Review of Methods for Vegetation Monitoring and Analysis in the Owens Valley, California

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List of Acronyms

ANOVA analysis of variance

AVIRIS Airborne Visible / Infrared Imaging Spectrometer

DTW depth to water

ENVI Environment for Visualizing Images

ESA Ecological Society of America

ET evapotranspiration

FRAP [California] Fire and Resource Assessment Program

ICWD Inyo County Water Department

LADWP Los Angeles Department of Water and Power

LAI leaf area index

LIDAR Light Detection and Ranging

MCV Manual of California Vegetation

M-W Mann-Whitney test

NDVI normalized difference vegetation index

NEON National Ecological Observatory Network

PCC plant crown cover (or percent cover)

PERMANOVA permutational multivariate analysis of variance

RS remote sensing

SE standard error

TM [Landsat] Thematic Mapper

Executive Summary

ES 1. Introduction

In December 2014, the Ecological Society of America (ESA) agreed to provide consultant services to Inyo County and the City of Los Angeles to assist with the development and implementation of vegetation monitoring and data analysis procedures for evaluating impacts of groundwater pumping in the Owens Valley, CA. ESA assembled a team of three experts in vegetation monitoring and data analysis, who were tasked to research and recommend monitoring and analytical methods, including strengths and weaknesses of alternatives. This Executive Summary presents the conclusions of the Team's review of existing monitoring and analytical methods, and outlines favored options for updating those methods and expanding the management benefits of the program while continuing to meet existing requirements set forth in the Green Book. The term "options" is deliberately used, rather than the alternative "recommendations," to make clear that these are choices for the agencies to consider for enhancing their efforts, not prescriptions to change the current vegetation monitoring and analysis methods, which continue to be widely used and accepted by the scientific community. More detailed discussions are located in the main text.

ES 2. Favored options for enhancing monitoring and analytical methods

This section focuses specifically on methods for monitoring, estimation of evapotranspiration, remote sensing, and statistical analyses. A subsequent section discusses additional options for identifying relationships between vegetation conditions and management actions.

ES 2.1 Monitoring baseline and methods and statistical analyses

The vegetation monitoring conducted independently by the Inyo County Water Department (ICWD) and Los Angeles Department of Water and Power (LADWP) is used to evaluate the effects of groundwater pumping by comparing current conditions with those recorded in a 1984 – 1987 baseline survey. Although not specifically part of the Team's charge, our review revealed no compelling reasons to update the baseline.

The point-line intercept sampling techniques used by ICWD (transects rerandomized each year) and LADWP (permanent transects) continue to be widely used and accepted by the scientific community. Either the permanent (if shown to be randomly distributed) or the randomized transects could be used for future monitoring. The joint sampling of the permanent transects that the two organizations conducted in the 2015 field season should provide useful comparisons of relative efficiencies of the two techniques.

A key question for monitoring efficiency is the sample size required to detect a given amount of change in percent cover attributable to groundwater pumping. Section 2.2.4 provides an example analysis for detecting 10 to 30 percent decreases in total cover, comparing a permanent transect parcel to a sample of transects from the baseline data. This example shows that compared to a normal distribution, use of a binomial approximation for the data can greatly reduce the sample size required to detect a given change, e.g. from n=439 to n=16 transects for each permanent transect parcel.

The field and remotely sensed plant cover and species composition data, plus categorical transitions between vegetation types (A to E), have been analyzed relative to the baseline and temporal trends using a variety of multivariate and univariate statistical techniques. These include ordinations, permutational multivariate analysis of variance, Sørensen similarity indices (used to compare plant community composition at different times or monitoring sites), and comparisons of specific community components (for example grasses or shrubs) at different times or monitoring sites.

These statistical techniques are widely employed in ecological science and are currently accepted by the scientific community. However, current univariate analyses are based on the assumption that the data are normally distributed, which is not necessarily the case. Common statistics programs can readily test this assumption. Options that could improve the power of the statistical analyses include testing hypotheses based on binomial, Poisson, or other discrete data distributions. While the tools are readily available in statistical packages, some specialized expertise may be required to properly use and program the techniques.

ES 2.2 Remote sensing methods

Remote sensing, through analyzing aerial photographs, digital aerial photographs, and Landsat satellite images, has been employed in several studies in the Owens Valley to analyze change in vegetation cover and to document the extent of flood zones in the Lower Owens River Project. These methods have the advantage of being able to cover large areas relative to field sampling, but the disadvantage of being at a coarser resolution and not necessarily capable of identifying changes in species composition.

One option for developing a better understanding of the utility of commonly available remote sensing products would be to compare cover estimates generated from the Landsat Thematic Mapper (TM) imagery time series analyzed by ICWD and parcels in which cover values are collected. The current analyses in this time series compare wellfield and control parcels through time using spectral mixture analyses to derive a comparable measure of cover. While temporal trends are evident using this approach, it is unclear to what degree remote sensing could be used to replace some of the field monitoring, partially due to an insufficient level of analysis of the degree of accuracy that it could replicate field measures.

Another option to consider as a remote sensing data source is Light Detection and Ranging (LIDAR). LIDAR provides highly accurate and precise measures of canopy height and extent and could be used to define and classify cover and to track changes in cover over time. However, one problem with many remote sensing systems in desert regions is that the high background reflectivity can make it difficult to get accurate measurements. Therefore, applications to desert shrubs are less common than in other ecosystems. Additionally, small leaves of most species in the region add to this issue.

Although these observations suggest LIDAR is likely not an option for augmenting ongoing monitoring in the Owens Valley, recent LIDAR and AVIRIS data collected by the National Ecological Observatory Network indicate that LIDAR may be useful in providing measures of cover on a parcel basis. The Team will seek to make that imagery available to ICWD and LADWP for consideration of the utility of LIDAR data. Further, remote sensing technologies are rapidly evolving and we recommend the agencies conduct periodic reviews to identify new opportunities to improve monitoring efficiency and analyses.

ES 3. Additional options for identifying relationships between vegetation conditions and management actions

It is already recognized by the staff of ICWD and LADWP that an important next step in vegetation monitoring is improving the ability to identify relationships between management actions and vegetation conditions. The ESA Team agrees. The Team's general conclusion is that the current sampling and statistical methods, although adopted in the 1980s, continue to be appropriate and widely accepted in the scientific community. However, a number of changes in protocols could increase the efficiency of the monitoring program and provide much richer information for management of the Owens Valley vegetation communities and groundwater withdrawal programs.

ES 3.1 Spatial arrangement of transects

The status quo is continued sampling of the mixture of random (ICWD) and permanent (LADWP) transects with no special attention to linking with management and environmental gradients. This requires no change in procedures, and over time it can provide information on how vegetation has changed generally across the landscape. However, the difficulty of attributing detected vegetation change to management actions would continue.

ICWD already reallocates sampling units each year through the rerandomization of sampling locations. This reallocation could be focused on stratifying sampling to monitor relationships of vegetation change across gradients of specific management actions or environmental changes. For example, adjusting the allocation of sampling units (or integrating with other monitoring initiatives) to array them across recognized environmental gradients (particularly elevation and the natural background depth to groundwater from the foothills on either side to the center of the valley), and to specifically identify how vegetation changes with distance to pumping locations, fire management strategies, range management, or nonnative plant invasion gradients, could provide better information for management decision-making. For continuity with past monitoring, existing parcels could continue to be monitored, but have transects located within the parcels in particular areas that include environmental or management gradients of interest.

ES 3.2 Developing a working spatial model of vegetation dynamics and groundwater

Some attempts have already been made to build an integrated model of vegetation dynamics and groundwater effects on them. A 10-foot groundwater contour has been developed and used to consider the tipping points between conditions that favor phreatophytic (groundwater-dependent) grasses and shrubs, and other Kriging of groundwater levels is regularly conducted. Modeling a range of groundwater depths could be used in conjunction with the vegetation map to make predictions about what changes in vegetation could occur at different levels of groundwater.

Existing monitoring data could then be used to calibrate the model to precipitation levels, and to make predictions about expected vegetation dynamics on a parcel basis. Subsequent development of a groundwater/vegetation dynamics model could be used to project the expected change to vegetation under varying groundwater level conditions. This type of model can be first produced simply using state transition hypotheses about vegetation types. As these are confirmed or rejected, a more fully parameterized landscape model could be developed. Development of monitoring data that span the environmental gradients of the valley (see section ES 3.1) could help in the generation of this landscape model.

ES 3.3 Thresholds tracking

Thresholds are standards or benchmarks that are used to detect certain conditions which could affect management decisions. While this is generally a laudable goal, the approach is only lightly tied to the concept that ecological or ecosystem processes, which are continuous, may exhibit alternate states when some factor changes such that a tipping point is reached. An example described during the July 2015 workshop included an area where the trees all died when groundwater pumping was more substantial than it is now.

Additional data about thresholds of interest could better inform the management of the system. This would require collecting enough information about the underlying processes to determine what would constitute a threshold of interest. Some processes that could be useful include the following.

(1) Further tracking of the depth to groundwater and the response of groundwater to individual precipitation events and seasonal snowmelt could be used to develop better models of the expected groundwater conditions at different times of the year and following different magnitude precipitation events.

(2) Phenological tracking of plant life cycle events within the five vegetation types, and across environmental gradients could improve the analyses of ground sampling and remote sensing results. This could be particularly important to the extent that ongoing climate change affects the timing of life cycle events.

(3) Monitoring the density of vegetation type cover across a spatial gradient of groundwater depths could provide better understanding of densities observed over time at monitored parcels.

Two kinds of criteria could be used to detect whether a threshold had been crossed. A statistical one would be whether a change in shrub or grass cover has occurred at a declared level of probability. An ecological criterion would be to identify what levels of plant cover change trigger a functional shift in the vegetation. The Team recommends that thresholds be explored through modeling, for example estimating the number of livestock supported at different levels of grass cover, and through experimentally reducing grass cover in the field, monitoring the subsequent recovery of grasses or invasion by shrubs.

ES 3.4 Adaptive management experiments

A key point regarding the status of existing monitoring is that the past 30 years of monitoring have focused on generally characterizing vegetation conditions across the landscape. Existing monitoring has not mainly focused on identifying causal relationships of management actions and changes in environment with changes in vegetation condition. Existing monitoring data can support assessment of coarse correlative relationships only, such as comparing vegetation in wellfield versus non-wellfield conditions. Both agencies are interested in improving their ability to attribute vegetation change to changes in management and environment. It is important to note that monitoring can detect change, but it is not equipped to detect cause-effect, which requires experimentation.

A series of planned, adaptive management experiments to address and refine priority management questions is a favored option as part of the next generation of monitoring in the Owens Valley. Advance planning will be required along with some reallocation of sampling effort. However, there are numerous advantages. First, extensive management and conservation actions are already occurring in the Owens Valley, so this option does not necessarily require new management actions, but rather, taking advantage of existing ones. Second, adaptive management experiments are probably the most effective and efficient way to identify thresholds, trigger points, and answers to other priority management questions discussed in this report. Third, this approach can identify interactions among the numerous factors simultaneously affecting vegetation, providing a realistic monitoring framework.

Options for adaptive management experiments include the following. A water drawdown experiment could be conducted by creating three levels of water drawdown by pumping: no change (control), lowering the water table by one meter, and lowering the water table by three meters. An alternate third treatment could be to raise the water table. Second, a prescribed burning experiment could be conducted with treatments that are either a simple yes or no, or alternate timings or frequencies of fire. Combining these two experiments would result in six treatment combinations (three water table levels with burning or not for each) and the ability to evaluate the effects of water and fire management by themselves, plus the interaction between them. The experiment would improve the agencies' ability to predict vegetation dynamics across the landscape. Ideally, multiple vegetation types and land-use histories would be included.

Other adaptive management experiments could improve the agencies' understanding of how management and environment are linked with vegetation change. For example, considerable investment has already been made in establishing a series of grazing exclosures across the landscape. These, or new grazing exclosures, could be targeted for different fire or water management actions, and the interaction between those actions and range management evaluated. The same idea could also apply to revegetation activities and nonnative plant control, for example testing the effect of reducing nonnative woody plants on the development of Type C grassland communities under various water management scenarios. A final example of a management action that could be tested and monitored is temporarily blocking some ditches or canals and allowing flooding of meadows. If it is feasible to implement this management action at some test sites, the agencies could test the hypothesis that it could help maintain Type C meadows or even convert Type B shrublands to Type C meadows.

The response variables in these experiments need not be complex and could be the basic plant cover and species composition data already used by the agencies. Moreover, the same point-intercept transects already employed could be used to monitor the experiments for continuity with existing monitoring. We are not recommending that adaptive management experiments replace the current monitoring, but rather to conduct them in tandem. In conclusion, adaptive management experiments are a proactive option that efficiently takes advantage of management actions and monitoring already occurring. They could improve the ability to delimit thresholds and avoid undesirable outcomes set forth in the Green Book, while identifying the management actions and environments that produce or maintain desired conditions.

ES 3.5 Life history tables

The agencies already have identified five land cover designations (A-E) that relate in some ways to life history traits, particularly to rooting depth and physiognomy. Compiling additional ecological knowledge about the species in the region would provide a number of benefits. For example, it could help identify indicator species that could help focus monitoring. It would also permit the formalizing of hypotheses about how different species, vegetation types, or plant functional types respond to varying conditions. The monitoring data collected could then be used to confirm, reject, or adjust the life history values recorded for different species.

Development of life history tables particularly attuned to scoring Owens Valley species on their ecological characteristics and their sensitivity and/or adaptive capacity to groundwater fluctuations (or other management questions) could contribute to a variety of analyses, including the frequency of a given species under different groundwater conditions over the years, for the adaptive management options discussed previously, and for developing hypotheses about the impacts of differing levels of groundwater pumping on particular species of interest.

ES 4. Conclusions

The ESA Team finds that current vegetation monitoring and analysis methods used by ICWD and LADWP continue to be widely used and accepted by the scientific community. However, the utility of these methods for detecting changes in vegetation due to groundwater withdrawal could be strengthened by taking the following steps.

1) Review, consolidate, and update monitoring methods and analyses, including selecting a single monitoring protocol (either permanent or randomized transects), determining a consistent sample size based on agreement about the level of change the agencies wish to detect, and considering co-locating some area-based measures with transects to test the feasibility of eventually transitioning to area-based monitoring.

2) Improve the monitoring design to more closely correspond with variation along groundwater pumping and other biophysical and management gradients.

3) Periodically review and as appropriate adopt new technologies, including remote sensing and handheld or aerial sensors, to increase monitoring accuracy.

4) Develop models of groundwater/vegetation dynamics in conjunction with improved monitoring methods.

5) Use applied adaptive management experiments to determine causal relationships between vegetation and factors that affect it, including groundwater, grazing, fire, and invasive species.

We believe that the diverse environment of the Owens Valley, in combination with Green Book mandates and the long history of monitoring, is an ideal setting for understanding influences of a range of management options during an era of environmental change. Expanding the “tool box” of management options with known effectiveness available to the agencies could significantly improve their ability to meet future challenges in uncertain future environments, while continuing to meet existing requirements.

1.0 Introduction

In December 2014, the Ecological Society of America (ESA) agreed to provide consultant services to Inyo County and the City of Los Angeles to assist with the development and implementation of vegetation monitoring and data analysis procedures for evaluating impacts of groundwater pumping on ecological resources in the Owens Valley, CA. ESA assembled a panel of three experts in vegetation monitoring and data analysis, who were tasked to research and develop options for improved monitoring and analytical methods, including strengths and weaknesses of alternatives. In support of this, the ESA Team reviewed materials, including annual reports produced by the Los Angeles Department of Water and Power (LADWP) and the Inyo County Water Department (ICWD), the Green Book (James et al. 1990), and relevant scientific literature. The Team participated in a workshop in Bishop, CA, July 21 – 23, 2015, where they met with LADWP and ICWD staff, who briefed the Team about the goals, purposes, and current methods of vegetation monitoring and data analysis in the Owens Valley. The Team also participated in a field trip to several monitoring sites to more fully inform their understanding of the monitoring program. The workshop concluded with a discussion of information needs and a schedule for completing the tasks assigned to the Team.

This report presents the results of the Team's review of existing monitoring and analytical methods, and outlines options for updating those methods and expanding the management benefits of the program while continuing to meet existing requirements set forth in the Green Book. The term "options" is deliberately used, rather than the alternative "recommendations," to make clear that these are choices for the agencies to consider for enhancing their efforts, not prescriptions to change the current vegetation monitoring and analysis methods, which continue to be widely used and accepted by the scientific community.

The report identifies five areas in which enhancements to existing protocols could be made. We provide suggestions for enhancing the ability of the agencies to detect correlations between vegetation change and changes in management actions and environmental variables, review possible approaches to expand the applicability of monitoring to capture trends along environmental and management gradients, and outline adaptive management experiments for identifying cause and effect linkages between management actions and vegetation change. These strategies for improving attributability could assist in identifying thresholds and avoiding the undesirable changes set forth in the Green Book.

2.0 Review, critique, and options for improvements and integration of current vegetation monitoring and analysis methods

This section summarizes the vegetation monitoring and analysis methods that ICWD and LADWP currently use.

2.1 Monitoring baseline

A 1984-1987 vegetation map, regarded as the baseline vegetation condition, is the main baseline for monitoring plant community change and assessing effects of water management in the Owens Valley. To develop the map, vegetation types were delineated and described at a 1:24,000 scale using point-intercept transect sampling of vegetation in the field, combined with aerial photographs on which vegetation types were delineated. Vegetation types were broadly classified into five types:

A (not dependent on groundwater and uses soil moisture largely recharged by precipitation),

B (shrubland dependent on groundwater),

C (meadow dependent on groundwater),

D (riparian/marsh dependent on groundwater and flowing or standing surface water), and

E (irrigated land).

A total of 2,126 parcels covering 91,930 hectares (227,160 acres) was mapped. Most of the vegetation is Type A (66%), followed by Type C (18%), Type E (8%), Type B (5%), and the rare riparian/marsh Type D (3%).

The Green Book (James et al. 1990), which directs vegetation monitoring and management in the Owens Valley, states how the baseline vegetation map is to be used: "….groundwater pumping and changes in surface water management practices will be managed with the goal of avoiding significant decreases and changes in Owens Valley vegetation from conditions documented in 1984 to 1987" (page 1). The Green Book then indicates that the groundwater-dependent vegetation *Types B, C, and D shall be managed to avoid conversions to a vegetation type with a letter preceding it*. For example, conversion of meadow (Type C) to shrubland (Type B) is stated as undesirable.

Although not specifically part of the Team's charge, our review revealed no compelling reasons to update the baseline. Since the 1980s when the vegetation map was developed, appreciation for the importance of shifting baselines has grown in ecological and conservation science. For example, we now have an improved understanding for how extreme events – such as severe droughts or floods – can influence ecosystem conditions for a long time, complicating defining a single "baseline" condition in a continuously changing system. Nevertheless, we believe that the approach of defining the baseline used in the 1980s was reasonable and was based on the best available information at that time. Furthermore, if a baseline were to be defined today, it too could be subject to the peculiarities of the contemporary environment although it may have the advantage of being able to include ranges of variability (assisted by long-term monitoring data) now readily accepted in ecological science.

However, several aspects of the existing baseline should be kept in mind for their potential influence on vegetation monitoring and assessment of management effects. The baseline conditions were contingent upon water management leading up to and at that particular time. They also depended on potentially many other factors at that time, such as weather, the status of nonnative plant introductions, grazing management, agriculture and pasture management, and native herbivores. Thus, if the baseline had been measured in a different year, it might be different. Moreover, managing ecosystems relative to an unchanging baseline poses challenges, as many major environmental conditions such as climate change are unrelated to local management. For example, precipitation was above average in 7 of 12 years leading up to and during the 1984-1987 baseline condition (Figure 1). In contrast, only 4 of the last 12 years had above average precipitation. This probably makes the 1984-1987 condition a rigorous standard for contemporary management to meet, which could be considered beneficial from a perspective of native vegetation conservation. This report does not consider the relative merits of the baseline further, as we assume the 1984-1987 baseline will continue to be the standard for evaluation in the Owens Valley.

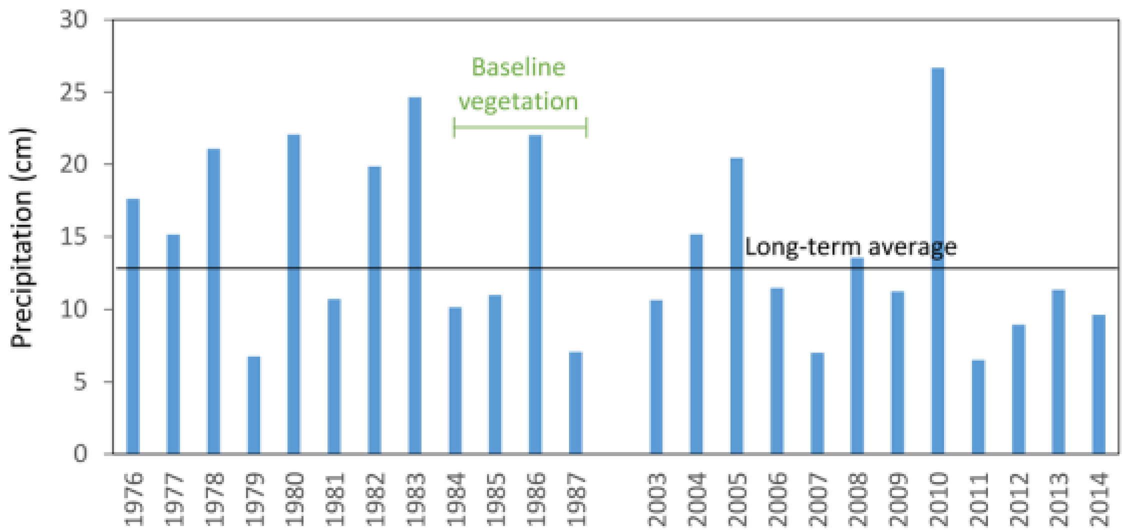


Figure 1. Climatic context for the 1984-1987 measurement of baseline vegetation and for contemporary vegetation monitoring, Owens Valley, California. Records are from the Independence, California, weather station reported in the Western Regional Climate Center (Reno, Nevada). The black line is average annual precipitation between 1925 and 2014. 1988-2002 data omitted in order to focus on decade before baseline and on more recent monitoring.

2.2 Current monitoring methods

There is a long history of monitoring vegetation in the Owens Valley, and uncertainties persist in how to best monitor changing conditions and compare with the baseline. Inyo County began monitoring vegetation in 1991 and LADWP began monitoring in 2004. Parcels were initially selected for monitoring by ICWD based on criteria such as the parcel being close to a pumping well, representative of one of the plant community types mapped by the baseline, characterized by soil data, and other criteria. As many as 100 or more parcels in total are sampled annually by the agencies, and the number of parcels and transects sampled has varied through time because of factors such as staff availability and questions regarding particular parcels.

Both agencies use a point-intercept transect as the sampling unit, similar to that used during the 1984-1987 baseline inventory. Sampling each transect entails recording live vascular plant “hits” every 0.5 meter along a 50-meter transect, yielding 100 possible hits per transect. The percentage of hits (out of

100 possible), by species, is taken to be percent plant cover. Multiple transects are sampled within each parcel, including a mix of permanent and randomly generated transects.

In general, the point-line intercept sampling techniques used by ICWD and LADWP continue to be widely used and accepted by the scientific community. The joint sampling of the permanent transects that the two organizations conducted in the 2015 field season could provide useful comparisons of the two techniques.

A significant difference in the two agencies' protocols is that the ICWD rerandomizes the transects each year, meaning that the same location within a parcel is not necessarily sampled among years, while the LADWP uses permanent transects, which were originally generated by randomly selecting from a pool of potential transect locations. Transects analyzed by each agency are aggregated by parcel to estimate average plant cover and species composition (species and their proportional contribution to total plant cover) for each sampled parcel. According to information provided during the July workshop, LADWP has sampled 1,443 transects within 126 parcels as of 2015. In 2015, ICWD and LADWP began monitoring vegetation jointly, which has the potential to increase the efficiency and scope of future monitoring. One of the major questions for the Team was to review and discuss the merits and limitations of monitoring conducted with permanent transects vs. annually randomized transects, because the agencies seek the efficiencies of joint monitoring. There are advantages and disadvantages to both approaches.

We break this discussion into 5 sections: comments on the use of the baseline; the use of permanent monitoring transects; the use of randomized monitoring transects; considerations for the number of replicates needed; and other considerations.

2.2.1 Strengths and weaknesses of using baseline data set for comparison to a monitoring data set

Strengths

1) This data set has value because it is a permanent record for future uses.

2) Specifically, the data are useful as a list of plant species encountered in the years 1984-1987.

3) Individual parcels can be accessed to obtain a list of individual species and their cover values in the baseline years that samples were obtained.

4) Species composition can be calculated for each parcel sampled using relative cover values.

5) Averages for cover values by species can be used to estimate average relative cover by species. This relative cover value is valid to use in a comparison to other data sets having relative species composition values. The calculation is standardized around a total cover value for the parcel (or site). "Relative cover" is used because the value is relative to the total cover present in a parcel. Therefore parcels with differing total cover can be compared.

6) Vegetation structure changes can be documented by monitoring parcels over time and comparing to baseline data. An example is change in lifeform cover of grass and shrub in a given parcel.

7) Baseline data can be used to monitor changes in a species life history studies by parcel.

Weaknesses

1) The baseline data set is assumed to have remained static in cover values over time, if these data are used to test for significant differences occurring in monitoring data from parcels. Statistical tests might be challenged. To resolve the problem, assume baseline data are fixed with no variation over time. Someone challenging this assumption would have to disprove that baseline data did not change significantly over time; i.e., that data values did not remain within the confidence limits of the mean cover present during the years for baseline sampling.

2) Changes in species composition cannot be interpreted as useful to detect cover changes related to water drawdown. It follows that the same plant species has to be used to obtain a difference in species composition for each parcel used in comparing baseline data to data obtained from monitoring parcel data. It is doubtful that any one species will continue to naturally occur in future sampling of parcels. The use of these data to detect any important decrease in plant cover data can be challenged professionally because of these reasons. The requirement that species composition be monitored along with plant cover causes a difficulty because composition simply does not remain static as species cover changes.

3) The use of plant cover data to detect effects of pumping on plants is problematic, because data collection does not provide for estimation of a direct relationship between cover change and water drawdown. The method currently used to estimate plant cover is dimensionless (no space) and data measurements of plant cover do not occur in direct relationship to pumping of water.

2.2.2 Monitoring using permanent transects

The assumption is that true change in plant cover can be measured by rereading the same permanently located transect. However, the reality is that collecting such data without error is not likely. The Team recognizes that permanent placement of cover transects throughout a given parcel appears to remove or at least reduce the amount of sampling error that occurs from random placement of transects. Section 2.4 provides some suggestions for reduction of such errors. Namely, data from randomly located transects provide unbiased estimates of plant cover that can be compared to baseline data. Consideration should be given to partitioning of parcels into smaller subunits that can be easily located and subsampled according to stratified sampling methods are indicate below.

The Team understands that permanent transects were located randomly within each parcel. If so, it is possible to make inferences about associated changes in similar parcels (vegetation types). Further, given that any individual transect value is not likely to be repeatable, a randomization model (Box et al. 1978) can be used to check for randomness.

2.2.3 Monitoring using randomized transects

The randomized transect locations yield unbiased estimates of the mean and variance of cover for that parcel. If the parcel was selected at random from a population of similar parcels, then the mean and variances of unsampled parcels of the same vegetation type might be predicted. As stated in the previous section above, we believe that either the permanent (if shown to be from a randomization distribution such as the normal distribution) or the randomized transects could be used for future monitoring. If the randomization test can be successfully applied to the permanently located transects, then the agencies should be able to determine which approach is more efficient to use for their joint program.

2.2.4 Statistical considerations

Several considerations merit attention for design of a coordinated field sampling campaign. Note that for more than three decades, ecological literature has emphasized the misuse of "replication" when in fact, repeated measurements are "observations," not "replications," and are correctly referred to as "pseudo-replications." The term in statistics for replication applies to replication of the experimental design, not to sampling design.

First, consider that the number of observations (sample size) needed to detect a change in cover depends on the amount of change that the agencies aim to detect. In order to avoid irreversible change it may be necessary to detect changes while they are still relatively minor. However, year-to-year fluctuations may also be natural, implying that a higher level of vegetative transformation is necessary to constitute significant biological or ecological transition, e.g., the change from a meadow type to a shrub type. The determination of what is biologically or ecologically significant is something the agencies should discuss. In correspondence with agency personnel, a 5-30% range in cover decrease associated with pumping was suggested that the ESA Team could consider for the purposes of a critique.

The 5-30% range for a change provides a basis to estimate the number of observations (sample size/parcel) needed to achieve a specified level of detection of a decrease in percent plant cover. Moreover, the level of cover lost would need to be assessed with respect to a significant change in cover of a parcel. We used a sample of permanent transects from a monitoring parcel to compare to a sample of transects from baseline data. Both data sets were from a similar parcel vegetation type. We calculated percent cover changes using the original data, 10%, 20%, and 30% decreases in total cover in the monitoring data set and compared each reduced set to the original percent cover data from the baseline. We obtained sample size estimates using both the normal distribution (u, s^2) and the binomial parameter estimates (np, npq) as input into an approximation equation based on Cochran (1978, p. 75).

For the original data sets, we obtained preliminary estimates from the normal distribution of $n = 1270$ point lines in the baseline parcel and $n = 439$ transects in the permanent transect parcel. When the binomial approximation was used, we obtained estimates for $n = 157$ for the baseline parcel and $n = 16$ for each permanent transect parcel. The alpha level was 0.05 while the 95% confidence level was used. In this case p will be within 10% of the actual error in estimating the proportion of hits on vegetation.

2.2.5 Other considerations

Various types of remote sensing imagery have become increasingly available since the establishment of the parcel delineations and the baseline transects. These advances, which can be supported by adoption of area-based vegetation plots in monitoring as are being used in large-region monitoring schemes such as the National Ecological Observatory Network (NEON), may make it desirable for agencies in the Owens Valley to consider adding or eventually converting some of their vegetation monitoring efforts to recording species and cover in area-based plots (rather than or in addition to) the transect methods currently used. NEON is actually using a 3-level monitoring scheme that also includes eddy flux towers, intended to provide the process components of landcover change, while the plots provide species composition and structure specificity, and the imagery is used to scale up to landscapes.

In contrast, the Owens Valley is considered by the National Park Service to be part of the Mojave Desert ecosystem (Figure 2; Pan et al. 2015). The NPS is using a macroplot approach which embeds transects within an area-based transect. The agencies may wish to review the NPS protocols for utility. This section focuses on a vegetation plot-based approach.

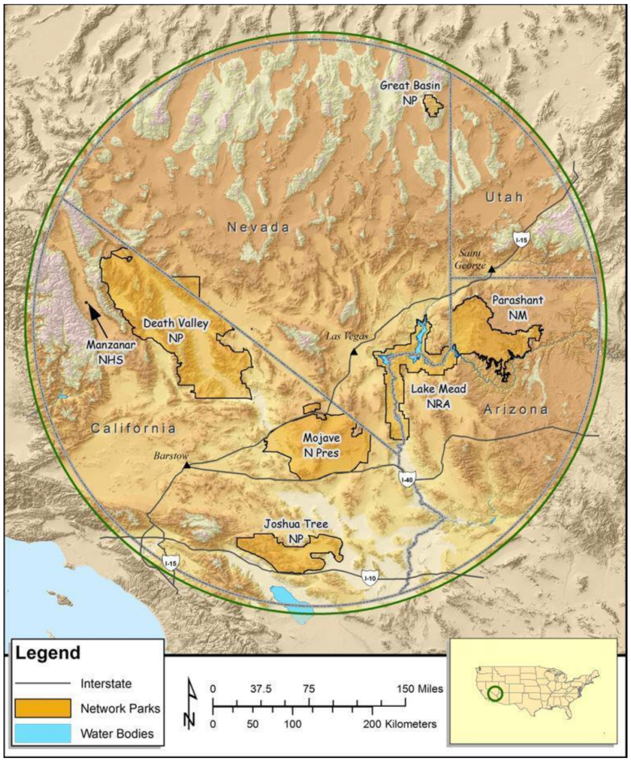


Figure 2. Depiction of extent of Mojave Desert Ecosystem according to the Death Valley Integrated Upland Protocol Narrative (2015).

A pilot effort to assess the utility of such an approach (and the methods for transitioning) would likely require several years. It could take the form of co-measuring in selected parcels using both the established transect methods and recording area-based measures. The results could be compared across several years to see how similar estimates of vegetation cover and species composition are to each other. The size and number of vegetation plots will likely vary depending on the vegetation type and objectives. For example, monitoring plots for shrublands range from large 100x100m plots to variable shaped 100m^2 plots (e.g., California Native Plant Society relevée protocols), and grassland plots consist not infrequently of quadrate plots of varying sizes. For integration with remote sensing, 30x30m (or better, 0.1 ha) plots could help align monitoring more closely with LandsatTM imagery. The first step would be to see how consistent are the measures of plant cover and composition as determined by the line transects and the plots. If there is good correspondence, then the linkages to remote sensing products could be developed. For a pilot test, one could consider the random placement of 10-15 plots in each of the B, C, and D parcel types, within either the well-related or the well-independent parcels. Comparison of the pooled values to pooled transect values in the same year would be the first test. Subsequent comparison to other years, and to the baseline would be of interest as well.

One thing that is not addressed as well in plot-based measures, but which emerged in the Team's discussions, is the concept of turnover or varying patterns of vegetation within a parcel. Line transects can permit a measure of the degree to which species composition occurs in patterns within parcels. The space between species and the sequential arrangement of species along transects offer perhaps another way to consider base conditions and to detect changes.

In terms of logistical tradeoffs, a major disadvantage of nonpermanent, rerandomized transects is that repeat photos are removed as an option for understanding vegetation change. Another logistical disadvantage of rerandomized transects is they require the extra work of developing random locations and locating new transects every year, as opposed to returning to permanent transects year. However, permanent transects have the logistical disadvantage that humans sampling the vegetation each year may impact the vegetation and affect results. Presumably, though, sampling effects of walking over transects should be constant across all sampling units, thus not biasing the comparisons themselves, and the field surveyors involved have stated that they have not noticed particular impacts from repeated sampling because they walk to the side of the transects. However, we do not know for sure if the sampling effects would be constant across all sampling units, and over time, sampling impacts to sites could affect comparisons to baseline conditions.

2.3 Remote sensing methods

Remote sensing (RS) can be conducted at multiple spatial scales and with varying numbers of bands to capture the signature of reflected light. RS, through analyzing Landsat satellite images, has been employed to analyze change in cover (Smith et al. 1990, Elmore et al. 2003, 2006, Inyo County Water Department Annual report 2013-2014). This method has the advantage of being able to cover large areas relative to field sampling, but the disadvantage of being at a coarser resolution and not necessarily capable of accurately identifying levels of cover and changes in species composition.

Types of RS that have been used in the valley previously include the aerial photography used for the original delineation of the basemap; LandSat TM, which has been used in a 23-year analysis; and digital aerial photography used to document flood zone extents in the Lower Owens River Project by LADWP. Several other RS studies have also been conducted in the valley, but are not as closely tied to the yearly reports (Smith et al. 1990a, b; Ustin et al. 1986). Considerable effort was made in 2006 in the Terrain-Induced Rotor Experiment, which used RS techniques for studying wind patterns on the lee side of the Sierra Nevada (http://journals.ametsoc.org/page/trex). Additionally, LADWP has aerial photography from 1944, 1968, 1981, 1993, and 1996, and 4-band aerial digital imagery from 2000, 2005, 2009, and 2014. Some of these datasets are license-restricted.

LandSat TM imagery is widely available and is already incorporated into ICWD's annual reports through the use of spectral mixture analyses that compare relative cover of perennials in wellfield and non-wellfield parcels through time and against the baseline year conditions. These results show some remarkable consistency in terms of temporal trends in wellfield and control parcels. Variations in the parcel-level RS measures within the five vegetation types yield high levels of variance when aggregating to a summary view.

Light Detection and Ranging (LIDAR) and hyperspectral data are other possible RS data sources. Since LIDAR provides highly accurate and precise measures of canopy height and extent, it could potentially be used to define and classify cover, and to track changes in cover over time. However, a problem with many RS systems in desert regions is that the high background reflectivity can make it difficult to get accurate measurements. Therefore, applications to desert shrubs are less common than in other ecosystems. Additionally, the small leaves of most species in the region add to this issue.

A recent example is LIDAR and AVIRIS data acquired as part of the National Science Foundation's NEON project (Figure 3; neoninc.org). Professor Susan Ustin, UC Davis, is involved in this project. She described how LIDAR and hyperspectral sensors were flown at low altitude and include a segment of the Owens Valley near Big Pine (pers. comm. Figures 3, 4 and 5 below). Even from a fixed wing aircraft, the LIDAR results in 15-20 points/m^2, and there are few hits on the vegetation due to the sparse cover. However, figures 4 and 5, showing vertical profile data for two vegetation types as measured from the LIDAR flights provide fairly believable renditions of vegetation height. Used for area calculations, it could potentially provide measures of cover on a parcel basis. Note that such analyses need to remove LIDAR data from features such as roads, wells and other non-vegetation items from such analysis.

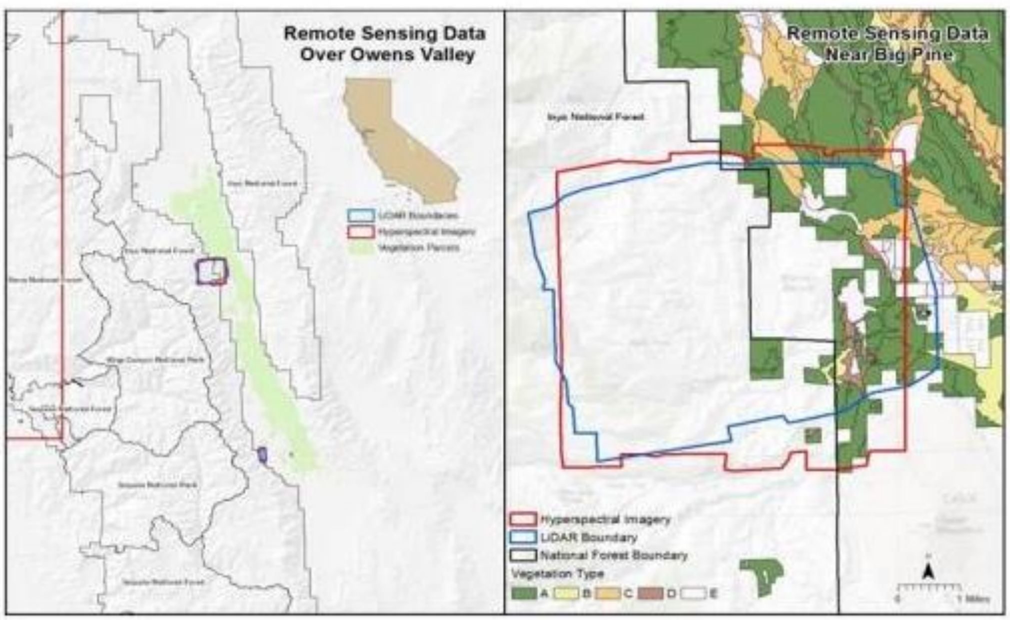


Figure 3. Maps showing the extent of LIDAR (2014) and AVIRIS hyperspectral data coverage (2014 and 2015) flights over the Owens Valley.

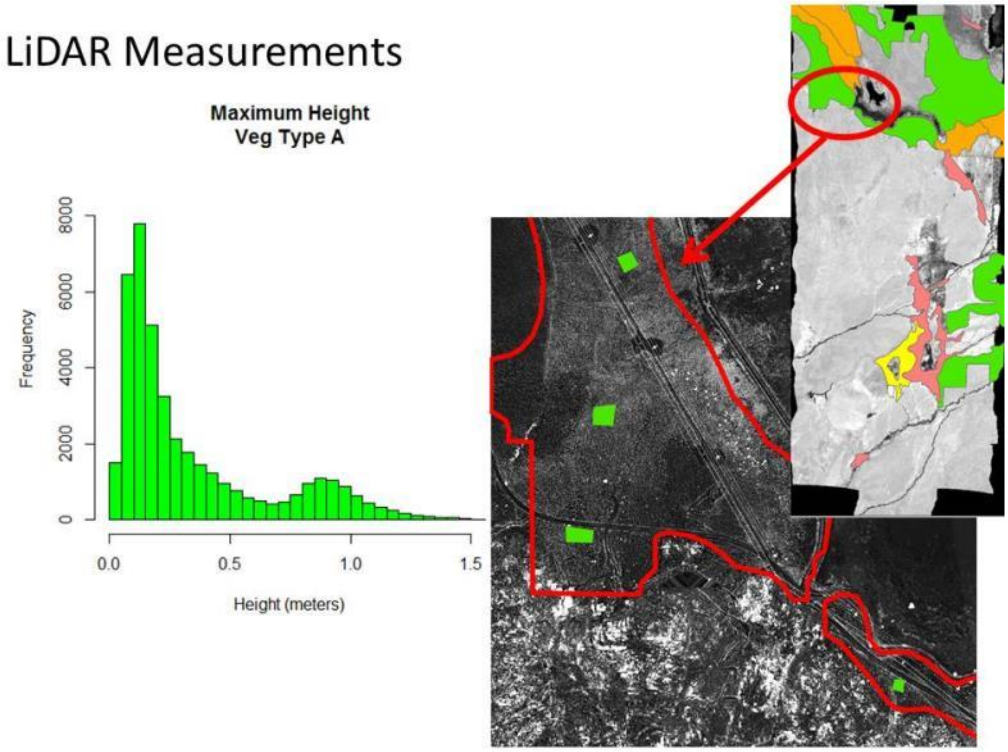


Figure 4. Vegetation Type A, LiDAR image at 0.5m resolution averaging 9 points per pixel. The image displays maximum height per pixel where dark areas represent low values and white areas represent high values. Areas outlined in red are designated vegetation parcels and the colored boxes are the selected areas that were used to generate the histogram.

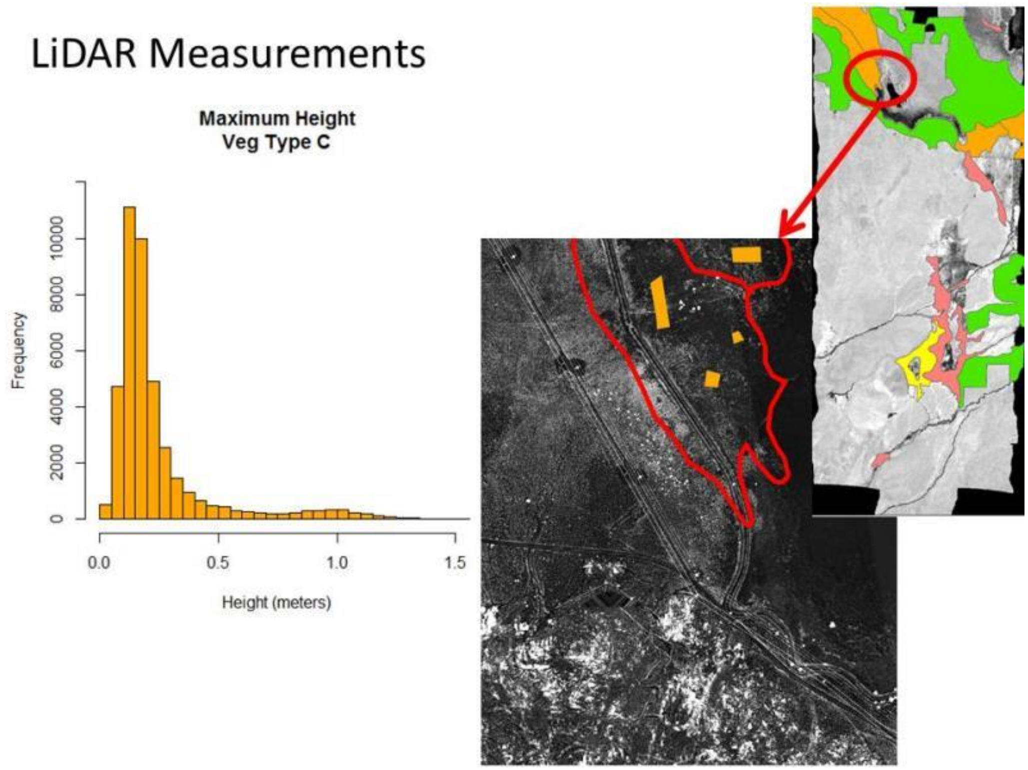


Figure 5. Vegetation Type C, LiDAR image at 0.5m resolution averaging 9 points per pixel. The image displays maximum height per pixel where dark areas represent low values and white areas represent high values. Areas outlined in red are designated vegetation parcels and the colored boxes are the selected areas that were used to generate the histogram.

The AVIRIS-next generation data, flown by NASA's Jet Propulsion Laboratory, comprise 432 bands. In most cases AVIRIS is a coarse spatial-resolution product. However, these flights provided this product in the 1.9-2.6m resolution. It was obtained using fixed wind-mounted version of the AVIRIS from October 9, 2014, and June 13, 2015. The processing of these data for parcels in the different vegetation types may provide interesting insights for further integration of remote sensing into either monitoring components of the program, or into hypotheses about the rates of different processes. Some examples for parcels that fell within the flight lines are provided showing relative moisture from two time periods (Figures 6-10). Note that hyperspectral data at this spatial resolution could also provide information about different species.

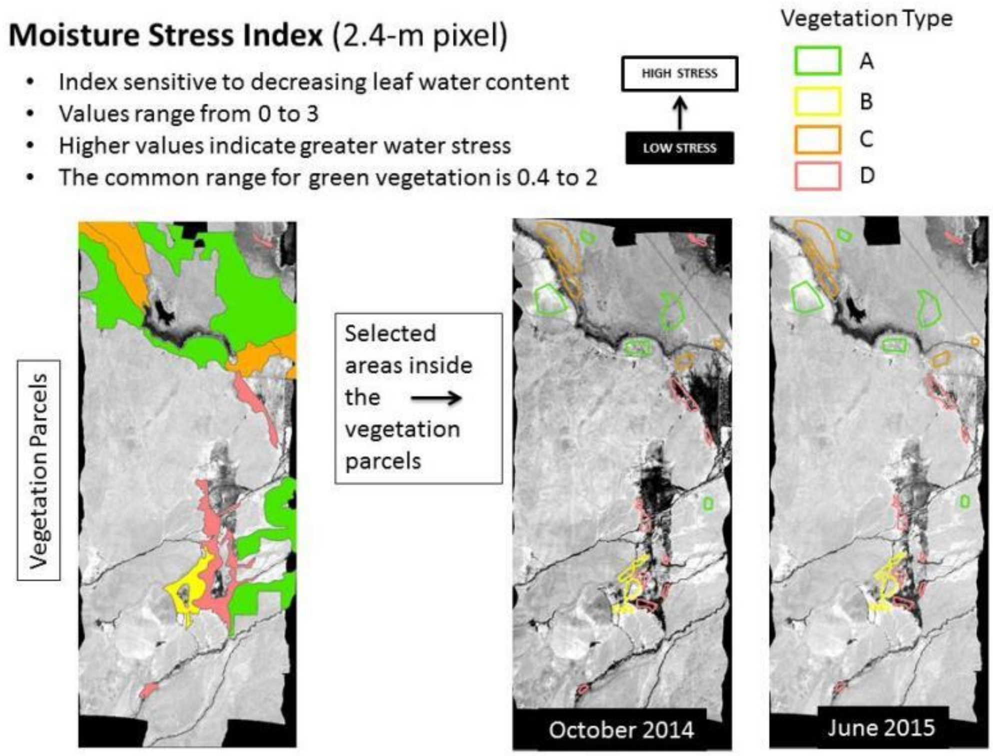


Figure 6. An overview of two hyperspectral flights (2.4m resolution) over Owens Valley in 2014 and 2015. The images display moisture stress index values where a darker color indicates areas of lower water stress and a lighter color indicates areas of higher moisture stress.

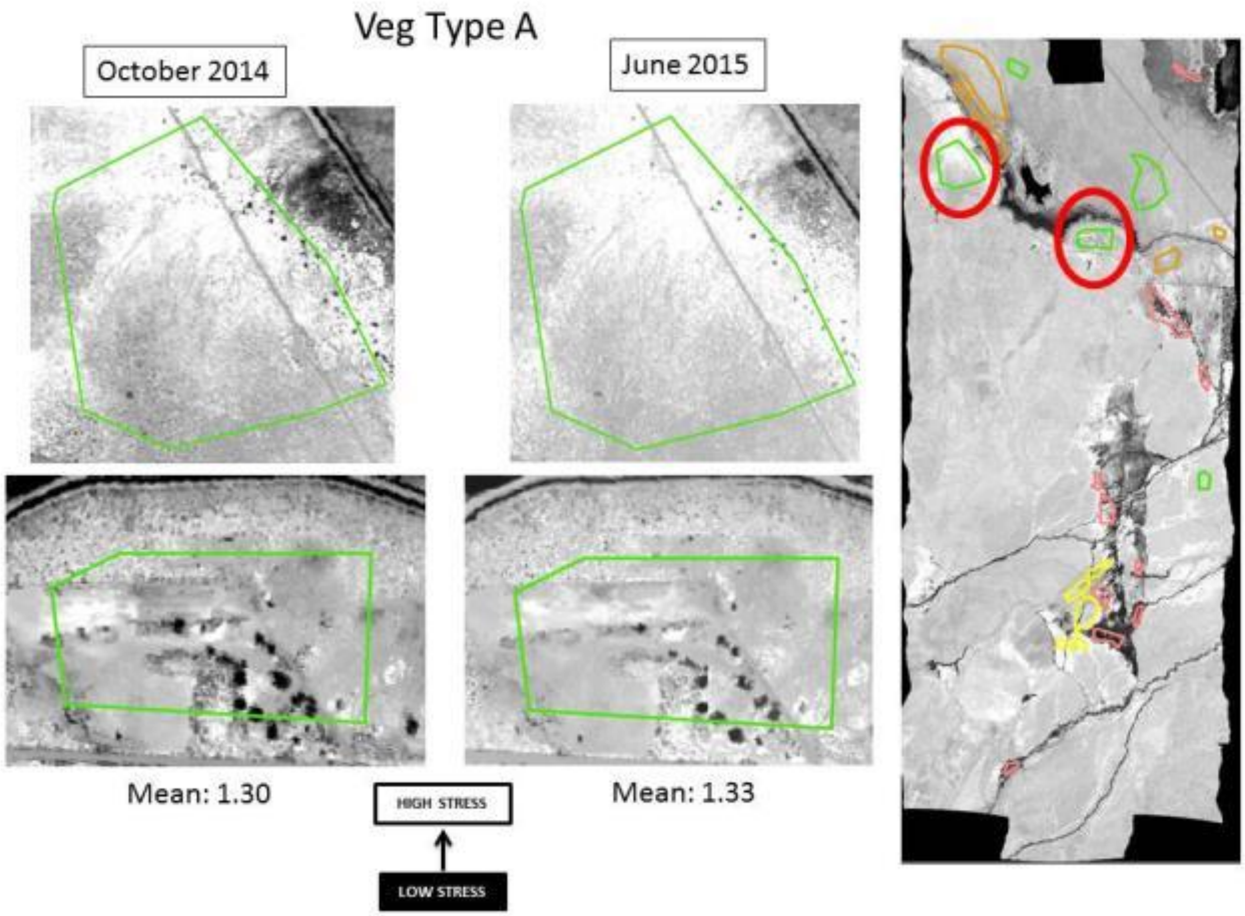


Figure 7. Moisture stress index image at 2.4m resolution overlaid with selected areas that occur in Vegetation Type A. An increase in the mean value indicates higher overall vegetation water stress.

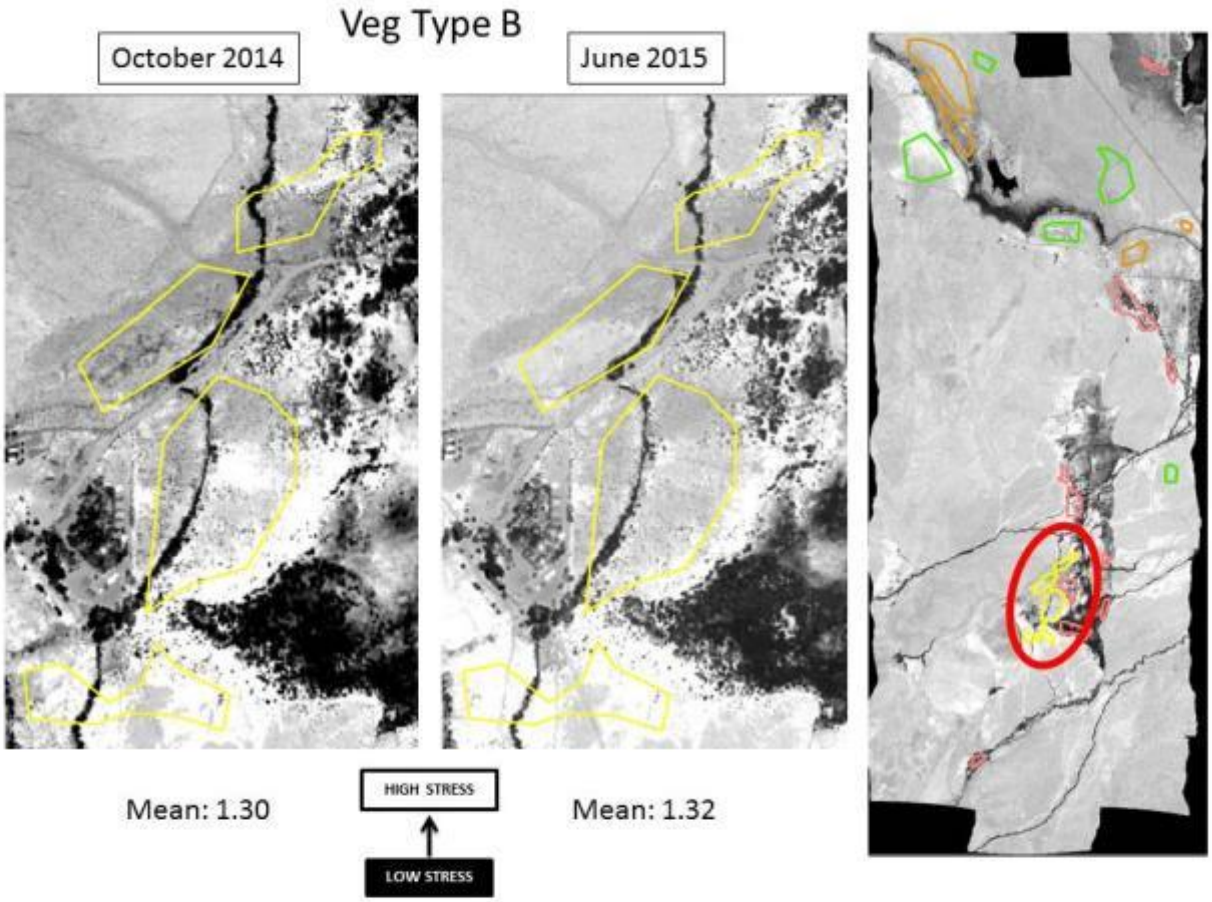


Figure 8. Moisture stress index image at 2.4m resolution overlaid with selected areas that occur in Vegetation Type B. An increase in the mean value indicates higher overall vegetation water stress.

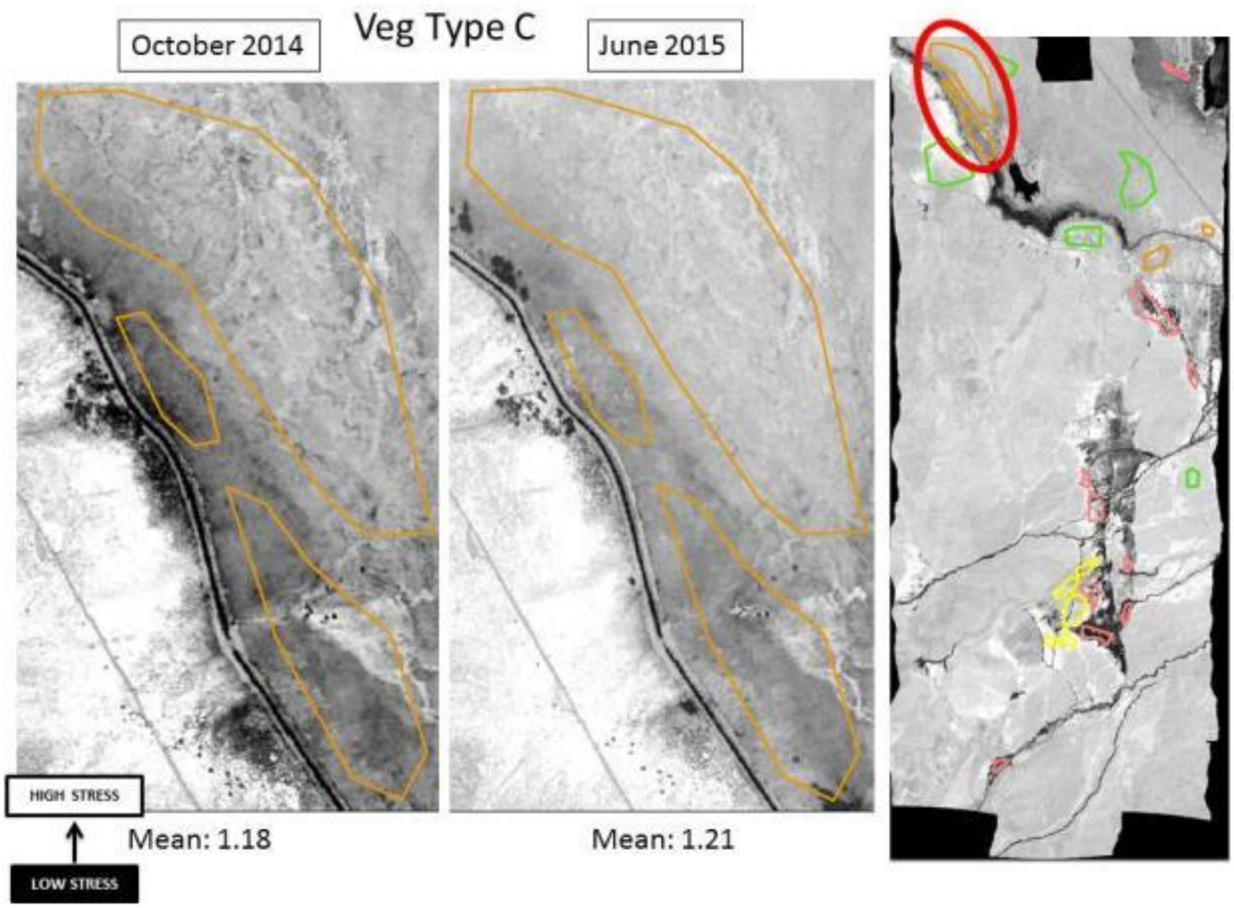


Figure 9. Moisture stress index image at 2.4m resolution overlaid with selected areas that occur in Vegetation Type C. An increase in the mean value indicates higher overall vegetation water stress.

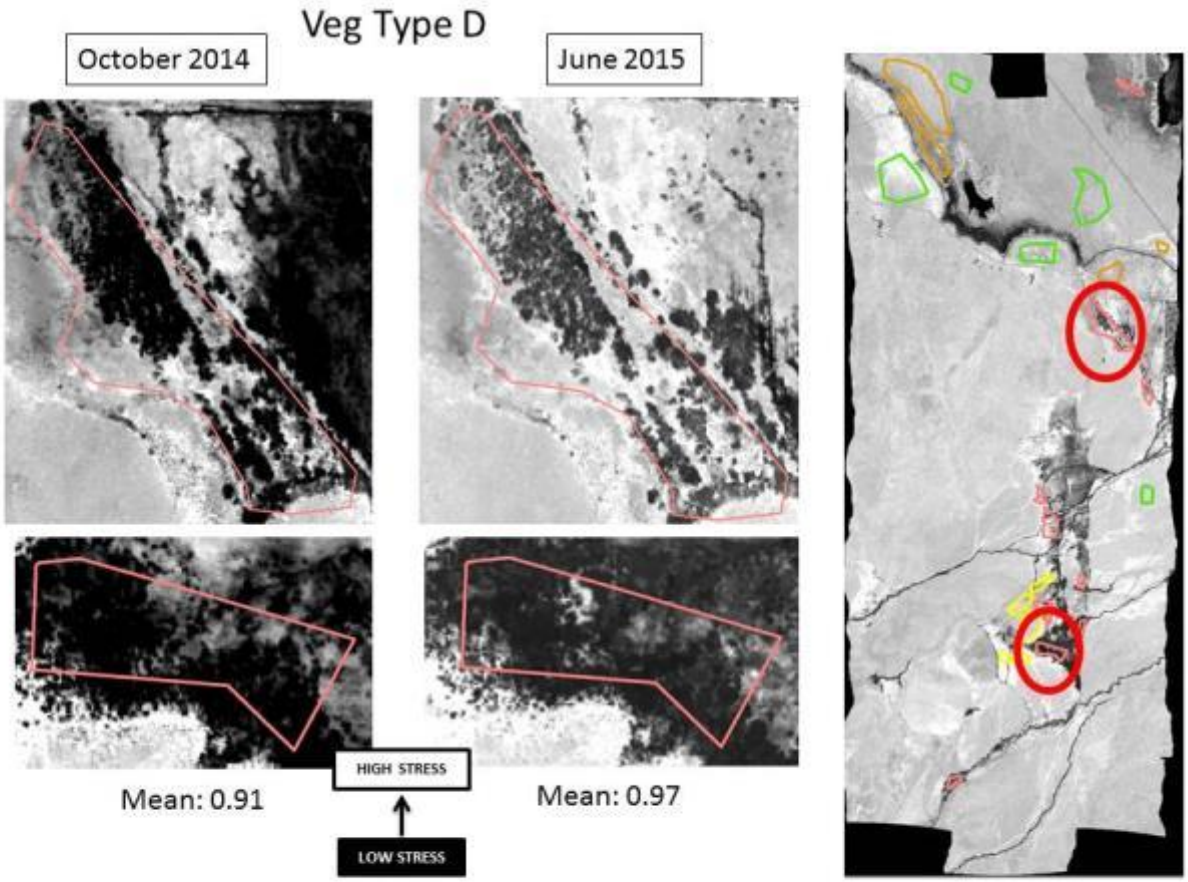


Figure 10. Moisture stress index image at 2.4m resolution overlaid with selected areas that occur in Vegetation Type D. An increase in the mean value indicates higher overall vegetation water stress.

The USGS used LIDAR in a study in the Mojave Desert where LIDAR informed findings on the effects of fire in invasive grasslands (beneficial to native shrubs) and shrubs (detrimental to native shrubs) (Soulard et al. 2012). LIDAR can be used terrestrially or aerially. Typically, LIDAR can be used with object-oriented classification to identify canopies, using distance metrics to obtain canopy heights. The Team concludes that LIDAR is likely not an option for augmenting ongoing monitoring in the Owens Valley. However, given the possible use of NEON LIDAR imagery for measuring cover, we will seek to make that imagery available to the ICWD and LADWP for further consideration of its utility.

Other issues with RS include the timing of image acquisition, the costs and expertise required to process sensor data for use in analyses, and how directly measured are the variables needed for an analysis. For example, there are no direct measures of ET that we are aware of in current sensors. Therefore measures of greenness, heat, canopy water content, or other measures would need to be transformed to ET. For example, air temperature can be used to model potential ET. Actual temperature around transpiring plants should be lower due to the evaporative process. Therefore, an indirect measure of ET could be modeled from the difference between these values. Normalized difference vegetation index (NDVI) is often advanced as a metric to differentiate vegetation or vegetation condition. However at 25% or less cover, NDVI has poor sensitivity, and it may be more accurate to correlate green cover to estimates of LAI (Ustin, pers. comm.). There are a number of approaches to do this, and the utility of the results would need to be considered if adopting a RS platform to provide ET metrics.

Given the considerable work already done on the Landsat TM time series, an option for the agencies to consider is to analyze the correlations between parcels for which cover was measured annually and the cover values derived from the RS. Given the many years of co-occurring data, it may be possible to develop correction algorithms for the RS values so that they replicate field-based measures. This would allow further consideration of the use of RS for monitoring vegetation change. There are also several new RS techniques using hyperspectral data for measurement of canopy water content and soil moisture, as shown in the example above. Use of these techniques in the future could increase accuracy of vegetation monitoring.

The LADWP has three 4-band, 1 foot resolution sets of digital aerial photos for the valley, from 2000, 2009, and 2014, and corresponding 2009 imagery derived from satellite data. There are also aerial photos in 9x9 inch format from 1944, 1968, 1981, 1993, and 1996. These images are potentially interesting from the perspective of mapping how the landcover in the valley has changed, relative to the photo year used for establishing baseline conditions. Processing for the hard copy images (if not already done) would include georeferencing scans of each image, followed by either head-up digitizing or the use of a semiautomated delineation technique. If the images are black and white, it is likely that traditional human photointerpretation would be the most likely way to produce maps from these sources, particularly since the region is relatively small. The 4-band color imagery could be used in deriving landcover maps as well, through the use of e-cognition, ERDAS, ENVI, or IDRISI .

Finally, the agencies are interested in several types of information that could be derived from RS, and which could inform different parts of their program in the Owens Valley. Avenues of interest include the determination of LAI, vegetation cover, species composition/community mapping, phenology, and change in these metrics over time. The current level of interest in each of these could be discussed by the agencies, and periodic reviews of RS capabilities could identify new opportunities as RS technologies continue to rapidly develop.

2.4 Statistical analyses

The Green Book sets forth two major measures of vegetation monitoring that are not supposed to be negatively affected by management, primarily groundwater withdrawal: total live perennial plant cover, and species composition. Total live perennial plant cover is more straightforward and easier to measure than is species composition. A currently accepted definition of species composition in vegetation science is “the species present and their relative abundance” (McCune and Grace 2002). Cover of each individual species, expressed as the proportion or percentage of the total plant cover contributed by each species (termed relative cover, summing to 1.0 or 100% when all species in a community are included), is often used as the measure of abundance. This has been the case in Owens Valley monitoring.

The agencies have analyzed the field and remotely sensed plant cover and species composition data, plus categorical transitions between vegetation types (A to E), relative to the baseline and temporal trends using a variety of multivariate and univariate statistical techniques. Multivariate techniques include ordinations, permutational multivariate analysis of variance (PERMANOVA), Sørensen similarity indices (used to compare plant community composition at different times or monitoring sites), and comparisons of specific community components (for example grasses or shrubs) at different times or monitoring sites. The Team concludes that these statistical techniques are widely employed in ecological science and are currently accepted by the scientific community. However, the Team offers more detailed discussions of these options as follows.

2.4.1 Multivariate techniques

There are several options for using multivariate techniques to help understand long-term trends in the Owens Valley data. These options, plus their assumptions, are discussed below.

1) Conduct multivariate statistical tests on the plant community data to determine whether a change has occurred from baseline or whether community composition differs among management units. Multi-response permutation procedures and PERMANOVA are two accepted techniques (McCune and Mefford 2011). The change through time or difference among management units could be declared "significant" at $P < 0.05$. The advantage of these statistical tests is that they provide a relatively definitive answer that a change has occurred, but they do not necessarily identify the nature of the change. For instance, present species composition could be found to differ at $P < 0.05$ from baseline, but follow-up tests would be required to determine which species or species groups were driving that change.

While these multivariate community techniques avoid many of the assumptions, such as normality, of traditional statistical techniques like analysis of variance and multivariate analysis of variance, they can have certain assumptions. PERMANOVA in a classical one-way analysis has the assumption that the observations are "exchangeable" in the rows (typically sample plots or transects) of the original matrix (Anderson 2001). This means that the rows are assumed to be independent of each other. Repeated measures, such as measurements on the same plot over time, are not independent and would violate the assumption of exchangeability. Therefore, when using PERMANOVA to analyze any type of repeated measures or nested data (e.g., sites prescribed burned or not burned nested within an overall water management polygon), the model must be correctly coded to accurately reflect the dependence among the sampling units. In a recent restoration project, for example, we coded a PERMANOVA model including four factors (such as grazing and soil type), year as a repeated measure, and all their interactions (Abella et al. 2015). PERMANOVA can similarly be used to analyze the type of repeated measures data collected at Owens Valley, but model coding is important for reflecting dependence when present.

The absolute minimal sample size for PERMANOVA and similar techniques is $n = 2$, such as an example in Anderson (2001). Of course, as in univariate analyses, larger sample sizes are better for increasing statistical power.

2) Compute Sørensen similarity indices of community composition through time or among management units (McCune and Grace 2002). The indices range from 0 to 100% similarity in species composition. Some type of threshold could be defined to declare communities "changed" or differing among management units, such as a difference of 25% or 33% similarity. The advantages of this approach are that the indices are easy to compute and are often more intuitive to understand than the multivariate statistical results. A disadvantage is that just like an arbitrary $P=0.05$ for statistical tests, any thresholds for declaring differences could be arbitrary. Ideally, however, a threshold could be linked with ecological meaningfulness, such as if there is a certain percentage difference in community composition that changes the function of the community. This is discussed in Section 3.3, Thresholds tracking.

It should also be noted that when Sørensen indices are computed for replicated sampling units, traditional univariate t-tests or ANOVA can be used to compare mean Sørensen similarity indices among groups.

3) Divide community composition into components, such as grasses versus shrubs, and compare the raw or relative cover through time or among management units using traditional univariate

or multivariate techniques (such as described in (1) and (2) above). For example, the relative cover of just grasses could be compared through time, to assess if grasses have declined to the point that a community has transitioned from meadow to shrubland. An advantage of this approach is that changes can be more definitively attributed to particular priority species groups (unlike in (1) and (2)). But that also is a disadvantage, because the full plant community is not necessarily being considered in the assessment of change. Similarly, particular indicator species might be identifiable that can signal that a community shift has occurred.

Several other multivariate techniques can be used to compare community change through time or among management units. For example, ordinations can be performed with “successional” vector overlays. The lengths and angles (direction of community change) of the vectors indicate community composition change and can also be subjected to univariate and multivariate analyses (such as t-tests) that produce P values. These techniques can be extremely valuable, but for the present purposes, they can become redundant with approaches 1-3 and are not necessarily recommended here, though exploratory multivariate analysis (such as basic ordinations) are an important part of community analysis (McCune and Grace 2002).

Relativization can be an important part of several of the multivariate analyses, such as ordinations. A relativization rescales a row or column in a data matrix (McCune and Grace 2002). For example, the cover of individual species within a plot can be scaled to be a percentage of the total cover for all species on a plot. This results in the relativized cover of each plot being 100% when all the relative covers of species are summed on a plot. A key point is that analyses conducted on data that are not relativized or that are relativized answer different questions. The questions in an investigation should drive the decision on whether to relativize data or how to relativize data. For example:

1) Analysis of matrix of raw cover values (no relativization) of species on plots. In this analysis, results can reflect the influences of BOTH the total plant cover on plots and the species that are present. This is because the underlying similarity indices, such as Sørensen indices, are based on shared abundance of species and total abundance of all species on a plot. As a result, plots that contain similar species but that have much different abundances of those species could be dissimilar in the final multivariate results.

2) Analysis of matrix of relativized cover where the total cover summed for all species is 100% on each plot. In this analysis, the total cover of plots would not enter into the analysis. The analysis would provide a “pure” analysis of just species composition (species present and their relative abundance). If two plots share identical species at similar proportions of abundance, the similarity between the two plots could be very high even if one plot had 80% total cover and the other plot had only 5% total cover. This is because total cover has been relativized on a plot basis.

There is not necessarily a “right or wrong” answer to relativization because it depends on the questions asked. In fact, in the A and B scenario above, it is often useful to conduct *both* analyses and compare the results. As a rule of thumb, if univariate analyses have determined that a group of sampling units differ significantly in total plant cover, then if isolating the question of whether multivariate species composition differs is of interest, it would best to relativize cover as in scenario B. Further information on several types of relativizations and their advantages and disadvantages for particular questions can be found in McCune and Grace (2002).

2.4.2 Univariate techniques

Species cover data contain several sources of variation which should be identified if possible. These sources of variation are useful to minimize or maximize estimates of cover variances and in turn, provide efficient estimates of differences in means and their variances (SE-standard error of the means). The numerical size of SEs affects the results of F-tests and t-tests and any variation unaccounted for is in the SE. Some data sets listed in reports refer to the large values of SE and these values were not used. Extraneous sources of variations residing in SE can be removed to reduce the SE value.

Since SE values differ for the same data set analyzed by various experimental designs, the value of SE indicates the most efficient design to use. This value will yield the smallest sample size needed. Data variation exists in parcels, sample dates, precipitation amounts, plus other factors that can be recorded as each observation is collected. These data are covariates, and removal of their effects will reduce the SE. In turn the best estimates will be obtained to test statistical differences between baseline cover means (1984 – 1987) and data sets from 1991 to present time.

Current univariate analyses are based on the assumption that the data are normally distributed. It is also known that large sample sizes (n>30) provide adequate estimates of means and variance from the normal distribution. The nonparametric Mann-Whitney (M-W) test often is used when data are not shown to be normally distributed. Randomization tests are becoming popular in place of commonly used ANOVA tests, for example, because the probabilities of the former tests are exact and free from any assumptions.

Cover data developed from presence/absence data (0, 1) follow~~s~~ a binomial or a Poisson distribution. The very large sample sizes used generally give the impression that a normal approximation is precise enough to detect the smallest effect of groundwater pumping on vegetation cover. However, options to improve the power of the statistical analyses include testing hypotheses based on binomial, Poisson, or other discrete data distributions.

The recent joint monitoring by the agencies and involvement of staff with expertise in current scientifically accepted monitoring and analytical tools, such as multivariate community analyses, is a positive trend. For example, ICWD has been analyzing the species composition data using variations of these techniques and has the software and staff expertise to perform the analyses. This may not always be the case, however. Furthermore, multivariate community analysis techniques are not taught as part of most traditional statistics courses and many traditional statisticians are not familiar with the techniques. Thus, use of these valuable techniques by the agencies depends on continuing to have the expertise in-house or locating contractors with the necessary expertise, who are often community ecologists and not traditional statisticians for these particular analyses.

3.0 Additional Options for Identifying Relationships between Vegetation Conditions and Management Actions

The staff of ICWD and LADWP already recognize that an important next step in vegetation monitoring is improving their ability to identify relationships between management actions and vegetation conditions, and the ESA Team agrees. As described previously, the Team's general conclusion is that the current sampling and statistical methods, although adopted in the 1980s, remain valid. However, a number of options for changes in protocols could increase the efficiency of the monitoring program and provide much richer information for management of the Owens Valley vegetation communities and groundwater withdrawal programs. This section summarizes these options.

3.1 Spatial arrangement of transects

The status quo with respect to spatial arrangement of transects is continued sampling of the random (ICWD) and permanent (LADWP) transects located generally across the landscape with no special attention to linking with management and environmental gradients. The advantage is that this requires no change in procedures, and over time it can provide information on how vegetation has changed generally across the landscape. The disadvantage is that the difficulty of attributing detected vegetation change to management actions would continue.

ICWD already reallocates sampling units each year through the rerandomization of sampling locations. Three alternative options for adjusting the spatial allocation of transects are as follows.

3.1.1 Option 1

Refocus the spatial allocation of transects to monitor relationships of vegetation change across gradients of specific management actions or environmental changes. For example, adjusting allocation of sampling units (or integrating with other monitoring initiatives) to specifically identify how vegetation changes with distance to pumping locations (e.g., Goedhart and Pataki [2011]), fire management strategies, range management, nonnative plant invasion gradients, or other management actions could provide better information for decision-making. For continuity with past monitoring, existing parcels could continue to be monitored, but have transects located within the parcels in particular areas that include environmental or management gradients of interest. Alternatively, existing transects could continue to be monitored but have management actions applied to them or new environmental data collected around them, as described below in Section 3.4, Adaptive management experiments.

3.1.2 Option 2

Implement Option 1 and incorporate interactions among factors, for example, water, fire, range, or nonnative plant management. For example, it is highly desirable to understand the effects of water management at sites that have been burned or that are managed for livestock. This situation of interacting factors most accurately reflects the setting in the Owens Valley where multiple factors are simultaneously influencing vegetation. As such, monitoring that includes interaction factors most accurately reflects on-the-ground conditions.

3.1.3 Option 3

Implement a combination of Options 1 and 2 for general monitoring but reduce general monitoring sampling effort to free up resources for implementing adaptive management experiments discussed in Section 3.4.

In conclusion, current monitoring is geared towards identifying only general trends in vegetation and coarse wellfield/no wellfield comparisons. Refocusing the sampling effort to monitor relationships of vegetation change with specific, priority management questions (such as changes in water depth) or changes in environment (e.g., wildfires) can increase the value of monitoring data for management decision-making. This can be accomplished by strategically adjusting the spatial allocation of sampling units to particular areas that are managed differently or that have varying environments which can be compared for their relationships with vegetation change. An example of this approach that could be expanded is Goedhart and Pataki (2011).

3.2 Developing a working spatial model of vegetation dynamics and groundwater

Subsequent to the establishment of current vegetation monitoring protocols by the two agencies, there have been numerous attempts to analyze the collected data to determine whether trends in vegetation are occurring and whether those can be tied to groundwater conditions and pumping. An example is in the annual LADWP reports that show the trends in yearly vegetation cover as averaged for all the parcels in each well's sphere of influence. These are means of the parcels within that location, varying from 1-8 parcels and with each parcel having a set of transects contributing to the mean. The yearly cover is compared to the baseline condition shown in a blue line. An ICWD study by Jabis (2012) found wellfield vegetation parcels generally show lowered cover relative to control parcels, also evident in the LADWP annual reports, but that shrubs seem to be increasing generally in the valley, at the expense of phreatophytic grasses. The framework of using wellfield units can be used to detect these types of change, although correlation is not causation. As Jabis points out, however, knowledge of plant ecology permits several robust conclusions to be drawn, particularly that the decline of phreatophytic, salt tolerant grasses could potentially be reversed through the management of groundwater pumping, perhaps in combination with other vegetation treatment protocols.

Based on these findings, an option for better calibrating management of Owens Valley vegetation and groundwater is further development of a working spatial model of the interacting dynamics of vegetation cover, composition at the level of physiognomic units, and groundwater. Additionally these findings raise the question of the degree to which other factors influence vegetation dynamics, for example, invasive species, grazing, and fire, as direct factors on vegetation, and runoff as an indirect factor that in some years reduces the need for groundwater pumping.

Some attempts to build an integrated model have already been conducted. A 10-foot groundwater contour has been developed and used to consider the tipping points between conditions that favor phreatophytic grasses and shrubs. Additionally, kriging of the depth to water hydrograph has been conducted for many years (e.g., Harrington 2003; Harrington and Howard, 2000) for values at individual parcels. Further development of a range of groundwater depths could be used in conjunction with the vegetation map to make predictions about changes in vegetation at different groundwater levels. The monitoring component of ongoing operations could then be used to test the assumptions about change in vegetation and to calibrate the model. Once it is calibrated, this would permit projections of the expected change to vegetation under varying groundwater levels. Development of monitoring data that span the environmental gradients of the valley could help in the generation of this landscape model.

The development of such models could take two steps. The first step is to simulate at a rough approximation changes in the depth to water (DTW). This could use the existing Kriged surface of groundwater and raise/lower it by 0.5 m intervals. The DTW for every parcel overlying the groundwater map could then be calculated, and biological estimates made of the stability or transition (or condition) of the mapped vegetation. This would allow some rough predictive capacity to be put in place. Observed changes in vegetation could then provide additional insights into ongoing processes in several ways: A) if changes occur and are consistent with estimated DTW field measures and the prediction, then the hypothesis for a particular parcel is confirmed with regards to the relation of the change to groundwater dynamics; B) if vegetation does not change, but DTW does, it may disprove the assumptions for that step in the vegetation/DTW assumptions.

The second avenue of model development is to attempt a more accurate model of the pattern of groundwater. Such an endeavor would start with a full review of the existing groundwater model, and examination to see how modification that includes more data or processes could be applied to create a more dynamic model that would first predict groundwater dynamics under various conditions, and second, relate those to predicted vegetation dynamics.

Additionally, a number of studies that used Landsat TM data and spectral mixture analysis to investigate regional patterns of plant community response also found that alkali meadow plant cover is correlated with groundwater decline (Elmore et al. 2003, 2006), even while the relationship between the remote sensing and field-measured conditions is not felt by all to have been satisfactorily resolved with these studies. However, these types of studies represent the type of information that could be used to develop regional level assessments and models, which proceed from plant and parcel-level dynamics to broader spatial scales.

3.3 Thresholds tracking

Thresholds as defined here are standards or benchmarks that are used to detect certain conditions which could affect management decisions. While this is generally a laudable goal, the approach is only lightly tied to the concept that ecological or ecosystem processes, which are continuous, may exhibit alternate states when some factor changes such that a tipping point is reached. An example described during the July 2015 workshop included an area where the trees all died when groundwater pumping was more substantial than it is now.

Lessons from combining well and vegetation analyses to date. Thresholds can take various forms, and represent different processes and varying lag times on the landscape. Thresholds as currently used are somewhat *a priori*-defined, being the target ET consumption of groundwater to help inform “On/Off” decisions on groundwater wells, and the response metrics of vegetation stasis and change among five vegetation groups in terms of cover and composition within parcels.

General thresholds of interest. Additional data about thresholds of interest could better inform the management of the system. This would require collecting enough information about the underlying processes to determine what would constitute a threshold of interest. Some options that could be useful include the following.

1) Further tracking of the depth to groundwater across the valley and the level and timing of response of groundwater to irrigation and seasonal snowmelt. These data could be used to develop better models of the expected groundwater conditions at different times of the year and following different magnitude precipitation events.

2) Phenological tracking of plant life cycle events within the five vegetation types, and across environmental gradients. Getting a better sense of the timing of bud break, leaf out, etc. could improve the analyses of ground sampling and RS results. This could be particularly important to the extent that ongoing climate change affects the timing of life cycle events.

3) Monitoring the shrub density of vegetation type cover across a spatial gradient of groundwater depths could potentially provide better understanding of densities observed over time at monitored parcels.

A specific statistical criterion for detecting that a "threshold" has been crossed (i.e. switch from one vegetation type to another) would be whether a statistical difference in shrub or grass cover has occurred at a declared level of probability. An important item to add to this criterion could be that the statistical difference is *persistent* for a certain number of years, and thus truly reflects a state change rather than a short-term fluctuation in vegetation.

A more ecological and functional approach to identifying thresholds could be identifying what levels of plant cover change trigger a functional shift in the vegetation. There are no easy answers currently as to what these thresholds should be. We recommend that identifying the thresholds be explored through modeling approaches, such as estimating what levels of grass cover support different levels of livestock grazing, which is an important land use in the Owens Valley. Another approach could be experimentally reducing grasses down to different levels and measuring whether grasses recover or continue declining if shrubs invade. This could help identify at what level of grass cover decline becomes a "risk" for sustainability of meadows.

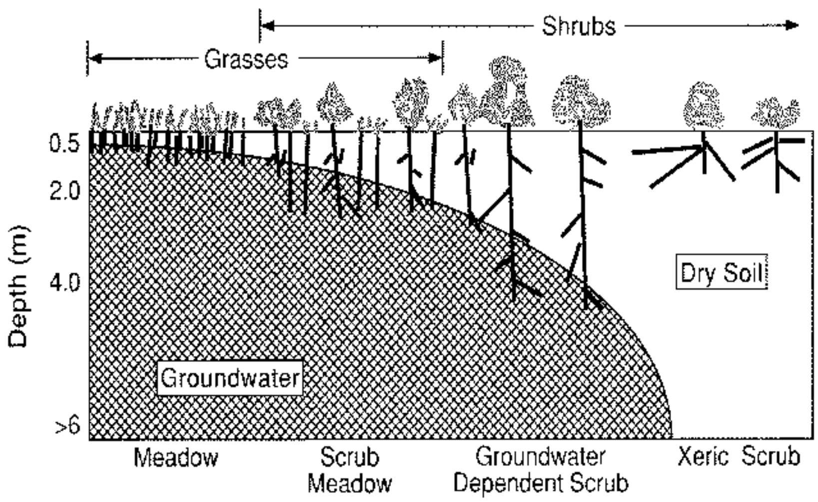
3.4 Adaptive management experiments

A key point regarding the status of existing monitoring is that the past 30 years of monitoring have focused on generally characterizing vegetation conditions across the landscape. Existing monitoring has not mainly focused on identifying relationships of management actions and changes in environment with changes in vegetation condition. Existing monitoring data can support assessment of coarse relationships only, such as comparing vegetation in wellfield versus non-wellfield conditions. Both ICWD and LADWP are interested in improving their ability to attribute vegetation change to changes in management and environment. Current monitoring and statistical analyses can detect change, but they are not equipped to detect cause and effect. This requires experimentation.

Implementing a series of planned, adaptive management experiments to address and refine priority management questions is an extremely attractive option as part of the next generation of monitoring in the Owens Valley. A disadvantage is that advance planning is required and so is some reallocation of sampling effort. However, there are numerous advantages. First, extensive management and conservation actions are already occurring in Owens Valley, so this option does not necessarily require new management actions, but rather, taking advantage of existing ones. Second, adaptive management experiments are probably the most effective and efficient way to identify thresholds, trigger points, and answers to other priority management questions discussed in this report. Third, this approach can identify interactions among the numerous factors simultaneously affecting vegetation, providing a realistic monitoring framework.

How can including adaptive management experiments contribute to the goals outlined in the Green Book? One of the greatest benefits could be helping managers identify combinations of treatments or their timings that prevent the undesirable changes outlined in the Green Book. For example, it is possible that prescribed burning can enhance the persistence of desired Type C grasslands during times of water drawdown, by limiting shrub encroachment (Figure 11). This is not known, however, and is a great example of the type of question difficult to address through general monitoring but readily addressed by planned, adaptive management experiments.

An important point is that we are not recommending that adaptive management experiments replace the correlational trends monitoring traditionally done in the Owens Valley, but rather that there is potential to use these approaches in tandem. Ideally, adaptive management experiments could be done to fill in specific knowledge gaps and used in concert with other suggestions in this report, such as re-allocating the spatial distribution of transects along management gradients. For example, much might be learned by placing monitoring transects within areas burned in the past and monitoring these sites over time. This would not provide the cause-effect inference that actual experimentation can, but it could identify correlational relationships between management actions and existing plant condition. Such correlational relationships, including those modeled via techniques such as Structural Equation Modeling, could then be more rigorously tested through adaptive management experiments for new management activities planned.



<u>Figure 11</u>. Conceptual general relationship between groundwater levels and plant community distribution hypothesized by Elmore et al. (2003) for the Owens Valley, California. How might overlaying fires, including different timing of burns, change these relationships?

Options for adaptive management experiments include the following. A water drawdown experiment could be conducted by creating three levels of water drawdown by pumping: no change (control), lowering the water table by one meter, and lowering the water table by three meters. An alternate third treatment could be to raise rather than lower the water table. Second, a prescribed burning experiment could be conducted with treatments that are either a simple yes or no, or alternate timings or frequencies of fire.

Combining these two experiments would result in six treatment combinations (three water table levels with burning or not for each) and the ability to evaluate the effects of water and fire management by themselves, plus the interaction between them. Extending the experiment to multiple parcels would improve the agencies' ability to extrapolate the findings across the landscape. Ideally, multiple vegetation types and land-use histories would be included.

Another option that could be tested and monitored is temporarily blocking some ditches or canals and allowing flooding of meadows (this differs from irrigation of meadows using sprinklers). If it is feasible to implement this management action at some test sites, the agencies could test the hypothesis that it could help maintain Type C meadows or even convert Type B shrublands to Type C meadows. Given that the Green Book implies that no net change in area of Type C meadows should occur (but it does not specify on a per parcel or landscape basis), restoration of these meadows on particular sites might compensate for the loss of Type C meadow on some other sites (including due to ongoing climate change). It is possible that planned flooding could help maintain or restore herbaceous vegetation in the

Owens Valley, as it did in a management trial in meadows of Lassen Volcanic National Park, northern California (Patterson and Cooper 2007). Likewise, overlaying revegetation activities (e.g., planting perennial grasses) with controlled flooding might improve restoration success.

Other adaptive management experiments could improve the agencies' understanding of how management and environment are linked with vegetation change. For example, considerable investment has already been made in establishing a series of grazing exclosures across the landscape. These, or new grazing exclosures, could be targeted for different fire or water management actions, and the interaction between those actions and range management evaluated. The same idea could also apply to revegetation activities and nonnative plant control, for example testing the effect of reducing nonnative woody plants on the development of Type C grassland communities under various water management scenarios.

The response variables in these experiments need not be complex and could be the basic plant cover and species composition data already used by the agencies. Moreover, the same point-intercept transects already employed could be used to monitor the experiments for continuity with existing monitoring.

In conclusion, initiating adaptive management experiments is a proactive option that efficiently takes advantage of management actions and monitoring already being conducted by the agencies. It could improve the ability to delimit site specific thresholds and avoid undesirable outcomes set forth in the Green Book, while identifying the management actions and environments that produce or maintain desired conditions.

3.5 Life history tables

The agencies have identified five land cover designations (A-E) that relate in some ways to life history traits, particularly to rooting depth and physiognomy (such as in the 2012 Jabis report). In addition, there are few, if any, native vascular plant species that are unknown to the botanists and vegetation ecology staff working in the valley, and therefore a preliminary table could be rapidly developed. Compiling additional ecological knowledge about the species in the region would provide a number of benefits. For example, it could help identify indicator species that could help focus monitoring. It would also permit the formalizing of hypotheses about how different species respond to varying conditions. The monitoring data collected could then be used to confirm, reject or adjust the life history values recorded for different species.

An example of the utility of this option is shown in an example from the Thorne et al. (2015) report on climate vulnerability of terrestrial vegetation in California, which used a statewide map (FRAP 2015) and national vegetation classification to classify exposure to future climate, including for Macrogroup 88, Mojavean Desert Scrub. Using the FRAP map, this type occupies parts of the Owens Valley (Figure 12). This map portrays the vegetation classed according to the climate conditions found at all locations where it was mapped (FRAP 2015 map). The pale yellow and red colors in the Owens Valley show that this vegetation type is in the less frequently experienced climate conditions, relative to locations in deeper blue, which have climate conditions more frequently encountered by the type. In this case this vegetation in the Owens Valley is climatically marginal, relative to that in many parts of the Mojave (the darker blue showing more frequently encountered climate conditions for the type). As part of the statewide exercise, five plant species were scored for nine characteristics relating to climate change (Table 1). Each characteristic in this case is ranked from 1-5, with 1 being more sensitive or lower adaptive capacity for that trait. For sensitivity, the measure is the degree to which an individual would be affected by climate change interacting with the column header. We know little about these plants' tolerance to temperature or precipitation, but assume that *Larrea* is less sensitive than *Yucca*, based on its distribution. However it is more sensitive to fire than *Pleuraphis*, and has similar dispersal capabilities. Being very long-lived, it has low sensitivity to the loss of any particular reproductive season. *Larrea* also has no regenerative capabilities after fire, scoring 1 for fire adaptation, moderate recruitment, and moderate seed longevity. All of these scores could be updated as more is learned about the species.

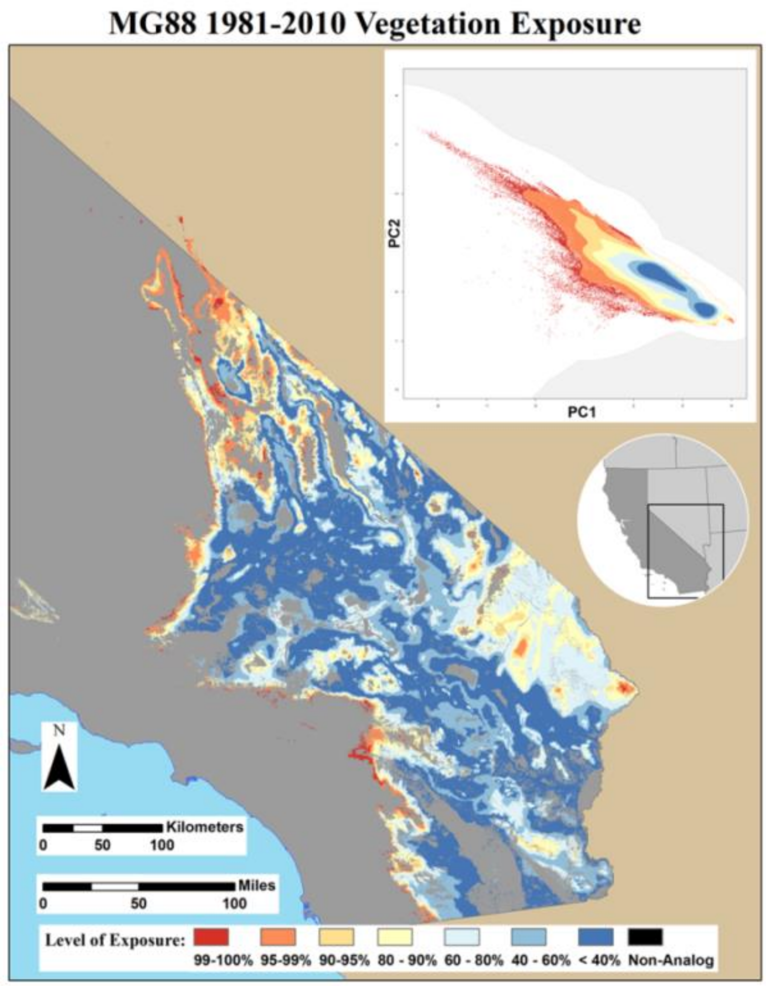


Figure 12. The extent of Mojavean Desert Scrub from the 2015 FRAP map. The colors represent the frequency with which climate conditions at any particular location are found across the entirety of the vegetation type. Orange and red colored grid cells in the Owens Valley indicate that stands of the vegetation found there are on the climatic margins for the type as it is currently distributed.

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Larrea tridentata	5	5	1	4	4	5	1	3	3	**3.4**
Encelia farinosa	4	4	1	3	3	2	1	5	1	**2.7**
Ambrosia dumosa	4	4	2	3	2	2	1	5	3	**2.9**
Pleuraphis rigida	3	3	4	3	4	2	5	1	1	**2.9**
Yucca brevifolia	3	3	2	2	2	4	1	1	3	**2.3**
Mean	**3.80**	**3.80**	**2.00**	**3.00**	**3.00**	**3.00**	**1.80**	**3.00**	**2.20**	
Grand Mean	**2.84**				**Mean**	**3.10**		**Mean**	**2.33**	

Table 1. Rank scoring of species in the Mojavean Desert Scrub macrogroup vegetation type for their relative sensitivity to climate and their adaptive capacity.

AllianceID_fk	Species	Life forms	Seed storage	Seed longevity	Mode of dispersal	Germination agents	Mode of sprouting	Survivability after fire/disturbance	Disturbance–stimulated flowering	Reproductive range	Recruitment	Regional variation
1	Abies amabilis	Tree; evergreen	Transient	Short?	Gravity; wind	None	None	Fire-sensitive; thin epidermis; high flammability	No	20–500 years	Low	Low
2	Abies bracteata	Tree; evergreen	Transient	Short	Animal; gravity; wind	Stratification—winter	None	Fire-sensitive; thin epidermis; canopy architecture susceptible	No	?–100+ years	Low	Low

ID	GroupCode_fk	AllianceCode	AllianceCaCode	ScientificName	CommonName	Provisional	ClassifLevel	PrimaryLifeform	CoverType	FireReturnInterval	FireSeasonality	FireSize	FireComplexity	FireIntensity	FireSeverity	FireType	FireRegionalKnowledge	FireCharacteristics	FireNote	FireWorkshopNote
146	667	668	36.330.00	Atriplex hymenelytra	Desert holly scrub		Alliance	Shrub	Shrubland	Long (25–150 years)	Summer–early fall	Medium	Low to moderate	Moderate to high	High to very high	Surface to passive–active crown fire	Southern California deserts	Geomorphic and fluvial processes rather than fire primarily disturb the alliance. Response to fire depends on the presence of on- and off-site seed sources and rainfall patterns.		
147	485	488	36.370.00	Atriplex lentiformis	Quailbush scrub		Alliance	Shrub	Shrubland	Long (35–100 years)	Spring–summer–fall	Medium to large—up to and beyond stand	Low to moderate	Moderate to high	High to very high	Active–independent crown fire	Central, eastern, and southern California	Data are incomplete on the response of <i>Atriplex lentiformis </i>to fire. <i>A. lentiformis </i>can survive some fires, and the most likely post-fire regeneration strategy is seed production. No reports exist showing sprouting or adventitious buds. <i>A	Fire resistant shrub, inhabits desert shrublands	

<u>Table 2</u>. Examples of life history characteristics tables from the Manual of California Vegetation.

Another example comes from the Manual of California Vegetation, 2nd edition, which contains life history tables and fire-related tables (Sawyer et al. 2009) (Table 2). The agencies already hold much important information about many plant species in the Owens Valley. Note that this type of information can be compiled for individual species, but also for plant functional types, a classification that has close ties to physiognomic characteristics, and can be applied to many species, informed by those for which something is known.

Development of life history tables particularly attuned to scoring Owens Valley species on their ecological characteristics and their sensitivity and/or adaptive capacity to groundwater fluctuations (or other management questions) could contribute to a variety of analyses, including the frequency of a given species under different groundwater conditions over the years, for the adaptive management options discussed previously, and for developing hypotheses about the impacts of differing levels of groundwater pumping on particular species of interest.

Much is already known about the common species in the valley. For example, the Green Book details evapotranspiration curves for the six most common shrubs (page 57). The Team had discussions with agency staff in the field about the relative depth of roots, their ability to be used in restoration, robustness to disturbances, and other metrics of interest. Given this expertise, formalizing the knowledge and questions through the use of life tables could guide either additional research or interpretation of changes detected in vegetation monitoring.

4.0 Summary of Favored Options for Extending and Improving Identification of Vegetation and Groundwater Dynamics

The favored options for extending and improving measures and analyses used to manage groundwater withdrawal and vegetation in the Owens Valley can be broadly placed into five categories.

1) Review, consolidate, and update monitoring methods and analyses

The vegetation monitoring programs could achieve greater efficiencies by selecting a single field protocol for the ongoing monitoring (either permanent or randomized transects). The agencies should discuss what level of change constitutes significant biological or vegetative change, and conduct a sample adequacy analysis for the number of transects (observations) needed to reach this level of detection. Use of the binomial distribution, not a normal distribution is suggested. Consider whether to modify the transect measures to shorter transects, but increase the number of observations to achieve detectability for the level(s) of change that are determined. Consider the possibility of co-locating area-based measures with transects as a test of the utility and feasibility of eventually transitioning to area-based vegetation monitoring.

2) Improve the design of the monitoring to be more sensitive to change

Several options are available to improve the overall design of monitoring. Most attractive to the review team is more formal incorporation of the environmental gradients in the valley. Since we know there are changes in both groundwater and vegetation from the bajada to Owens river, arraying monitoring such that it can capture the changes along these gradients would allow for a more systematic interpretation of the yearly results. This can tie into options under (4) below, of developing predictive models of how vegetation is expected to respond given changes in groundwater.

3) Periodically review and as appropriate adopt new technologies, which could require adjustment in how the monitoring is done

As described in Section 2.3, Remote sensing methods, and (1) above, use of handheld or aerial sensors could be used to increase the accuracy of LAI estimates. Further, although the literature to date suggests that LIDAR is not likely an option for use in the Owens Valley, recent NEON data indicates that LIDAR may be used to define and classify cover and to track changes in cover over time. LIDAR can be used terrestrially or aerially. Typically, LIDAR can be used with object-oriented classification to identify canopies, and using distance metrics to obtain canopy heights. This is therefore worth further exploration by the agencies.

4) Develop models of the expected groundwater/vegetation dynamics to be used in conjunction with monitoring to improve projections

Section 3.2 describes this option in detail. Development of a working spatial model of the interacting dynamics of vegetation cover, composition at the level of physiognomic units, and groundwater would provide a useful tool to improve Owens Valley groundwater and vegetation management.

5) Use applied adaptive management experiments

Applied adaptive management experiments, described in Section 3.4 of this report, can be used to determine the causal relationships between vegetation and a variety of factors that it interacts with including groundwater, grazing, fire, and invasive species. While meeting requirements of the Green Book (e.g., avoiding conversion of Type C meadow to Type B shrubland), there are excellent opportunities to expand resulting management benefits for ecological conservation and land productivity for diverse uses. This may require some creativity, integration of management activities that are already occurring, and initiation of some new management techniques.

The ESA Team believes that the diverse environment of the Owens Valley, in combination with Green Book mandates and the long history of monitoring, is an ideal setting for understanding influences of a range of management options during an era of environmental change. Expanding the “tool box” of management options with known effectiveness available to the agencies can only improve their ability to meet future challenges in uncertain future environments.

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