An LFA Interpretive Framework:

Using the Sigmoidal Curve to Interpret Changes in LFA Indicators over Time

Restoration practitioners (RPs) collect data on LFA indicators over time and need to interpret whether these data are trending towards values predicting successful landscape rehabilitation. Although RPs could apply complex simulation and statistical models to predict data trends, we recommend a simple graphical procedure that plots data for indicators being monitored on restoration sites over time and fits an S-shaped (sigmoidal) curve to these data. The aim is to see if the plotted values are trending towards those expected based on measuring LFA indicators on reference sites.

Sigmoidal curves

Plots of values for landscape restoration indicators, such as soil surface assessments (SSA), typically have a sigmoidal (S-shaped) form (Figure 1). This is because landscape processes being repaired usually recover slowly at first, but then more rapidly with time, before leveling off, hopefully, at values similar to those found on reference sites; this trend indicates successful recovery. We have found sigmoidal curves when plotting data for indicators of landscape processes being repaired on restoration sites (see chapters 4-12, Tongway & Ludwig, 2011).

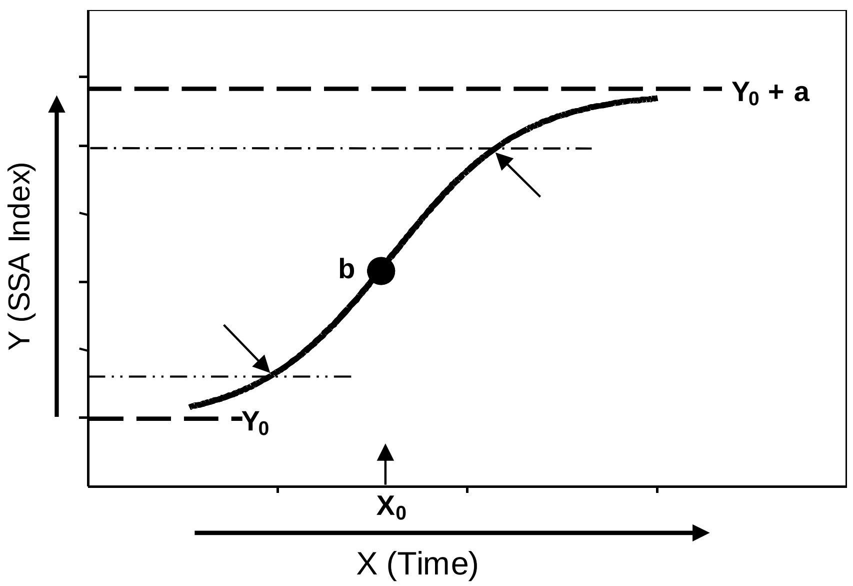

Figure 1. A sigmoidal curve of the form: $y = y_o + [a/(1 + e^{-(x-x_o)/b})]$.

Although data forming an S-shaped (sigmoidal) curve can be represented by a number of different equation forms, we chose the form: $\mathbf{y = y_o + a/(1 + e^{-(x-x_o)/b})}$, because the four parameters in this sigmoid equation predicting **y** (e.g., an indicator of landscape function; a soil surface condition index in Figure 1) have useful meanings for describing landscape processes:

$\mathbf{(y_o+a)}$ represents the upper asymptote, or the expected maximum value for the indicator of the landscape process being evaluated;

$\mathbf{y_o}$ represents the lower asymptote, or minimum value expected for the process indicator;

$\mathbf{x_o}$ represents the location of the inflection point of the curve on the x-axis, that is, where the rate of change in the values for the process indicator switches from having an increasing (rising) trend to having a decreasing (slowing) trend; and

b represents the rate of change or slope at the inflection point, $\mathbf{x_o}$, for the process indicator. Smaller **b** values represent quickly responding processes (e.g., rapid ecosystem recovery), and larger **b** values denote slower responses (e.g., slower ecosystem recovery). Sigmoid curve slope parameter values can be compared, for example, between different landscape restoration sites to see which ones are recovering more quickly.

In other words, these sigmoid curve parameters represent values related to the functional behaviour of processes in the landscape. For example, how stable is the landscape when processes are fully functional? How unstable is the landscape when processes are being severely stressed and damaged? In most cases, the stability of “functional” responses are related to the nature of the vegetation and soil and their capacity to resist damage, such as erosion.

The location of the points of maximum curvature (arrows; Figure 1) can be used as threshold values. The point of maximum curvature usefully represents landscape threshold values for management. For example, the upper point could be used to differentiate between self-sustaining landscapes close to the ‘ultimate goal’, and those that are under threat of accelerated erosion.

The sigmoid curve described above (Figure 1) can be fit to plots of data for landscape restoration indicators using commercial software packages, such as SPSS Sigmaplot. If the data is S-shaped and the equation form, $\mathbf{y = y_o + a/(1 + e^{-(x-x_o)/b})}$, adequately fits these data, then estimates of equation parameters and statistics describing the ‘goodness-of-fit’ will be provided by the package output. To accurately estimate parameters, sigmoid curve-fitting software packages require relatively large sample sizes (e.g., N > 20 data).

Approximating sigmoidal curves & parameters

As noted above, sigmoid curve fitting procedures requires a lot of data, including values from reference sites. However, in many cases, data for indicators of landscape processes are sparse because of the difficulty of frequently monitoring restoration and reference sites. We have found that such sparse data appear to clearly follow an S-shaped trend (see examples in chapters 4 to 12, Tongway & Ludwig, 2011). In such cases, it is still useful to fit a sigmoid curve to these data by ‘eye’ (at least 5 data points are needed; Figure 1), and to roughly estimate parameter values (i.e., upper and lower asymptotes, and inflection and threshold points). Although these values will only be approximations due to the sparse data, they still provide information useful for interpreting trends and whether restoration treatments are repairing damaged processes.

The sigmoidal curve is intuitively attractive because values for landscape biogeochemical processes must have upper and lower bounds, and the line between these bounds often represents a change from a processes being very dysfunctional to being highly functional. The sigmoidal curve can also represent changes over time in the reverse direction, that from functional to dysfunctional (i.e., desertification). Noy-Meir (1981) utilised the S-shaped form when modeling ecosystem functioning in resource limited landscapes. Bastin *et al* (1993) also reported sigmoidal curves for how remotely sensed indicators changed spatially with distance from cattle watering points (i.e., grazing gradients).

Rapidly approximating sigmoidal curves thresholds

Properties of the sigmoidal curve fit by ‘eye’ can be used to rapidly estimate thresholds for each of the LFA indices being evaluated. The sigmoid curve form, $\mathbf{y = y_o + a/(1 + e^{-(x-x_o)/b})}$, is symmetrical around the inflection point, **b**, so that in terms of landscape function, **b** is half way between the upper and lower asymptote values. The inflection point is conceptually where landscape functions start to become “self-sustainability” when processes are recovering from stress and disturbance. In other words, as indicator values for landscape functions climb above the inflection point, landscape become more and more capable of absorbing stress and disturbance while gaining functionality.

To rapidly approximate where the inflection point, **b**, is located, one simply selects an example of the least functional landscape (a highly disturbed site prior to the application of restoration technologies) and an example of the most functional landscape (e.g., a reference site). Then the following simple calculations can be applied (Figure 2):

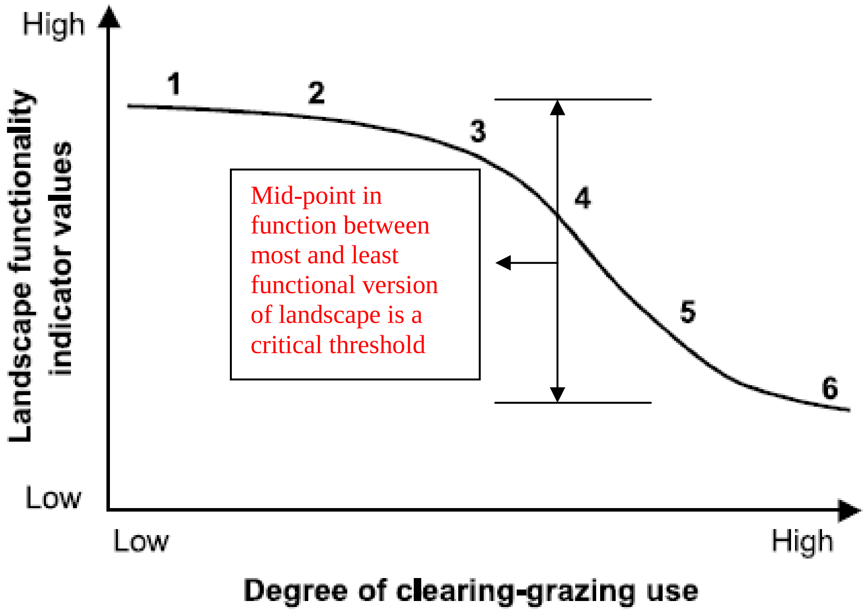

Figure 2. For each of the LFA indices being evaluated, critical threshold (CT) values can be rapidly calculated using the equation: CT = [(highest value – lowest value)/2] + lowest value.

If, however, the most and least functional examples selected provide LFA index values that are not close to the true upper and lower asymptote values (points 1 and 6; Figure 2), then the estimated inflection point, **b**, is likely to be a poor approximation of the critical threshold value. In this case, we recommend fitting a sigmoid curve to the available data by 'eye' approximating where the inflection point is located from the shape of the curve. This procedure enables an early estimation of critical threshold values. The alternative is to wait until sufficient data are available to adequately fit a sigmoid curve to the data using a software package.

References

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Noy-Meir, I. 1981. Spatial effects in Modelling of arid Ecosystems. pp 411-432. In: Arid-land ecosystems: Structure, functioning and management, Vol.2. (Eds. D.W.Goodall and R.A. Perry) Cambridge University Press, Sydney, NSW, Australia.

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