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# Understanding integrated disturbance

Assisted regeneration 215gpkv2612

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The puzzle we are trying to solve in planning a restoration project is often recreating a reasonable approximation of an undisturbed ecosystem for a site, including both above- and below-ground structure (species, arrangement, sizes, architecture) and function (hydrologic cycles, nutrient cycles, energy flows, competition, symbiosis, etc). Water and nutrient limited arid and semi-arid ecosystems tend to be very brittle, easily damaged and challenging to repair; but recovery can be initiated and encouraged with suitable planning and restoration work.

Even relatively minor disturbances that would be of little concern in wetter and more temperate ecosystems can lead to profound and long lasting changes that limit recovery in the arid and semi-arid lands. Understanding the changes that have taken place and addressing the most critical problems is essential to develop successful restoration projects and management strategies.

The rate at which ecosystems can recover from human or natural disturbance is a function of the nature, magnitude, and frequency of the impacts they have experienced. Seeds and essential plant symbionts (mycorrhizal fungi, for example) may no longer be present, and soil structure, soil fertility, and air/water interchange are likely to be very adversely affected. Extreme temperatures, grazing by domestic and wild animals, reptiles, and insects, limited moisture, and low fertility soils combine to make plant establishment very slow even in areas where no disturbance has taken place. Conditions appropriate for the widespread establishment of some species may occur only a few times in 100 or perhaps 1,000 years if everything is in good condition, but if the ecosystem is damaged or degraded there may be little recovery without intervention.

The plant species and ecosystems we see in the arid lands today were often shaped, ordered, changed, and damaged by previous users. For a brief review of the major impacts on the dry lands of the Southwest (Lovich and Bainbridge 1999).

## A site environmental history

Developing a site history is one of the most useful steps in understanding disturbance and planning restoration work. Understanding the type, nature, location, and intensity of disturbance can make planning for restoration much more effective. We can develop a site history by looking backwards using a wide range of tools (Bainbridge, 2007).

- Aerial photographs, in some cases to the 1920s.
- Interviews and oral histories to the late 1800s and in some areas 1,000 years ago or more
- Books, property records, and newspapers.
- Photographs to the late 1800s, ideally paired photos.
- Illustrations, diaries, land grants, and journals.
- Archeological records to several thousand years ago
- Tree rings may give us a clear climate record and site specific information.
- Sediment and pollen records enable us to go back even further.

The value of early accounts is limited by the experience and skill of the traveler or reporter; but in some cases they can be quite helpful. These early histories are important because although reference sites are desirable for restoration projects there are few, if any, good reference sites in most arid and semi-arid lands.

Disturbance effects on most sites are many and pervasive. Tens of thousands of dollars could be spent to fully understand the changes in ecosystem structure and function for even a small site; but this is rarely possible, and not really necessary. We can often learn enough by looking at vital ecosystem and landscape attributes to help us distinguish between the underlying causes of problems and often more visible symptoms. A better understanding of the causes and history of disturbance can improve restoration planning and implementation.

Although it may not be possible to restore a site to predisturbance condition (it may now have very different soils, hydrologic function and human management), it is desirable to know, to the best of our ability, what was here before. A site history helps us understand what we see today, guides our choice of assessment tools, and can help determine the most appropriate restoration and management strategies. It can reduce the cost of assessment in the field, and can help us find the key problems and critical intervention points.

Although site evaluation is often done by an individual, it is much better to work with a multi-disciplinary team. The cross discipline pollination that takes place during site evaluations is very valuable as concerns of soil scientists are shared with the botanists, biologists, hydrologists, archeologists, mycologists, climatologists, and entomologists.

The foundation of most restoration projects is the soil and how water flows across or seeps into the soil. While desert soils may appear lifeless much of the year, living organisms, from bacteria to animals and plants, strongly influence their fertility, structure, and behavior and all are easily disrupted by disturbance. Small organisms such as ants, bacteria, fungi, microarthropods, nematodes, earthworms, springtails, protozoans, termites and yeasts play important roles in soil nutrient cycling and development. Some may be active at considerable depth. Changes in these little studied, and often overlooked, organisms can lead to undesirable changes in soil moisture relations, soil structure and fertility, and plant and animal communities. Restoration requires replacing the structural characteristics of mature ecosystems, yet more research has been conducted on the above ground architecture and characteristics than on the critical soil properties and soil ecosystems. Relatively simple tools like penetrometers and infiltrometers can be useful. Areas with good plant cover may hold and save much of the rain that falls in intense storms while areas that have been disturbed experience sheet flow, flash floods, and severe erosion.

Soils in the desert often have very low nutrient levels, with a thin layer near the surface having the highest levels. Phosphorous and nitrogen are often concentrated in the top 2-3 cm of undisturbed desert soil. Low levels of macronutrients are generally not a problem, unless the surface soil has been lost, but macronutrient imbalances may be important.

The addition of nitrogen from pollution related dryfall can pose problems throughout the drylands of Southwest North America. Even modest additions can increase nitrogen levels dramatically and shift the competitive balance to non-native grasses that can carry wildfire in these fire sensitive ecosystems. Compaction and disturbance usually reduce populations of beneficial soil organisms. Total numbers of fungi, bacteria, nematodes, microarthropods and macroarthropods tend to be much lower in disturbed soils. Changes in soil moisture caused by reduced infiltration and lower moisture holding capacity of damaged soils may make nodulation by nitrogen fixing rhizobia more difficult or impossible and limit infection by beneficial mycorrhizal fungi.

An understanding of the vegetation composition of the reference and disturbed sites is desirable to clearly identify disturbance effects, planning restoration procedures, and monitoring sites after restoration. It is impractical to make a complete census of even a relatively small site; but, cover, density, and frequency of selected plant species at a site can be accurately estimated with quantitative measurements on as little as 1% of the total site. Sampling procedures must be related to the data needed, expected variation over time, and the degree of precision necessary. Plant cover, density, and frequency are often considered important and can be easily measured in most dryland ecosystems. Aerial photos are often very helpful in desert monitoring and community evaluation because the larger plants are clearly visible and often live a very long time. Satellite photos may also be used for site analysis.

Disturbance markedly increases the severity of the microclimate. Temperature swings are larger on disturbed sites, radiation is more intense, evaporation is increased, and wind speeds and sandblast are more severe. Disturbance usually increases herbivory by reducing food supplies and increasing seedling visibility. Herbivory appears to be a common factor limiting survival of desert plants in undisturbed ecosystems, and is even more important on restoration project sites. Restoration work often increases herbivory by introducing nitrogen rich succulent plants to an otherwise barren environment. Irrigation and transplanting in the midst of otherwise dry and largely leafless plant material produces a "salad bar" effect that can become a serious problem.

Photography should be a regular part of any monitoring effort, with digital images and prints. Photo points and photo interpretation are very useful, inexpensive and ideal for communicating disturbance effects and recovery for non-botanists. Print on papers that are stable for a long storage life. Check with archivists and photo museums for current recommendations for storing digital images. Repeat photographs can provide considerable information at low cost. I like to use paired photos on every restoration project for monitoring. Paired photos are simple, fast, easy to understand, powerful and low cost.

**Function and vital attributes**

Exploring ecosystem function and vital attributes can help improve restoration planning. What are the trends in function, keystone species or vital attributes? These can be more challenging questions than simply studying water flow, counting plants and determining spacing or sampling soil characteristics. The cycling and movement of nutrients, energy, soil, and water on site and between adjacent ecosystems are all of interest. It is also helpful to understand, at least in general terms, the seed bank dynamics and movement of seeds and propagules onto and off the site.

**Understanding the integrated effects of disturbance**

The many individual types of disturbance described can all affect plant establishment and long-term survival on their own, but they rarely occur in isolation. More commonly many coincide and the adverse effects are interactive or synergistic. When combined they make recovery much more difficult than the evaluation of each impact by itself would suggest. These interactions are not well understood but the following formula is a preliminary attempt to assess these interactions and to relate them to plant establishment. Plant establishment becomes increasingly difficult as the number of deteriorating environmental factors increases. Here is an approach to consider disturbance, assuming each sub-element is additive not synergistic, but that taken all together there are synergistic effects.

$$\text{NET DISTURBANCE} = [\,(D_1)\,(D_2)\,....(D_n)\,]$$

For example, soils might consider:
$D_1$ increased **soil compaction** and **reduced infiltration**, where:
Ud = undisturbed soil strength/compacted soil strength
Id = reduced infiltration/undisturbed infiltration
fn = other factors

$$D_1 = \frac{[(Ud)+(Id) + fn]}{n}$$

$D_2$ reduced **soil fertility**, where
Nd = Available nitrogen disturbed/N undisturbed
Pd = Available phosphorus disturbed/P undisturbed
Kd = K disturbed/K undisturbed
Od = Organic matter disturbed/Organic matter undisturbed
Md = mycorrhizal inoculation potential disturbed/mp undisturbed
Rd = rhizobial inoculation potential disturbed/rp undisturbed
Dn = other factors

$$D_2 = \frac{Nd + Pd + Kd + Od + Md + Rd + Dn}{n}$$

$D_3$ more **adverse microclimate**, where
Wd = windblast undisturbed/ windblast disturbed
Mxd = max temperature undisturbed/ max temperature disturbed
Smd = soil moisture bare soil/ soil moisture under plants

$$D_3 = \frac{Wd + Mxd + Smd + Dn}{n}$$

$D_4$ loss of **seed bank**
Sba after disturbance
Sbbd before disturbance

$D_4$ = Sba/Sbbd

$D_5$ **increased herbivory**, where
Rs = reduced shelter
Gp = increased grazing pressure,

$$D_5 = \frac{Rs + Gp}{2}$$

Here is an example from my experience over many decades of research and project implementation. Some factors are clearly more important than others and a better understanding of these factors should make it possible to develop constants to properly weight these differences. The factors are averages, assuming these considerations are additive, not synergistic.

$D_1$. soil compaction and infiltration
Ud = undisturbed/road soil strength = 0.53
Id = road /undisturbed infiltration = 0.66

$$D_1 = \frac{0.53 + 0.66}{2} = 0.59$$

$D_2$. soil fertility
Nd = nitrate N road/undisturbed = 0.16
Pd = extractable P road/undisturbed = 0.40

Kd = available potassium = often no difference
Od = decrease in organic matter = 0.50
Md = mycorrhizal infection potential disturbed/undisturbed (estimated) = 0.10
Rd = rhizobial inoculation potential disturbed/undisturbed (estimated) = 0.10

$$D2 = \frac{0.16 + 0.40 + 0.50 + 0.10 + 0.10}{5} = 0.25$$

$D_3$. more severe microclimate
Wd = windblast undisturbed/ disturbed (est.) = 0.5
Mxd = max temp. shade/ max temp. sun = 0.9
Smd = soil moisture (SP open/SP plant canopy) = 0.6

$$D_3 = \frac{0.5 + 0.9 + 0.6}{3} = 0.66$$

$D_4$ seed bank after/seed bank before (estimated)

$D_4 = 0.2$

$D_5$. increased herbivory
hd = reduced shelter = 0.9
ip = increased pressure= 0.9

$$D_5 = \frac{0.9 + 0.9}{2} = 0.9$$

**Integrated revegetation potential is then:**

The integrated recovery potential shown here assumes there are synergistic effects between these factors.

Recovery potential = 0.59 x 0.25 x 0.66 x 0.2 x 0.9 = 1.5 percent of undisturbed

This suggests that this disturbed site may take a very long time to recover without intervention. Recovery of a disturbed site may be take hundreds of years on badly disturbed sites that are not restored or treated. These seems reasonable when related to existing studies of recovery rates of arid and semi-arid lands. Developing a better understanding of the interactions between these different factors is essential to predict damage and to plan restoration activities.

If soil structure, infiltration, and fertility can be made better than before disturbance and full protection is provided for young plants, then the chance of plant establishment may be improved close to predisturbance conditions. But this can be costly. Today we have the added challenge of climate change. This is likely to mean more severe droughts, increased temperatures, more intense storms, and more pressure from inhabitants trying to survive ever greater hardships.

**Summary**

The challenge of revegetation and restoration of arid and semi-arid lands is daunting. Many environmental factors can be degraded by human activity in the desert, but assessing the nature and magnitude of changes in key factors can improve restoration planning and reduce restoration cost by enabling limited resources to be directed at critical problems and vital attributes. The most important lesson from these studies is obvious, but often neglected: minimize the area, intensity, and frequency of disturbance to arid and semi-arid ecosystems.

Reading:

Bainbridge, D. A. 2015. **Gardening with Less Water**: Low tech, low cost techniques cut water use 90%. Storey Press. *Silver Nautilus Award Winner*

Bainbridge, D. A. 2014. Soil penetrometer. *Restoration Notes* 2(3):1-4 *https://works.bepress.com/david_a_bainbridge/37/*

Bainbridge, D. A. 2012. Restoration of arid and semi-arid lands. Chapter 10, pp. 103-114. In van Andel, J. and Aronson, J. (eds), **Restoration Ecology: The New Frontier**, 2nd edition, Blackwell Publishing Ltd, Oxford UK.

Bainbridge, D. A. 2007. **A Guide for Desert and Dryland Restoration: New Hope for Arid Lands.** Island Press, Washington, DC. 391 p.

Lovich, J. and D. A. Bainbridge 1999. Anthropogenic degradation of the Southern California desert ecosystem and prospects for natural recovery and restoration. *Environmental Management*. 24(3):309-326.

Caravanserai in Easter Jordan. Overgrazing for thousands of years by camels horses, sheep and goats. Yet even here there were some plants growing where water collected  in accidental pits or depressions. More palatable species could be found on cliffs and high up on ruins that the very agile goats could not reach.