as a whole. For example, assume we are interested in monitoring the changes in a sagebrush-grassland mixed plant community. This type of vegetation consists of alternating patches of sagebrush with stands of perennial grasses between the sagebrush patches. Now let us assume that we sample ten locations in this vegetation, but that all ten are in sagebrush patches. Our understanding of the dynamics of this vegetation would then be seriously flawed because we would not have any data on the grass component. Our data would suggest that the plant community was a continuous stand of sagebrush.

Vegetation monitoring is based on vegetation sampling, and sampling is based on statistics. If the vegetation we were sampling consisted of only one species, and this species was perfectly uniform in all its attributes throughout the area we were interested in, then we would need to only take one sample. However, native vegetation seldom consists of a single species, and species vary across the landscape in response to variations in environmental factors across the landscape. Therefore, vegetation sampling consists of taking more than one sample and some knowledge of statistics is required to be able to analyze these data and determine what can be properly surmised from this sample, relative to the vegetation as a whole.

A population consists of all individuals of a particular type within a defined area in a defined period of time (McLendon 1997). An example would be all the big sagebrush shrubs in the Owens Valley in 2005. That population would be somewhat different than all the big sagebrush shrubs in the Owens Valley in 2010, because shrubs would grow, some might die, and some new shrubs would establish between 2005 and 2010. The population would also be different if a different area was defined. For example, all the big sagebrush shrubs north of Big Pine in 2005 would be a smaller population than those in the entire Owens Valley in 2005.

The purpose of sampling is to arrive at an estimate of the value for a particular variable for the entire population without measuring all the individuals in the population. As such, this is only an estimate of the true value of that variable for the population. The sample may provide a very good estimate or a very poor estimate of the true value, depending on how well the sampling procedure is designed and implemented.

The most commonly used statistical parameter in sampling is the sample mean. The sample mean is the average of the values for a particular variable within a sample. It is the sum divided by the number of observations in the sample. An example might be the height of big sagebrush shrubs in the Owens Valley. One might measure the heights of 20 shrubs, add these 20 values, and then divide by 20. The resulting value would be the sample mean, and also the estimate of the population mean. We would know that every big sagebrush shrub in the Owens Valley is not that exact height. Perhaps no big sagebrush in the Owens Valley is that exact height. This mean value is simply an estimate of the average height of all the big sagebrush in the Valley. How good an estimate it is depends on 1) how representative those 20 shrubs we sampled are to all the big sagebrush in the Owens Valley and 2) how accurately we measured the heights of the 20 shrubs.

The mean is a point estimate. It is a single estimated value for that variable for the entire population. The mean can provide much information about the population, but it does not provide all the information we may need. It does not, for example, tell us anything about how variable the population is. Are all the shrubs that exact height, or are there some taller ones and some shorter ones? How many short ones are there and how many tall ones? If we should walk up to a big sagebrush shrub that was not included in the sample of 20 and measure its height, how well does it fit into the population? Is this shrub an average shrub, or is it unusually tall? If it is very short, should this be of concern to us or is that to be expected for a few shrubs within the general population?

The second most useful statistical parameter is generally some measure of variability. Two parameters, both closely related to each other, are most commonly used to measure variability in vegetation sampling: variance and standard deviation. The variance is calculated by subtracting the mean from each individual observation, squaring each of these values, taking the sum of the squares, and dividing by the number of observations minus one. The standard deviation is the square root of the variance.

These two parameters, the variance and the standard deviation, are used in various ways to better understand statistically the characteristics of the sample and therefore of the population. One example is what is known as confidence intervals. A confidence interval is the range in values around a sample mean to which a given statistical probability of success can be given. For example, if a 95% confidence interval is specified, there would be a 95% probability that the true population mean lies somewhere between the upper and lower bounds of the confidence interval of the sample mean. Conversely, there is a 5% probability (1 out of 20 chance) that the true mean lies outside this confidence interval. The wider the confidence interval, the more variable is the population attribute.

Statistics are based on probability theory. Statistical comparisons (e.g., confidence intervals) and tests must always be used within a probability context. Statistics should not be used to attempt to "prove" something. Instead, statistics should be used to determine how likely a given hypothesis might be. Statistics may tell us that a certain hypothesis has a 95% probability of being true. However, there is still a 5% probability that it is false. The purpose of statistics is to provide a better understanding of the likelihood that conclusions based on the sample data are reasonable.

If two samples are taken from the same population and the means calculated for each of the two samples, it is unlikely that the two means will have exactly the same value. Statistics provides tools that can be used to evaluate these types of differences. Statistics are often used to determine if samples taken from two areas, or the same area at different times, are different enough from each other to justify that the populations are different. For example, assume that part of an area supporting a stand of willow burned 20 years ago. Perhaps we are interested in determining if the area has recovered from the fire. We might sample an area that had been burned and an adjacent area that had not been burned in the fire 20 years ago. Our reasoning might be that if the mean cover of willow in the two areas was the same, the burned area has recovered. But the two means are not likely to have the exact same mean, even if the burned area had fully recovered. Therefore, our question becomes how different can the two means be and still be considered as coming from the same population? Statistically, we compare both the means and the variability in the two samples. We could use the confidence intervals around each of the two means to do this. Since the confidence interval around a mean tells us the range in possible values for the mean, based on the variability in the sample, the two confidence intervals can be compared. If the two confidence intervals overlap numerically, the two means are not likely to be different. This would imply that the burned area has recovered. However, we have not proven that the area has recovered from the burn. We have only shown that there is a given probability that the vegetation in the burned area, as measured by sampling the willow, has recovered.

Change Over Time

Vegetation monitoring can be conducted for many different purposes. Different purposes require somewhat different sampling designs and perhaps different techniques. Therefore, it is important to determine what, specifically, we want to determine from our sampling.

Vegetation monitoring is vegetation sampling for the purpose of detecting changes over time (Bonham 1989:266). The first step in a monitoring program is to define what it is that is being monitored. For vegetation, this requires defining two things: the units to be sampled and the attributes to be measured. The unit is what comprises the population that we are attempting to monitor change in. For vegetation sampling, it is the vegetation in the particular area we are interested in. Sampling will then be conducted within this area over time. When vegetation monitoring is being conducted on a landscape basis, as in the case of the Owens Valley, these sampling units are usually contiguous areas supporting similar vegetation (Bonham 1989:265).

Delineation of these sampling units is often not a simple task. The vegetation across a landscape is a mosaic reflecting the complex interactions of environmental factors across the landscape. However, vegetation units can generally be mapped on the basis of contiguous areas that are dominated by one or two dominant or co-dominant species (Gnauck and McLendon 1972, Daubenmire 1978, Bonham 1989:265). These vegetation units defined for a monitoring program should be as homogeneous as possible (Daubenmire 1968:79-81). Care should be taken that ecotones (transition areas from one plant community to another) and areas of differing disturbance history not be included in these units (Daubenmire 1968:80).

There are many vegetation attributes that can be measured. These include height, weight, productivity, cover, density, and diversity. These attributes can be measured on the basis of total overall vegetation, by lifeform (e.g., grasses, forbs, shrubs, trees), by individual species, or even by plant parts (e.g., leaves, stems, trunks, crowns). Each of these attributes provides a somewhat different measure of vegetation response and there is no single attribute that is all-inclusive, relative to measuring vegetation (Daubenmire 1968:42, Bonham 1989:277, McLendon 1997:25).

Numerous vegetation sampling techniques exist (Brown 1954, Daubenmire 1968, Bonham 1989). Some are more applicable to sampling certain vegetation attributes than are others, and each technique has its advantages and disadvantages (Oosting 1956:41, McLendon 1997:25). Care should always be taken to match the proper technique with the attribute or attributes being sampled. Attempting to sample a given attribute with the wrong technique will limit the usefulness of the data collected.

Once the sampling units, attributes, and techniques have been selected, data collection can begin. The next major step is to determine the sampling locations within the unit. There are two primary approaches to selection of locations. One is systematic placement. The other is randomization. Systematic placement involves some method, generally a grid, of locating the sampling locations at regularly spaced intervals within the sampling area. Randomization, where the location of the sampling sites are randomly located, has the advantage over systematic placement from the standpoint of statistical theory (Bonham 1989:95).

"The objective for sampling is to obtain an unbiased estimate of the population parameters: the mean and its variance" (Bonham 1989:10). Randomization assures that selection of samples is unbiased (John 1971, Snedecor and Cochran 1989). This is a strong reason for randomly selecting the initial sample locations. However, once the initial locations are randomly located, there is a strong reason for locations not to be changed over the period of monitoring. Our purpose is to monitor vegetation changes over time (i.e., temporal variability). If our sample locations change each sampling period, then we mix spatial variability with the temporal variability we are attempting to monitor.

Spatial variability arises because the sample units we have selected are not perfectly homogeneous because of the interaction of complex environmental factors across the landscape. Daubenmire (1968:79-80), in his textbook on plant synecology, stated the problem clearly. "One of the most fundamental requirements for a valid statistic is that the stand which is sampled must be homogeneous, for a fraction of an area cannot be relied upon to represent the entire area unless the latter is homogeneous. ... However, in synecology absolute homogeneity is unobtainable, so that our problem is one of eliminating as much heterogeneity as possible, especially variability attributable to differences in intrinsic habitat factors and history of disturbance." No matter how careful we are in delineating our sample units, environmental differences across the area will result in spatial heterogeneity in the vegetation.

For some types of vegetation sampling, it would be desirable to sample this spatial heterogeneity. If we were interested in characterizing the vegetation mosaic for instance, we would want to sample this heterogeneity. However, when our purpose is to measure changes over time, we want to minimize all other sources of variability. This especially includes spatial heterogeneity. Otherwise, variations in the data caused by differences across the landscape become confused with changes over time, and we become unable to differentiate between the two, or even to know that the spatial variability is now included in our monitoring data. We then increase the error in our data and attribute too much of a change in vegetation over time.

The use of permanent monitoring locations eliminates the inclusion of spatial heterogeneity into the monitoring data. "Best estimates of foliar or basal cover, for the purposes of monitoring, are obtained by measurement from permanently located plots or lines" (Bonham 1989:282).

SECTION 2. SAMPLING METHODOLOGY

In 1984-87, LADWP mapped the vegetation on the lands they owned in the Owens Valley and sampled the vegetation on those areas with native vegetation. The mapping units were termed parcels. A parcel was considered to be a contiguous area of relatively homogeneous vegetation and land use. These parcels varied in size from less than 10 acres to over 1,000 acres. Over 2,100 of these parcels were delineated, including about 400 that were not in native vegetation (e.g., urban areas, ponds, lakes, agricultural, abandoned fields, woodlots). The vegetation of each parcel was sampled only once during the 1984-87 sampling period.

In 1991, ICWD began a vegetation monitoring program, and has continued the vegetation monitoring on an annual basis since then. Each year, ICWD selects a number of parcels to sample. This number varies from year to year, but averages about 70 parcels per year. Eighteen of these parcels have been sampled every year since 1991.

Line-Point Transect Method

The Green Book (1990) is the technical document agreed to by LADWP and ICWD for vegetation monitoring. As per Green Book (1990) guidelines, the technique ICWD uses to sample vegetation cover is the line-point transect technique, using the following methodology. A 50-m (164-ft) long tape measure is stretched between two points. An observer walks down the tape and at each recording point along the tape stops and records if live plant tissue is present at that point along the tape and, if so, what species of plant it is. A total percent cover value is then calculated for each species present at that site by adding up the total number of points at which that species was recorded as present and dividing the sum by the total number of sample points along the transect. ICWD uses 100 sample points along the transect, recording at each 0.5-m mark on the tape measure.

The line-point transect technique is a widely-used and accepted method of sampling vegetation cover (Bonham 1989:120). The Green Book (1990) stipulates that only the first plant species encountered at each sample point be recorded. As pointed out by Daubenmire (1968:44), a more accurate method is to record coverage of each species, even when the canopies overlap. "Coverage is determined separately for each species overlapping the plot regardless of where the individuals are rooted and regardless of superimposed canopies of different species, but ignoring intraspecific overlap" (Daubenmire 1968:44). By Green Book (1990) methodology, if another species exists below the first species, e.g. a grass plant below a taller shrub, the second species will not be recorded as present. This sampling methodology, even though acceptable for some uses, can produce misleading results because only the first species encountered at each sample point is recorded means that any other species present will be ignored in the sampling. This results in a bias in the data for taller species, mostly shrubs, with values for shorter species, mostly grasses, appearing smaller than they actually are (Bonham 1989:97). In addition, if only leaves are recorded, rather than any live part of the plant, the statistical variability of the data is increased because leaves are more seasonally influenced than stems and trunks.

In addition to first- or multiple-contact considerations, the line-point transect method can be used to record various aspects of plant cover. Common examples include basal or canopy cover. Canopy cover can be further divided into total live cover (cover of all live plant parts) or leaf cover (cover of leaves only). During the 1984-87 sampling period, LADWP sampled total live cover, recording only first contacts.

The accuracy of any sampling method is dependent on both the limitations of the technique itself and how well the method is applied by field crews. A substantial amount of research has been conducted by scientists to determine the accuracy of the line-point transect method, especially when used to sample cover of shrublands and grasslands. Shrublands and grasslands (meadows) are the most common vegetation types in the Owens Valley. First of all, the maximum accuracy of the method is limited by the number of sample points used to collect the data (Bonham 1989:269). This is often expressed in terms of percentage of total points along the transect. The Green Book methodology records cover at 100 points along the transect. Therefore, the maximum potential accuracy of the method is 1 out of 100, or 1 percentage point. This is not 1% of the mean. It is 1% cover. Therefore, the method, as defined by the Green Book, cannot detect changes in vegetation of less than 1%.

In practice, the accuracy of the method has been found to be less than this theoretical 1%. Brady et al. (1995) reported that the sampling accuracy associated with the line-point transect method, when sampling basal cover, allows for distinguishing only a two-percentage point change, using ten 100-m transects at the 95% probability level. Basal cover can be sampled more accurately than leaf cover (Bonham 1989:98), therefore the accuracy of the method when sampling leaf cover is less than 2 percentage points. Heady et al. (1959) found the method accurate to only 3.3 percentage points when sampling total cover in California coastal shrublands and 2-3 percentage points for individual species. Becker and Crockett (1973) found that the accuracy when sampling grassland vegetation ranged from 70-79%, depending on which species was being sampled.

These studies indicate that the line-point transect method is accurate only to 2-3 percentage points when sampling shrubs. Other studies have shown that the accuracy of the method when sampling grasses under practical conditions is about 70-80% of the mean. A 70% accuracy would be equal to 3 percentage points when the mean cover value was 10%. Greater accuracy (80-90%) generally requires large sample sizes (e.g., more than 100 transects for big sagebrush) (Kinsinger et al. 1960, Hanley 1978). ICWD generally uses 14-30 transects per parcel.

The results of these studies from the scientific literature do not negate the use of the line-point transect in vegetation monitoring. In fact, most of these authors agree that it is a valid technique. What these studies do provide for us is an evaluation of how good the technique can be when properly used. We should then be careful not to attempt to use data collected with this technique inappropriately. Data collected by this technique may be able to detect changes on the order of 3 percentage points, but not less than that.

The accuracy of data collected by the line-point method is also influenced by proper application of the technique in the field. The accuracy of the data collected by the line-point transect method is highly sensitive to proper technique by field crews (Walker 1970). Factors that result in decreased accuracy using the line-point transect method include 1) sampling during windy periods, 2) allowing the tape measure to "droop", rather than keeping it taut, 3) making observations along the tape while the observer continues to walk, 4) inconsistent alignment of the observer's view perpendicular to the tape, 5) variable distances from tape to different types of plants (shrubs compared to grasses), 6) incorrect identification of plant species, and 7) observer fatigue. These factors combine to decrease the accuracy of the data even further than the 3 percentage points that the scientific studies indicate for the technique.

Sampling Bias

Sampling bias is another factor that can influence the accuracy of vegetation monitoring data. Sampling bias occurs when the probability of selection of any one observation in a sample is greater than another observation (Snedecor and Cochran 1989:6). Common examples of sampling bias in vegetation monitoring include avoidance of dense stands of thorny plants, a tendency to over-sample certain species and under-sample others, and viewing points along a line-transect from varying angles in response to proximity of plants to the transect. These sources of bias are often unconsciously manifested in sampling and are difficult to quantify.

A more serious source of bias can also occur in a sampling program. When samples are taken from areas that have been obviously impacted by factors not accounted for in the monitoring program (e.g., vehicle traffic, scrapping of the soil surface, trampling by livestock) and the data are not adjusted to reflect the effects of these impacts, serious bias is introduced into the sampling design because it includes the variation in vegetation caused by these factors with changes over time.

Spatial Heterogeneity

ICWD re-randomizes the location of transects in each parcel each year. Initial randomization is a valid procedure to eliminate bias in sample location. However, subsequent annual randomization of transects is not a generally accepted procedure in vegetation monitoring. Instead, permanent location of the transects is the proper approach. When the data are collected from permanent transects, variation in the data from year to year is temporal variation, assuming that the location is not exposed to a new disturbance. When the transects are re-located each year, the data reflect spatial differences as well as temporal differences. The specific area sampled one year is not the same area sampled in another year. Therefore, the change in vegetation reflected in the data combines these two sources of variation and it becomes impossible to distinguish between changes over time and changes in location. This is a serious short-coming in the current sampling design.

Data from two parcels sampled by ICWD will be used to illustrate the problem imposed by spatial heterogeneity. The first of these examples is BGP 162 (Big Pine 162). ICWD has been collecting vegetation data from BGP 162 since 1991. During this time, a total of 389 transects were sampled in this parcel (Figure 1). Six species were the most abundant species recorded in this parcel. Three were shrubs (ARTR = Artemisia tridentata = big sagebrush; ATTO = Atriplex torreyi = Nevada saltbush; CHNA = Chrysothamnus nauseosus = rubber rabbitbrush), two were grasses (DISP = Distichlis spicata = inland saltgrass; SPAI = Sporobolus airoides = alkali sacaton), and one was an annual forb (SATR = Salsola tragus = Russian thistle).

Based on the data collected by ICWD, these species are not distributed evenly across the parcel (Figure 2). The shrubs are more abundant in the south half of the parcel than in the north half. The grasses are concentrated primarily in the eastern half of the parcel. Russian thistle is concentrated in the north one-third of the parcel, with another area just below the middle of the parcel.

Based on vegetation, the parcel is a mosaic that can be divided into 8 vegetation types (Figure 3). Type 1 is dominated by Nevada saltbush and rabbitbrush. It occurs through much of the central and western portions of the parcel. Type 2 is dominated by Nevada saltbush and Russian thistle and is located in the northern and the southwestern portions of the parcel. Type 3 is dominated by Russian thistle and occurs in several patches in the northern part. Russian thistle is indicative of early-successional conditions (Allen and Knight 1984; McLendon and Redente 1990, 1991, 1992), suggesting that some type of disturbance has occurred more recently or more intensely in the northern part of the parcel. Type 4 is dominated by Nevada saltbush and alkali sacaton and is located mostly in the northern part of the parcel, with an additional area near the center. Type 5 is dominated by saltbush, rabbitbrush, and inland saltgrass. This type is located primarily in the east-central part of the parcel. Type 6 is similar to Type 5, except sacaton replaces rabbitbrush. This type is also located in the east-central part of the parcel. In Type 7, sagebrush becomes abundant, along with saltbush and rabbitbrush. This type is located in patches throughout the parcel, but with the largest areas in the south half. Big sagebrush is indicative of late-successional conditions (Daubenmire 1988, McLendon and Redente 1991, 1994), suggesting that this area of the parcel has probably been the least disturbed. Type 8 is similar to Type 2, with rabbitbrush joining Nevada saltbush and Russian thistle as the major species. This type is located in one area along the west-central edge of the parcel.

ICWD collected data from 32 transects in the parcel in both 2002 and 2003. Six of the 2002 transects (19% of the total) were located in the northwest neck of the parcel. This is an area with a high proportion of Russian thistle. In 2003, only 4 transects (12% of the total) were located in this area. Therefore, this area of the parcel was sampled 50% heavier in 2002 than in 2003. In 2002, the sampling indicated an average of only 1.7% cover in this area, consisting of Nevada saltbush (0.7% cover) and Russian thistle (1.0% cover). In 2003, the sampling indicated an average of 0.3% cover in this area of BGP 162, consisting entirely of rabbitbrush.

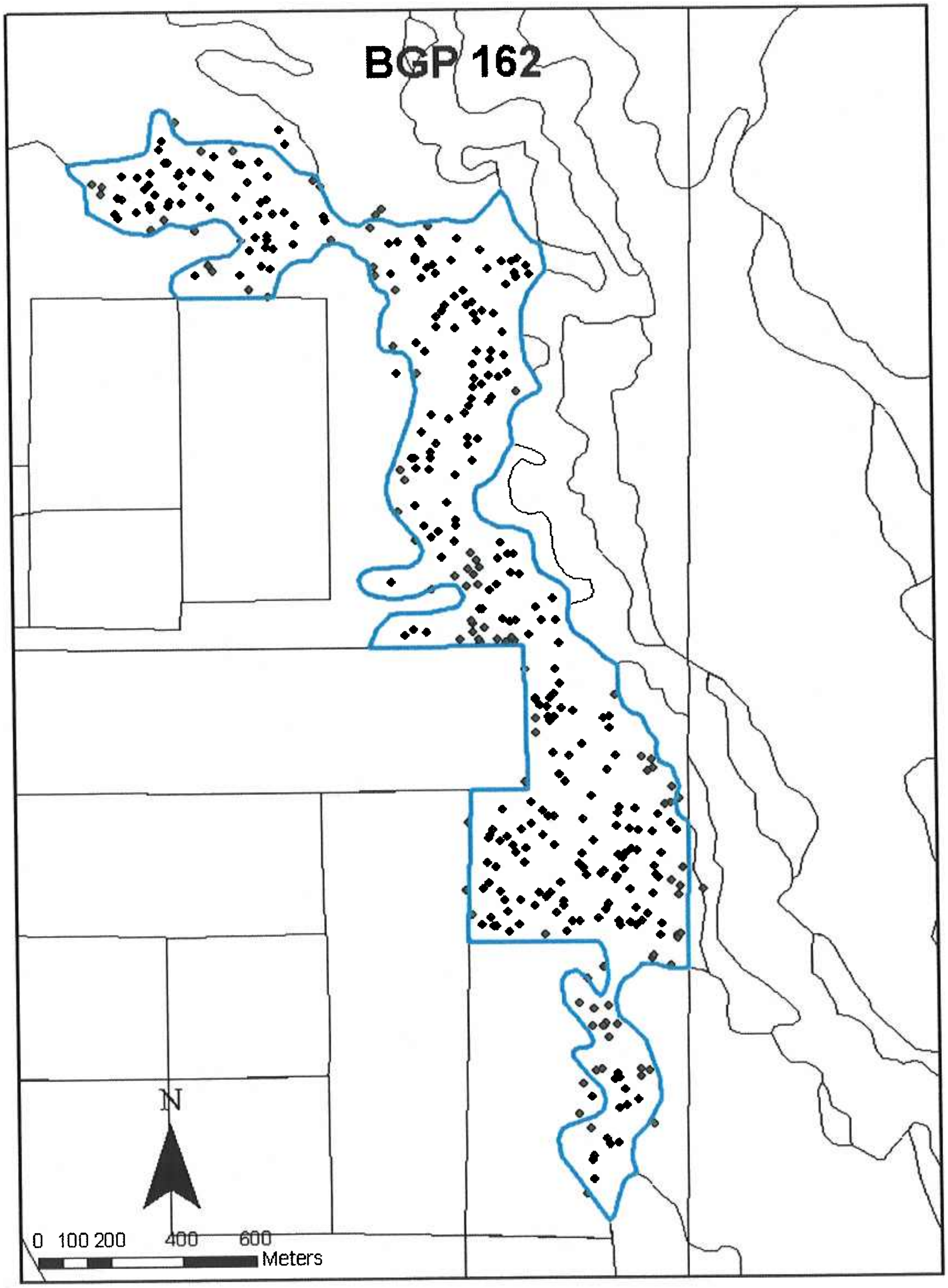


Figure 1. Location of the ICWD vegetation transects in BGP 162 (outlined in blue), 1991-2003.

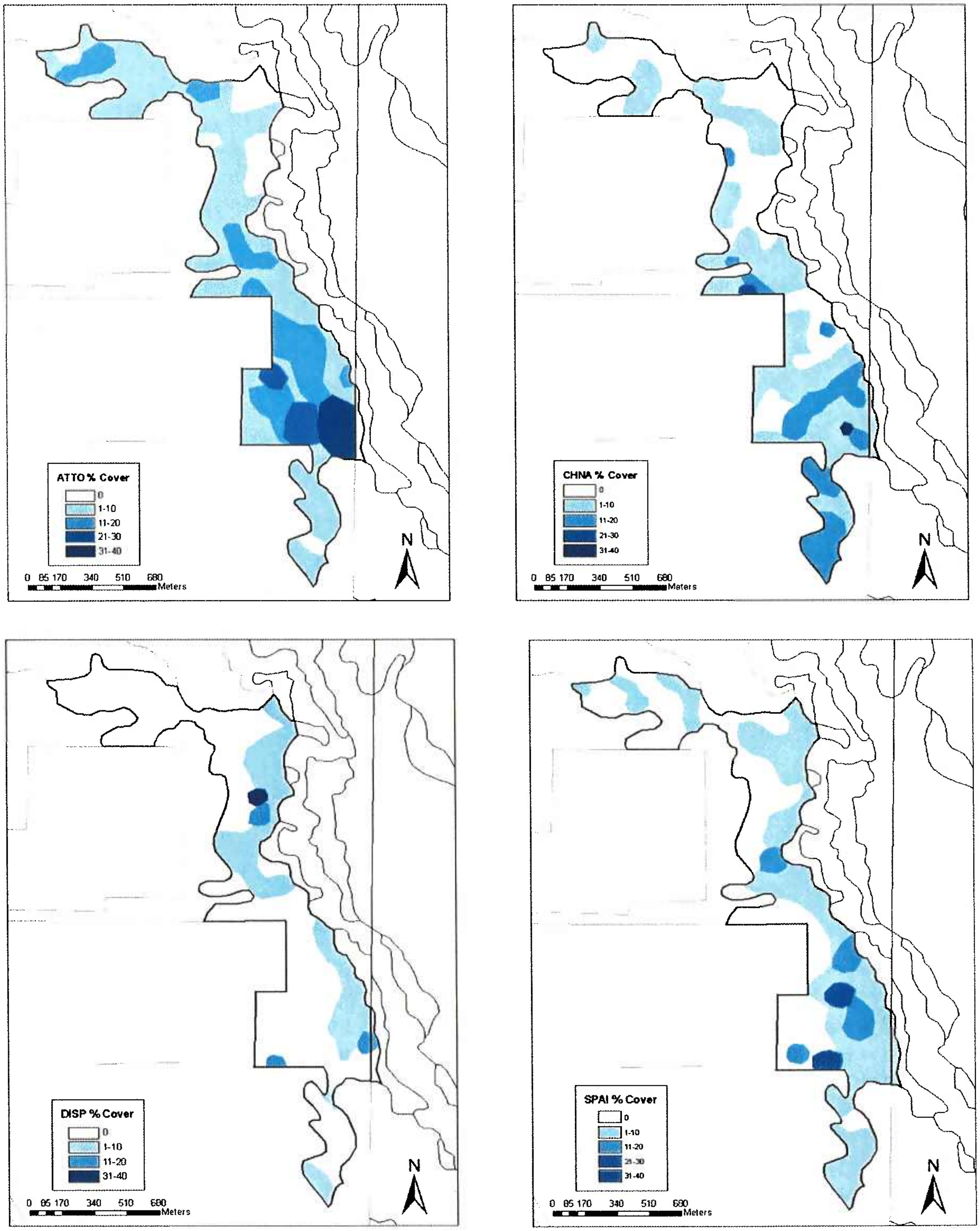


Figure 2. Distribution maps for the four major perennial species in BGP162 based on 1991-2003 ICWD vegetation monitoring data (ATTO = Nevada saltbush, CHNA = rabbitbrush, DISP = inland saltgrass, SPAI = alkali sacaton).

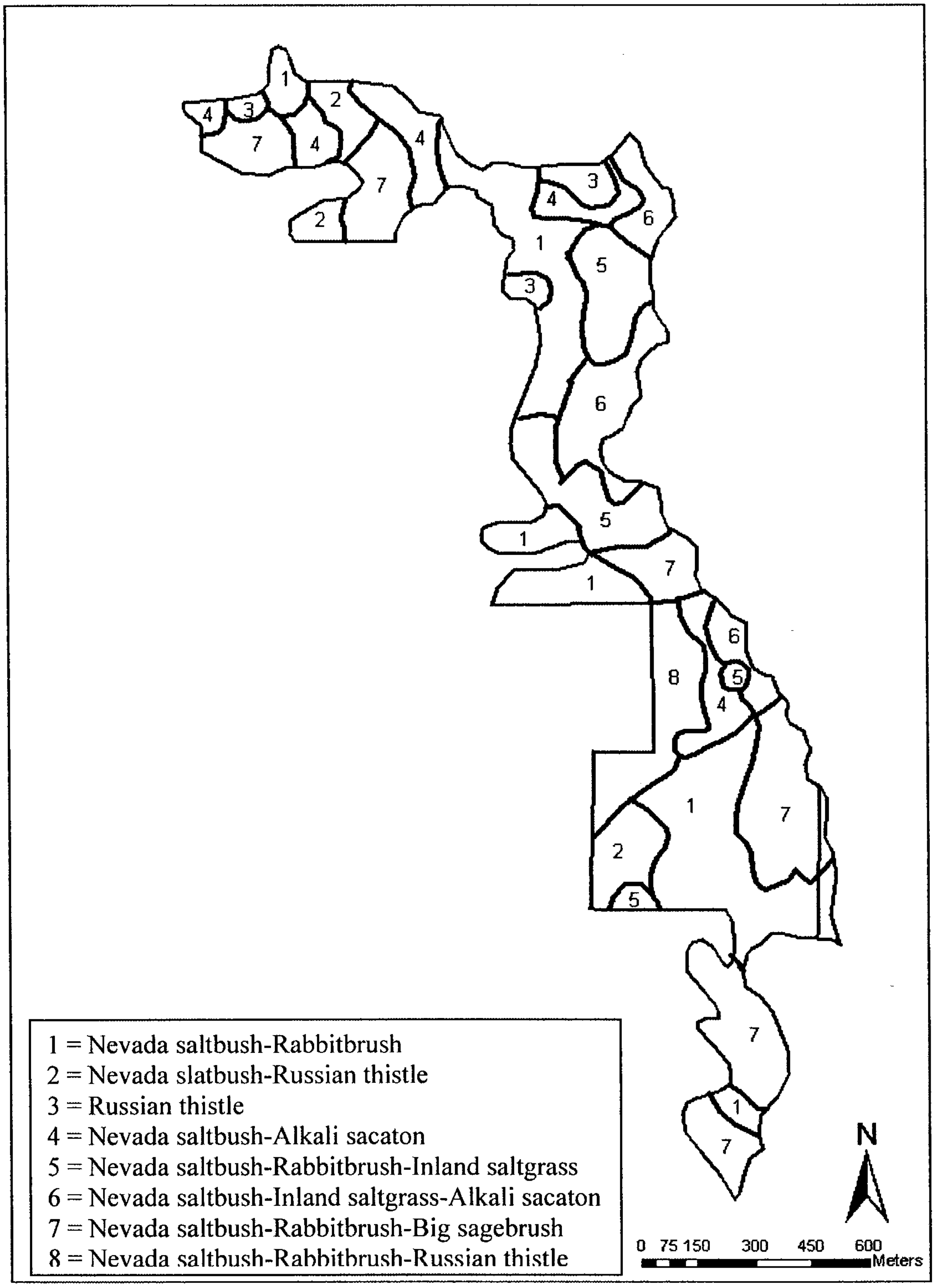


Figure 3. Vegetation Map for BGP 162 based on 1991-2003 ICWD vegetation monitoring data.

Sampling indicated the overall average cover for the entire parcel was 8.4% in 2002 and 13.7% in 2003. At first, it would appear that cover increased in the parcel by 63% (13.7/8.4 = 1.63) between 2002 and 2003. However, if 6 transects had been located in the northwest neck in 2003, as they were in 2002, this would have decreased the total cover in 2003 to 12.9%, assuming that the total transect count remained at 32 and the 2 transects replaced had average cover values. Re-location of 2 of the 32 transects in 2003, to conform to the distribution in 2002, decreased estimated total cover in the parcel by almost 1 percentage point (a decrease from 13.7% to 12.9%). Therefore, in this one example, spatial heterogeneity accounted for at least 15% of the annual vegetation change in this parcel. In fact, the total amount of annual vegetation change attributable to spatial heterogeneity was more than 15% because some variability certainly resulted from the re-randomization of the other 28 transects.

Another example can be seen from this parcel. Two transects were located in the far south end of the parcel in both 2002 and 2003. However, the transects were located in different parts of this area in the two years. In 2002, they were located along the western edge and in 2003 they were located along the eastern edge. In 2002, total cover for these two transects averaged 7%, with values of 3% for big sagebrush, 3.5% for rabbitbrush, and 0.5% for Nevada saltbush. In 2003, total cover averaged 10%, with means of 2% for sagebrush, 1% for Nevada saltbush, 1% for rabbitbrush, and 2% for shadscale (Atriplex confertifolia). Because the transects were located in different areas, it is impossible to determine if total cover actually increased by 43% (from 7% to 10%), and if sagebrush and rabbitbrush decreased, Nevada saltbush increased, and shadscale invaded the area, or whether these changes were entirely the result of spatial heterogeneity in this area of the parcel.

MAN 007 (Manzanar 007) represents another example of how spatial heterogeneity is affecting the results reported by ICWD. Data have been collected from a total of 194 transects in this parcel. Nevada saltbush is fairly uniformly distributed over this parcel, but rabbitbrush tends to be concentrated in the northwest 20% and the southeast 10% of the parcel, and sacaton tends to be concentrated in the northwest 20%. In addition, an airstrip is located in the center of the parcel (Figure 4).

In 2002, 7 out of 30 transects (23%) were located within 100 m (109 yards) of the edge of the airstrip. Total cover averaged 5.6% for these 7 transects, with the most abundant species being rabbitbrush (3.4%) and Nevada saltbush (2.0%). The low cover values are indicative of disturbance related to the airstrip. In 2003, 11 transects were located within 100 m of the airstrip and total cover averaged 15.5% for these 11 transects. Nevada saltbush cover averaged 10.8% and rabbitbrush only 1.5%. For the parcel overall, cover averaged 14.6% in 2002 and 23.7% in 2003.

If four fewer transects had been located adjacent to the airstrip in 2003, as they were in 2002, the overall average cover value of the parcel suggested by the sampling in 2003 would have been even higher. It would have shown an increase from 23.7% to 25.4%, or a 7% increase. Therefore, at least 7% of the vegetation change suggested by the sampling between 2002 and 2003 can be attributed to spatial heterogeneity associated with 7-11 of the 30 transects.

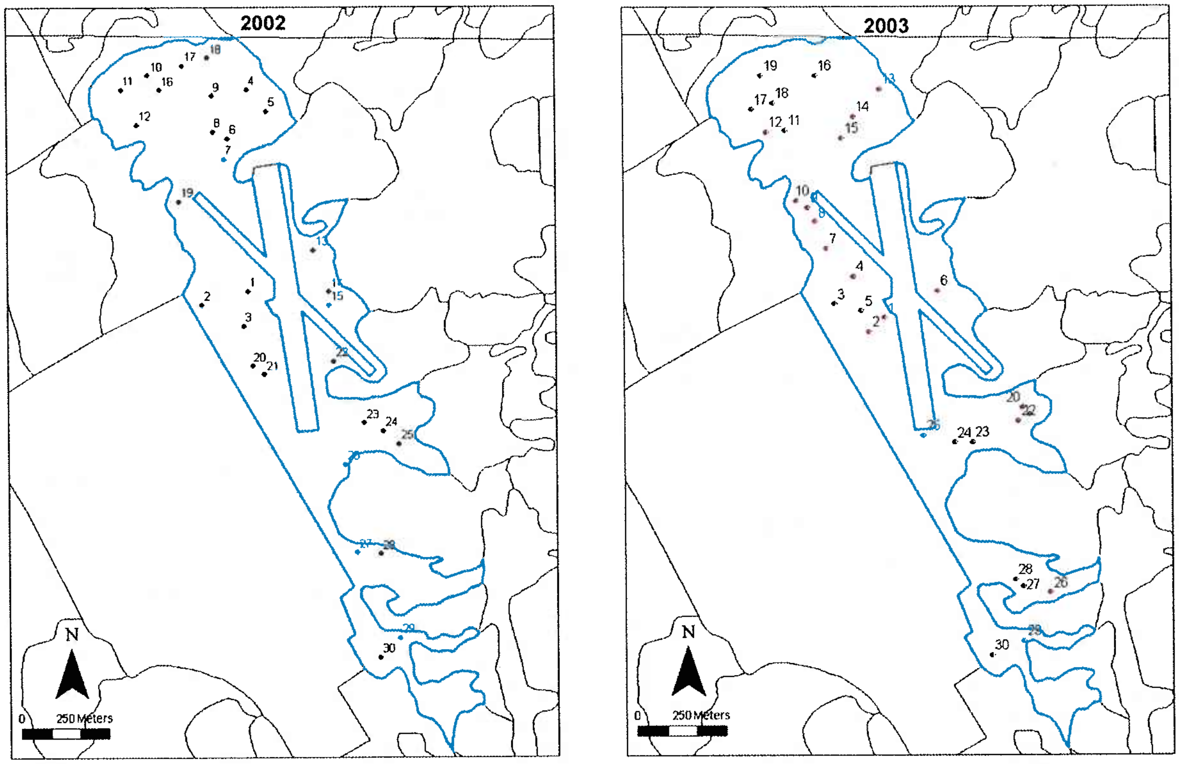


Figure 4. Location of ICWD vegetation transects in MAN 007 in 2002 and 2003.

These two examples illustrate the problem associated with spatial heterogeneity and annual re-randomization of transects. In these examples, at least 7-15% of the variation currently being attributed to temporal changes is being caused by spatial variability. This substantial error in the data can potentially lead to a serious misinterpretation of the data.

SECTION 3. VEGETATION CHANGE IN THE OWENS VALLEY

The goal of the vegetation monitoring program is to determine what changes are taking place in the vegetation in the Owens Valley. Once these changes have been determined, an effort can be given to determine the 1) significance of these changes and 2) the causes of these changes.

To say that something has changed requires that measurements of the something of interest be made at least twice in time. The later measurement must be compared to an earlier measurement to determine if change has taken place. In most cases, there is some significance to the earlier measurement. It is what we are interested in comparing the current condition to. Just to say that something has changed generally does not hold much value. Living things are constantly changing.

In vegetation monitoring, we are sometimes interested in evaluating annual changes. However, we know that annual fluctuations are common in plant communities (Daubenmire 1968:42, Bonham 1989:98). These annual changes can be in response to a large number of environmental factors and combinations of factors. These include such things as climatic fluctuations, grazing intensity (livestock or wildlife), life cycles, and repeated disturbance events. Therefore, we should expect a dynamic aspect to whatever vegetation attribute we are sampling. It is only if this annual fluctuation becomes unexpectedly great or continues over a longer period of time that we generally take special interest in it. A sudden and strong fluctuation might signal response to a disturbance event such as drought, fire, heavy grazing, pathogen outbreak, vehicle traffic, or trampling. More often, we are interested in trends, changes over periods longer than one year. Trends are better indicators, at least for perennial vegetation, of overall ecological conditions than are single point comparisons, such as annual changes. Vegetation responses to precipitation fluctuations, moderate livestock grazing, and succession take more than one year to be fully manifested.

Annual Changes in Vegetation

The ICWD vegetation monitoring data can be used to illustrate types of annual changes in vegetation on some of the parcels in the Owens Valley. These data can only be used to illustrate the changes because the temporal variation in the data has been combined with spatial variability resulting from the annual re-randomization of transects.

ICWD has collected vegetation data on 137 parcels since 1991. This is less than 8% of the total native vegetation parcels in the Valley. Data sets that are complete for all years exist for only 18 of these 137 parcels, or for 1% of the 1729 native vegetation parcels. An evaluation of all changes on all parcels sampled since 1991 is a complex task, and one that is beyond the scope of this paper. Instead, we will concentrate on the 18 parcels that have continual data sets.

Care must be taken in how these results are interpreted. Any conclusions reached based on the data from the 18 continuously-sampled parcels applies only to these 18 parcels, not to the vegetation Valley-wide. The reason conclusions based on these data can not be applied Valley-wide is because the sample populations were not randomly selected, therefore bias was involved in their selection. The 18 continuously-sampled parcels are not an unbiased sample of the vegetation as a whole, and therefore may or may not be representative of the vegetation as a whole. This does not imply that these data do not have any usefulness, only that they represent only 1% of the parcels. We know very little about what is happening on the remaining 99% of the native vegetation in the Owens Valley from these data.

This limited sampling is consistent with the purpose of the ICWD vegetation sampling program. The purpose of the ICWD vegetation monitoring program is not to measure vegetation change in the native vegetation in the Owens Valley. The purpose, as prescribed by Green Book (1990), is to sample those parcels where detrimental impacts from groundwater pumping are suspected to have occurred. This is a much more focused purpose for a vegetation monitoring program. Care should be taken not to mis-interpret the data. Our purpose in presenting some of these data is to illustrate the concepts of annual fluctuations in vegetation, limitations in the data resulting from statistical and sampling considerations, and changes in vegetation over time. Our purpose is not to imply cause of these changes or to imply that the examples we report are valid for any parcels other than those specified.

ICWD commonly uses the term "perennial cover" (Manning 2004). The use of this term can be misleading. The implication is that this is total perennial cover, when in fact it is leaf cover of some of the perennial species. Any species that was growing beneath a leaf of a taller perennial plant was not recorded. Therefore, actual total perennial leaf cover was probably higher than that reported by ICWD.

Perennial cover data for the 18 continuously-sampled parcels are presented in Table 1. The 18 parcels are divided into two groups: control and wellfield. The 4 control parcels are those on which it is assumed that the vegetation has not been impacted from groundwater pumping. The 14 wellfield parcels are those parcels on which the vegetation has been subjected to the effects of groundwater pumping in some of the sampling years.

Three obvious observations can be made from these data. First, the values fluctuate substantially from year to year. This is true for all 18 of the parcels, and it should be expected. Annual variation in vegetation response variables, leaf cover for example, is common in plant communities (Buffington and Herbel 1965, Daubenmire 1968:42, Turner 1990, Paschke et al. 2000, Navarro et al. 2002, West and Yorks 2002). Such fluctuations in the vegetation commonly occur in response to fluctuations in various environmental factors such as precipitation, grazing by livestock and wildlife, depth to groundwater, insect and pathogen outbreaks, and ecological succession. Annual changes in cover of 20-40% are common in these parcels, and maximum changes of over 100% were recorded during this 13-year period. Annual changes of these magnitudes are typical of arid and semi-arid shrublands and grasslands. West and Yorks (2002) reported annual increases and decreases of 30-35% in canopy cover in sagebrush communities in Utah that were protected from livestock grazing. McLendon and Redente (1994) reported fluctuations of almost 100% in annual production in a sagebrush community in northwestern

Colorado. Courtois et al. (2004) reported annual changes in shrub cover of 50-150% at sites in Nevada protected from livestock grazing. Therefore, the fluctuations in the vegetation on these 18 parcels indicated by the ICWD monitoring data do not appear to be unusual. They are consistent with what would be expected from general ecological theory and from studies conducted in other areas of the Great Basin region.

Table 1. Perennial cover (%) in 18 parcels sampled by ICWD each year beginning in 1991.

Parcel	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Control													
IND096	20	16	23	18	28	31	24	28	16	26	23	20	30
IND163	9	10	15	8	18	16	18	24	16	16	12	8	17
PLC223	25	17	32	26	35	27	26	24	27	28	29	15	22
UNW039	8	29	27	21	36	44	28	49	35	44	31	31	29
Mean	16	18	24	18	29	30	24	31	24	29	24	19	25
Wellfield													
BGP154	18	13	16	18	22	29	44	30	25	36	29	18	23
BGP162	8	8	8	10	12	15	11	14	9	23	12	8	14
BLK009	8	22	19	14	27	22	27	32	22	25	21	13	23
BLK016	16	11	18	12	21	18	30	20	22	33	39	25	28
BLK024	23	24	26	22	34	24	25	33	16	27	23	16	29
BLK094	22	19	31	12	29	31	38	50	37	35	28	17	34
BLK099	46	44	49	42	50	57	50	67	80	62	43	38	42
IND111	23	25	34	17	37	31	37	48	37	39	37	26	28
IND139	11	13	20	8	29	24	16	39	20	24	26	18	35
LAW063	5	2	5	5	7	8	12	6	15	10	9	4	6
LAW120	15	13	20	12	29	29	30	42	33	41	47	18	24
MAN007	15	12	16	10	29	10	14	24	16	18	21	15	26
MAN037	7	8	19	18	26	15	24	29	21	44	26	8	15
TIN028	13	17	18	12	19	19	16	21	11	15	20	11	15
Mean	16	17	21	15	27	24	27	33	26	31	27	17	24

The second observation that can be made from the data in Table 1 is that changes in vegetation have been similar between the control parcels and the wellfield parcels. In 1991, mean perennial cover was 16% in both groups of parcels. Twelve years later, perennial cover had increased in both groups of parcels, with the mean values in 2003 about the same in both groups.

The third observation that can be made from the data in Table 1 is that a larger portion of the changes in cover values from year to year is within the accuracy limitations of the sampling technique (i.e., 2-3 percentage points). For example, the reported cover value for BGP 154 in 1991 was 18% and the value in 1992 was 13%. A 3% percentage point accuracy would imply that the 1991 mean might be as high as 21% or as low as 15%. Likewise, the 1992 mean might actually be as high as 16% or as low as 10%. Comparing the lower accuracy range for 1991 (15%) to the higher accuracy range for 1992 (16%), indicates that the sampling technique is not accurate enough to detect differences between these two annual means.

There are 216 possible direct (year to next year) same-parcel comparisons that can be made from the data in Table 1 (12 pairs x 18 parcels). Of these 216 comparisons, over half (109) were less than the accuracy limitations of the sampling methodology. This is not to say that change did not occur in those years. It may have or it may not have. However, the accuracy of the sampling technique was insufficient to detect a change.

Three conclusions result from evaluation of the data from these 18 ICWD-sampled parcels. First, the annual fluctuations in the vegetation data are typical of this type of vegetation. Fluctuations of these magnitudes, both as increases and decreases between years, are similar to those reported in the scientific literature for the Great Basin region and described previously. Secondly, the changes in average perennial cover since 1991 have been similar between parcels subjected to groundwater pumping and those that were not. The third conclusion is that the magnitude of change, from one year to the next, is less than the accuracy of the sampling method, at least half the time.

Comparison to Baseline

The comparisons discussed in the previous section were comparisons of annual changes. What is happening from year to year? The conclusion reached is that the fluctuations indicated by the ICWD monitoring data are typical of shrubland and grassland vegetation in the Great Basin region. We should expect values to increase and decrease from year to year, and they do.

However, another criterion exists by which vegetation change can be measured. Between 1984 and 1987, LADWP collected vegetation data from the parcels supporting native vegetation. This data set has been considered to be baseline for a number of purposes. There is no simple way of determining whether or not these baseline data are representative of long-term conditions in the Owens Valley, and there is no ecological reason to believe that the condition of the vegetation was better or more desirable during that period than at any other period before or after. These baseline data simply represent the earliest comprehensive set of vegetation data available for the Owens Valley.

A monitoring program, any monitoring program, has to have a starting point or a reference point. In vegetation monitoring, we would like this starting point to be as far in the past as possible so that we can collect data over a relatively long period of time. The longer our period of record, the more reliable we consider our data because a longer period of time includes more environmental fluctuations and long-term trends in the data. Short-term ecological data sets can often lead to incorrect conclusions. Longer-term data sets do not assure correct conclusions, but at least they provide more information with which to draw our conclusions. The 1984-87 baseline data provide for the longest comparison of vegetation change currently available for the Owens Valley.

Baseline data are available for most of the parcels sampled by ICWD in their annual vegetation monitoring program. Some of the ICWD-sampled parcels have not been sampled in recent years. Consequently, data for these parcels provide little value in evaluating longer-term changes in vegetation. Of the 137 parcels sampled by ICWD since 1991, 89 parcels have data available for baseline and at least one year between 2001 and 2003.

We have selected four parcels to illustrate changes in vegetation since baseline (1984-87). We do not suggest that these four parcels are representative of either changes in the Owens Valley vegetation in general or those 137 parcels sampled by ICWD since 1991. We only use the data from these four parcels to illustrate the concepts presented earlier in this paper.

The four parcels we have chosen to illustrate these concepts are BLK 009, IND 096, IND 111, and PLC 223. IND 096 and PLC 223 are control parcels and BLK 009 and IND 111 are wellfield parcels. IND 096 and IND 111 are examples of parcels that the vegetation under baseline conditions was dominated by shrubs, but also had substantial amounts of grass cover. Conversely, PLC 223 and BLK 009 were grass-dominated parcels, with some shrubs.

Figure 5 presents changes in sampled mean perennial cover on the two shrub-dominated parcels, along with the 95% confidence intervals of each of these sample means. The sample means are the average of the transects sampled in each respective year and the confidence intervals are based on the variability within these transects. A number of observations can be made from these graphs. First, annual mean perennial cover fluctuated in each parcel. This is to be expected because vegetation is not static. It is dynamic. Secondly, the sample means for all years on the control parcel (IND 096) did not differ statistically from baseline. However, this was because of the great variability (wide confidence interval) in the baseline data for that parcel. The confidence interval for baseline in the wellfield parcel (IND 111) was much narrower, indicating a much more homogeneous baseline sample. Despite this narrow baseline confidence interval, 8 of the 13 annual sample means did not differ statistically from baseline.

A third observation from the data in Figure 5 is that there was a decline in perennial cover between 2000 and 2002, on both the control and wellfield parcels, and then an increase between 2002 and 2003. These 2000-2003 changes are most likely in response to changes in precipitation. Growth-year (September-August) precipitation in 2001 averaged 4.4 inches in the Owens Valley (mean of 9 stations). In 2002, it averaged only 1.6 inches. In 2003, it averaged 8.0 inches. Therefore, 2001 was an average year, 2001 a very dry year, and 2003 was above average. Vegetation changes on both the control and wellfield parcels reflected these precipitation patterns. There was a 16% decline in cover between 2001 and 2002 on the control parcel (IND 096) and a 29% decline on the wellfield parcel (IND 111). These declines were similar (26%) to those reported between 2001 and 2002 at 16 permanent monitoring sites in Nevada (Courtois et al. 2004).

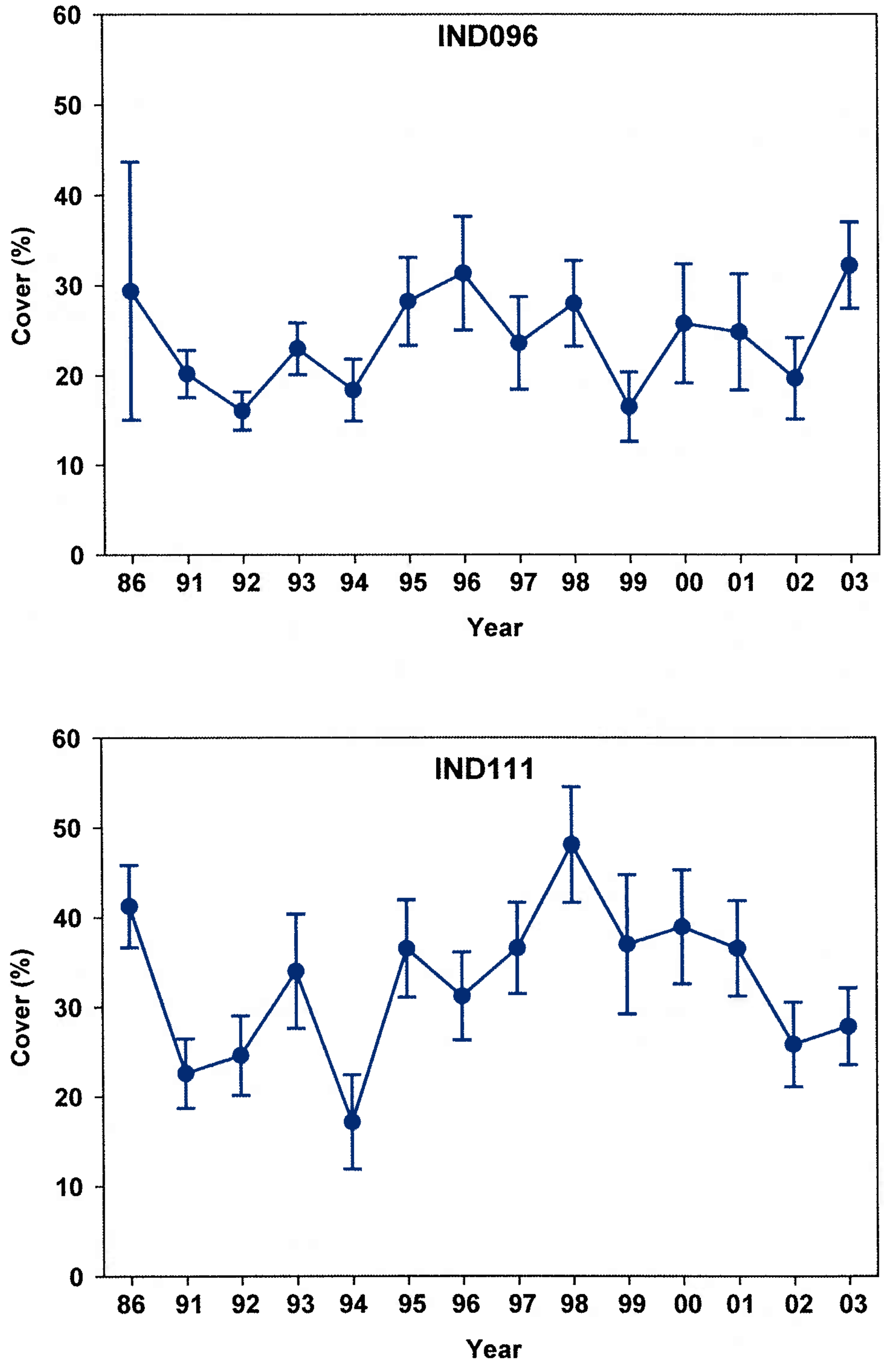


Figure 5. Annual changes in sampled perennial cover (%) of the vegetation in IND 096 (a control parcel) and IND 111 (a wellfield parcel). Sample means are indicated by circles and the 95% confidence intervals of the means are indicated by the bars.

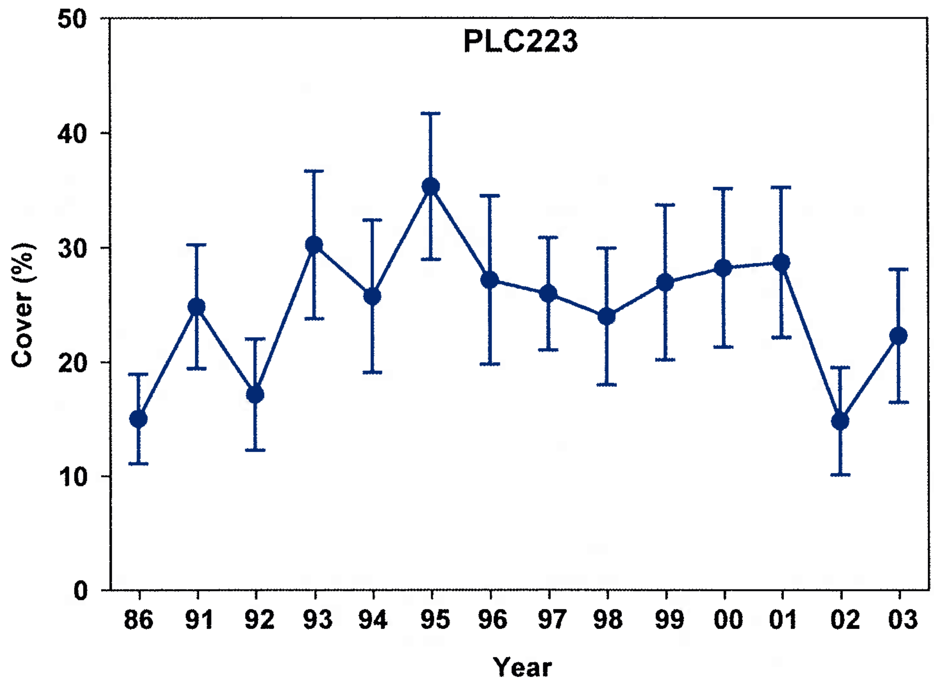
Figure 6 presents similar data for the two grass-dominated parcels, PLC 223 (control) and BLK 009 (wellfield). Very similar vegetation change patterns occurred in response to the dry year (2002) on these two parcels as occurred on the two shrub-dominated parcels. However, in this case, the sampled perennial cover on the wellfield parcel in 2003 was equal to the baseline mean. In addition, sampled cover was equal to baseline in this wellfield parcel (BLK 009) in 10 of the 13 years.

Cover of all perennial species combined is a useful variable for some uses, but not all. Plant ecologists understand that how much vegetation is present is only one of many ways of measuring the significance of vegetation change. Other very important criteria include changes in individual species, especially the most abundant species, and changes in composition (the relative amounts of the species present). These variables can be even more important in evaluating the ecological implications of vegetation change than simply total cover or cover of all perennial species.

Figure 7 presents data for cover of grasses and shrubs, rather than for total perennial cover. The grasses are mostly alkali sacaton and inland saltgrass, and the shrubs are mostly Nevada saltbush and rabbitbrush. Lifeforms (i.e., grasses, shrubs) were used instead of individual species for purposes of simplification.

The vegetation of IND 096 consists mostly of shrubs, therefore the graphs of total perennial cover (Fig. 5) and cover of shrubs (Fig. 7) are very similar. IND 111 is also dominated by shrubs, but grasses are more abundant in this parcel than in IND 096. Under baseline conditions, the vegetation in IND 111 was about 75% shrubs and 25% grasses (Fig. 7). This composition changed substantially by 1991. Between 1991 and 2002, the vegetation in this parcel had proportionately more cover of grass and less shrub cover. Extremes occurred in 1991 and 1996, when grass cover was equal to shrub cover. Exceptions were in 1993 and 1998 when the ratio of shrubs to grasses returned to the 3:1 baseline value. Between 2001 and 2002, there was a decline in perennial cover in IND 111 (Fig. 5), and this decline included both shrubs and grasses (Fig. 7). This was the dry period. In 2003, perennial cover increased over the sampled value in 2002. However, this increase was in shrubs only. Cover of grasses continued to decrease. Although sampled grass cover continued to decrease in 2003, the ratio of shrubs to grasses returned to the baseline ratio of about 3:1. These data indicate that over the period 1991-2002, changes in the vegetation of IND 111 are occurring and that these changes are primarily an increase in grasses and a decrease in shrubs. This pattern may now also be occurring on IND 096, where grasses may have been increasing since 2000.

The control parcel PLC 223 had more grass cover than shrub cover under baseline conditions (Fig. 7). Both shrub and grass cover had increased by 1991, but shrub cover increased more than did grass cover. This resulted in a change not only in cover, but in dominance. The ecological characteristics of this plant community had changed from a grass-dominated community to a shrub-dominated community. And this change has continued through 2003. This vegetation dynamic would not have been noticed by evaluating total perennial cover (Fig. 6).



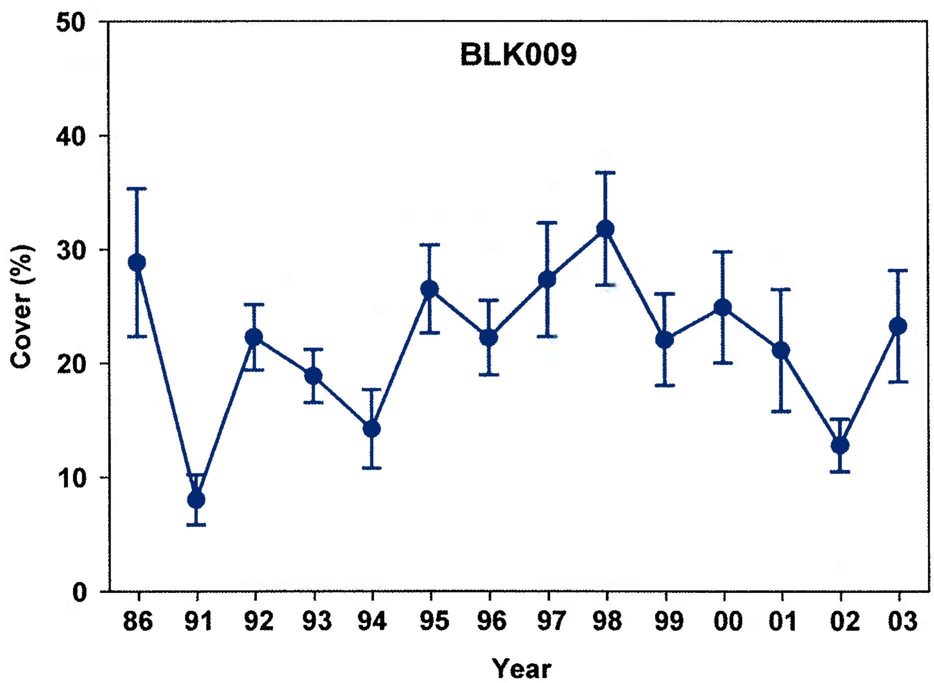


Figure 6. Annual changes in sampled perennial cover (%) of the vegetation in PLC 223 (a control parcel) and BLK 009 (a wellfield parcel). Sample means are indicated by circles and the 95% confidence intervals of the means are indicated by the bars.

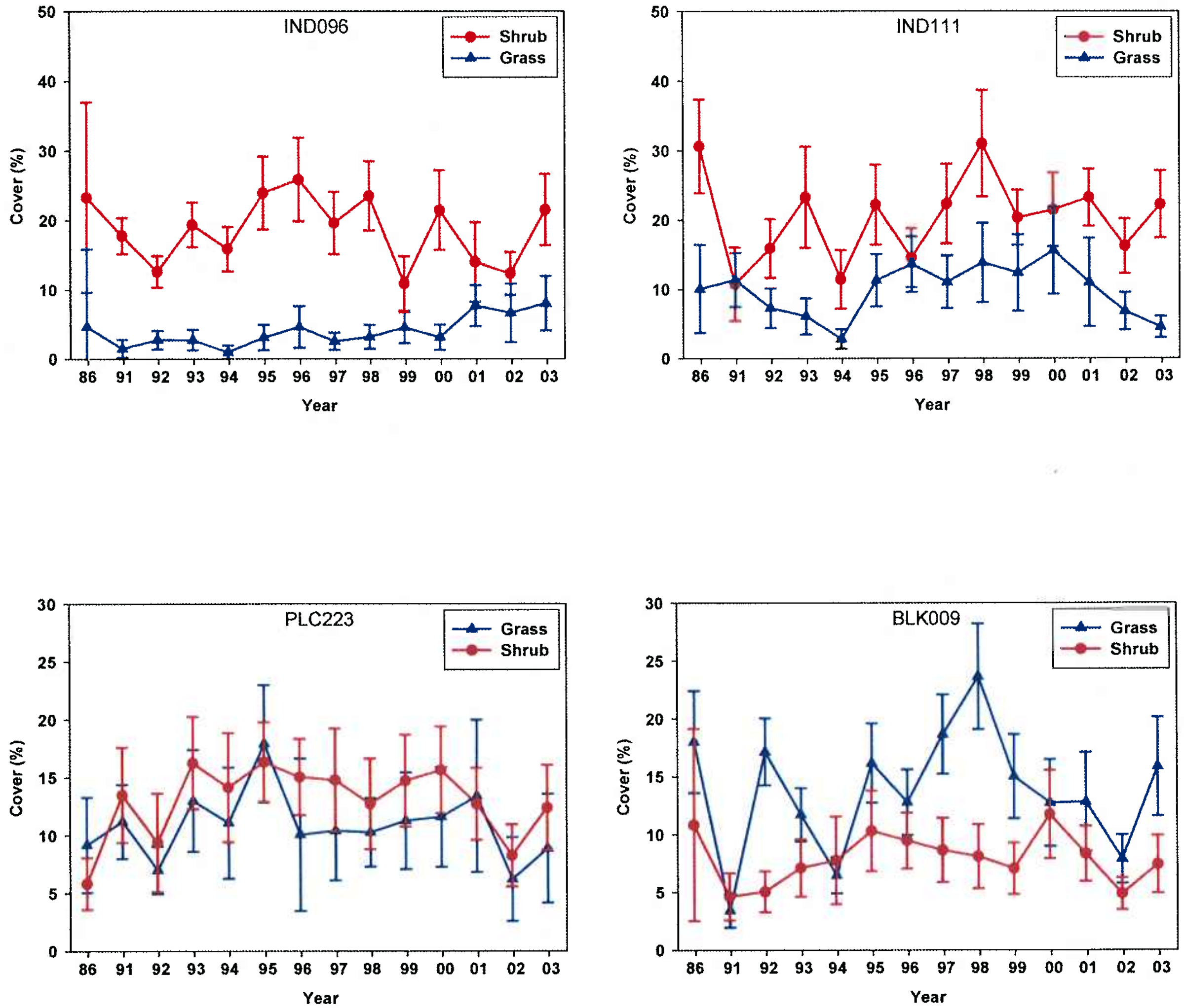


Figure 7. Annual changes in sampled cover of shrubs (red) and grasses (blue) in two control parcels (IND 096 and PLC 223) and two wellfield parcels (IND 111 and BLK 009). Sample means are indicated by circles (shrubs) or triangles (grasses) and the 95% confidence intervals of the means are indicated by the bars.

This change in the basic characteristic of the vegetation has not occurred on BLK 009. Like the control parcel PLC 223 vegetation, the BLK 009 vegetation was grass-dominated under baseline conditions (Fig. 7). However, the vegetation in BLK 009 has remained grass-dominated. The sample means for both grass cover and shrub cover were not statistically different from baseline conditions in 2003, but relative to grasses, shrubs were decreasing somewhat in 2003. Under baseline, grass cover was more than 50% greater than shrub cover. By 2003, grass cover was twice shrub cover.

These types of changes in composition, as opposed to changes in total perennial cover, may be of practical importance in some cases, but not in others. However, they probably are of ecological importance. The changes in vegetation that have occurred on these four parcels illustrate the types of changes that are occurring on other parcels. They also illustrate the concepts presented in the first two sections of this paper. Perhaps the most important concept presented is that vegetation is dynamic. It changes over time. And these changes are complex and thus most likely have complex combinations of factors causing them. Perhaps the second most important concept illustrated by these data is that care must be taken in how these types of data are interpreted. Statistical variability, limitations of sampling techniques, and influence of spatial variation must be taken into account if proper interpretations are to be made. And it should always be remembered that sampling produces estimates of the true population values. The estimates may be accurate, but they remain estimates. The better the sampling technique, the more detailed the statistical analysis, the more refined the sampling design, the better the estimates. But they remain estimates.

Selection of Parcels to be Sampled

The purpose of the ICWD vegetation monitoring program is not to monitor long-term changes in the vegetation of the Owens Valley. If it were, the parcels selected for sampling would need to be representative of all the vegetation in the Owens Valley and all the selected parcels would need to be sampled on a regular basis. Instead, the ICWD vegetation monitoring program, as prescribed by the Green Book, is for the purpose of monitoring for suspected vegetation changes resulting from groundwater pumping. As a result, the selection by ICWD of parcels to be sampled is biased. This does not mean that it is wrong, only that each year only some of the previously sampled parcels are re-sampled, and the selection of these parcels for re-sampling is not random. It is important to recognize this fact because it has a strong effect on proper interpretation of the data.

ICWD sampled 96 parcels in 2002 and 65 parcels in 2003. A comparison can be made between those parcels sampled in 2002 that were re-sampled in 2003 and those that were not re-sampled in 2003. If the mean perennial cover values of the two groups were approximately equal in 2002, then the effect of bias in the selection of 2003 parcels is probably minor. If however, the two means are statistically different, then the bias becomes important and must be accounted for in any ecological interpretations.

Perennial cover for 2002 averaged 19.6% in those parcels sampled in both 2002 and 2003. The mean for those parcels that were not re-sampled in 2003 was 21.9%. Therefore, the 65 parcels selected by ICWD for re-sampling in 2003 had, on average, 10% less cover than the parcels that were not selected for re-sampling.

The fact that ICWD chose to re-sample parcels with lower cover does not mean they were wrong in doing so. There may have been a legitimate reason for doing so. For example, if ICWD was interested in monitoring vegetation change only on those parcels showing the least recovery since baseline, then they might concentrate their efforts on those particular parcels. However, to use these data to imply that these patterns also hold for other parcels is inappropriate. This is where the issue of sampling bias becomes important. Had the selection of parcels sampled in 2003 been made at random, then conclusions from the 2003 data could be applied to the other parcels. However, when sample selection is biased, then the conclusions hold only for those parcels selected.

One result of this bias in the 2003 data is that the estimate of perennial cover in 2003, compared to earlier years including baseline, is likely to be low. The average perennial cover value in 2003, on the parcels for which baseline data are also available, is 25%. Mean perennial cover on these same parcels under baseline was 31%. These two numbers suggest that perennial cover in 2003 was 6 percentage points below baseline. However, the 2003 data were biased low. Therefore, the actual value for 2003 was probably greater than the sampled value of 25%, perhaps on the order of 10% low. Therefore, an adjusted value for 2003 might be 27-28%, rather than the sampled 25%. This value of 28% brings the 2003 sampled value to within 3 percentage points of the baseline value, and this is the margin of error in the sampling technique.

CAUSES OF CHANGE

The emphasis in this document has been on evaluating methods of measuring vegetation change and applying the results of this evaluation to some of the data currently available. However, from both management and ecological standpoints, it is seldom enough to simply show that changes have taken place. Instead, we usually want to know why the changes have taken place.

Vegetation change is taking place in the Owens Valley. There are annual fluctuations in cover of perennial species and cover of individual species. There are also overall trends. Determining the causes of vegetation change is much more challenging than determining whether or not change is taking place. Many factors are involved, and each has its role. In many cases, the roles change depending on what other environmental factors are also influencing the vegetation at that location. Vegetation change in the Owens Valley has been attributed to numerous factors: precipitation, depth to groundwater, competition from associated species, livestock grazing, ecological succession, and insect and pathogen outbreaks. It is not difficult to hypothesize any and all of these factors as contributing to vegetation change in the Owens Valley. Their ecological impacts have been documented in studies elsewhere and it is difficult to believe that they do not function in similar manners in the Owens Valley. But to hypothesize that a factor is the cause of a known change in vegetation is very different from establishing that it did indeed cause the change. Establishing possible or potential effect is not the same as establishing cause and effect.

Establishing cause and effect can be very challenging. It is not always possible. But it is certainly a useful goal. In upcoming papers in this series, we will begin this process by evaluating existing data to attempt to determine what factors, and combination of factors, may be causing vegetation change in the Owens Valley.

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