Measuring the success of ecological restoration

Practical guidance note

Department of Climate Change, Energy, the Environment and Water

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

Artist and designer Nikita Ridgeway from Aboriginal design agency Boss Lady Creative Designs created the People and Community symbol.

Cover photo: Vegetation restoration on former Snowy Hydro Scheme site in Kosciuszko National Park. Emma Kynaston/DCCEEW

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Background to the guidance note

It is standard practice to compare the status of performance indicators at ecological restoration sites against reference or analogue sites to monitor restoration progress and demonstrate restoration success. Reference sites are used to sample the characteristics of the restoration target ecosystem to provide benchmark values for monitoring progress and measuring success.

Although use of reference sites is commonplace, standard methods for defining the target reference ecosystem, selecting reference sites and measuring success are surprisingly lacking. This practical guidance note provides support to:

- help determine the appropriate **target reference ecosystem(s)** within which reference sites should be located
- decide **how many reference sites** should be established to determine reliable performance indicator benchmark values
- show how the data collected from reference and restoration sites should be used to **measure restoration success**.

The practical steps and analytical approaches described here are detailed in Oliver et al. (2023). The open access article also details 2 case studies, including a post-mining ecological rehabilitation project in the Hunter Valley which we use in this guidance note to provide specific examples of outcomes and variables.

Measuring restoration success

Step 1. Define the reference ecosystem

An ecosystem consists of interacting biotic (plants, animals, fungi, bacteria) and abiotic (soil, water, air) parts, but it has no particular size. An ecosystem can be as large as a whole region, or as small as a single tree. A larger ecosystem, for example a temperate grassy woodland, will likely include more environmental variation than a smaller ecosystem, for example a single tree.

The reference ecosystem represents the characteristics of the target ecosystem against which restoration progress and success are measured. The selection and definition of the reference ecosystem are fundamental to determining the success, or otherwise, of the restoration program. Key considerations include defining the scale and theme of the reference ecosystem (described in Step 1), and the desirable condition or state of the reference ecosystem (described in Step 2).

In terms of determining the scale of a reference ecosystem, an ecosystem that is too large may include so much environmental variation that is unhelpful for measuring restoration success at a particular location. On the other hand, where an ecosystem is too small and includes only a limited amount of environmental variation, it may be difficult and expensive to locate and sample.

Therefore, before the reference ecosystem can be identified and reference sites can be established, stakeholders must first agree on the scale of environmental variation the reference ecosystem should include.

We refer to this as defining the **acceptable thematic scale** of the reference ecosystem. **Acceptable**, because it needs to be agreed by stakeholders; **thematic**, because different ecosystem themes can apply in different situations (for example, native vegetation, geology, soils, climate, catchments); and **scale**, because it sets the scale of environmental variation expected within the reference ecosystem. For example, for a native vegetation theme, stakeholders in New South Wales could define the reference ecosystem at one of the 3 existing vegetation classification scales:

- plant community type (a small amount of environmental variation within each type)
- vegetation class (a greater amount of environmental variation within each type)
- vegetation formation (the greatest environmental variation within each type).

The aim of this first step is to agree on a scale of ecosystem classification that best matches the management need or restoration objectives, and is practical and affordable to use. The following 2 questions will help stakeholders find agreement on the reference ecosystem acceptable thematic scale.

Question 1. Do the management or restoration objectives already define the reference ecosystem thematic scale (for example, a particular level in a vegetation classification hierarchy)?

- If yes:
    - identify the target reference ecosystem at that thematic scale.
- If no:
    - go to Question 2.

Question 2. Are the management and/or restoration objectives clearly defined?

- If yes:
    - identify the reference ecosystem thematic scale that best relates to these objectives
    - then identify the reference ecosystem at that thematic scale.
- If no:
    - work with stakeholders to clearly define the management and/or restoration objectives
    - then return to the start of Question 2.

At the completion of Step 1, one or more target reference ecosystems will have been defined at an agreed thematic scale appropriate to the management and/or restoration objectives. In the case study example (see Oliver et al. 2023) one of the reference ecosystems identified was a recognised plant community type (agreed thematic scale), the Central Hunter ironbark grassy woodland (target reference ecosystem).

Step 2. Define the reference ecosystem condition state

Most ecosystems exist in a range of condition states due to past disturbance, and they can vary through space and time. 'State-and-transition' models help to understand, explain and manage ecosystem dynamics. They identify a range of alternative stable states and transitions between states which may occur within an ecosystem.

Some of these states may not represent a desirable restoration outcome (for example, Central Hunter ironbark grassy woodland with a groundcover dominated by exotic species). In addition, ecological, economic, practical and social constraints on restoration may limit what condition states or outcomes are achievable. For example, attempts to restore sites to a perceived 'natural' or historic state may be futile in many landscapes due to what in effect are irreversible ecological or socio-economic constraints. Different constraints at different locations means there is no one single model for setting restoration goals. As such, careful consideration by stakeholders of alternative stable states and their transitions is essential to setting achievable restoration goals.

Step 2 requires stakeholders to agree on what the desirable outcome or condition state is within the reference ecosystem(s) identified in Step 1.

We refer to this condition state as the **desirable stable (reference) state. Desirable**, because again it requires agreement among stakeholders; and **stable**, because it reminds us that ecosystems are dynamic and the characteristics of any one site can change over time in response to weather, climate, weeds, pests, disease, fire and other pressures and disturbances.

Importantly, these pressures and disturbances can shift (that is, transition) a reference site from a desirable state to an undesirable state. A useful reference site for monitoring restoration success is a site with a small chance of transitioning to an undesirable state. Therefore, a useful reference site should be stable through time, or if disturbed it should return to its pre-disturbance condition state within an acceptable timeframe without intensive effort. Consideration of what this timeframe should be is central to defining the reference ecosystem condition stable state.

We refer to this as the **acceptable management timeframe**. This sets the timeframe that we would expect the desirable reference site characteristics or condition to be stable, meaning that any changes in these characteristics resulting from disturbance are transient. As for Step 1, the **acceptable management timeframe** needs to be agreed by stakeholders before the characteristics (condition state) of the reference ecosystem and reference sites can be finalised. The following 3 questions will help stakeholders reach agreement on the acceptable management timeframe and the desirable stable (reference) state.

Question 3. Do the management or restoration objectives already identify the management timeframe?

- If yes:
    - define the characteristics of the desirable stable (reference) state such that sites are likely to recover these characteristics following likely disturbance within the identified management timeframe.
- If no:
    - go to Question 4.

Question 4. Are state-and-transition data and/or expert knowledge available that may help understand transient dynamics within a desirable condition state compared to a transition to an undesirable condition state?

- If yes:
  - do these data or experts suggest a management timeframe and is it acceptable to stakeholders?
- If yes:
  - define the characteristics of the desirable stable (reference) state such that sites are likely to recover these characteristics following likely disturbance within the acceptable management timeframe.
- If no:
  - go to Question 5.

Question 5. Are there other considerations that could also be used to help identify the acceptable management timeframe (for example, duration of funding to support restoration site monitoring and management, or the expected timeframe to demonstrate restoration success)?

- If yes:
  - use these considerations to agree on an acceptable management timeframe and define the characteristics of the desirable stable (reference) state such that sites are likely to recover these characteristics following likely disturbance within the acceptable management timeframe.
- If no:
  - agree on an acceptable management timeframe and define the characteristics of the desirable stable (reference) state such that sites are likely to recover these characteristics following likely disturbance within the acceptable management timeframe.

At the completion of Step 2, the **acceptable management timeframe** will have been set. Based on the agreed timeframe — and on potential ecological, economic, practical and social constraints on restoration outcomes — stakeholders will have defined the **desirable stable (reference) state**. In the post-mining case study example, the acceptable management timeframe was set at 20 years to align with the NSW *Biodiversity assessment method* (DPIE 2020); and stakeholders defined the desirable stable (reference) state for Central Hunter ironbark grassy woodland (a reference ecosystem) as extant woody native vegetation much greater than 20 years old, with no evidence of cultivation, minimal exotic plant cover, but variable fire and grazing history.

Step 3. Define the measure of restoration success

Performance indicators are used to measure and monitor key attributes of the biophysical environment at restoration and reference sites. Their selection will vary depending on the context of the program and the restoration aims, and are generally determined in consultation with stakeholders. The NSW Resources Regulator provides a set of recommended performance indicators that relate solely to the ecological rehabilitation of mined land (see links in 'More information' section).

The restoration industry's standard for judging restoration success is the comparison of performance indicator values at restoration and reference sites. However, as Step 2 shows, ecosystems are dynamic and the characteristics of a reference site within a reference ecosystem will vary, therefore we should not use a single reference site or a single benchmark value to measure success.

So how do we set a benchmark value for a **performance indicator** when we know this value will vary among reference sites?

Firstly, we must use multiple reference sites to sample this variation. Secondly, we need to abandon the use of the mean value of reference site indicator values as a target point and replace it with **target bands** based on the range of variation observed across multiple reference sites.

Using a target band based on the range of variation observed at multiple reference sites provides significant benefits:

1. it accommodates the dynamic nature of ecosystems and a range of potential restoration outcomes
2. it avoids a focus on a narrowly defined restoration target value that can lead to adverse restoration outcomes
3. it recognises that values above (as well as below) the observed reference site range may neither be desirable nor indicative of a healthy and resilient ecosystem.

We call this target band the **acceptable range of variation**. **Acceptable**, because stakeholders should take a precautionary approach and trim the full observed range by an agreed amount due to the potential presence of unrepresentative values at one or more reference sites (that is, data outliers).

We recommend an acceptable range of variation based on the 10th and 90th percentiles (or 80% credible interval) as a default measure. This balances the full distribution of the range of variation likely across reference sites while minimising the influence of unrepresentative or unusual values. Different methods for determining acceptable ranges of variation are detailed in Oliver et al. (2023).

The question below will help stakeholders reach agreement on the measure of restoration success.

Question 6. Do stakeholders agree on 10th and 90th percentiles (or 80% credible interval) as the measure for the acceptable range of variation?

- If yes:
  - accept these measures and move onto Step 4.
- If no:
  - agree on an alternative acceptable range of variation, document the reasons why it should differ, and move onto Step 4.

At the completion of Step 3 stakeholders will have agreed on the measure of the acceptable range of variation for each performance indicator in each reference ecosystem. In the case study example, the target band for the total organic carbon performance indicator was determined to be 2.5–7% for the Central Hunter ironbark grassy woodland reference ecosystem.

Step 4. Determine the number of reference sites needed to calculate the acceptable range of variation

It is important that a sufficient number of reference sites are used to estimate a reliable acceptable range of variation in performance indicators used to measure restoration success.

Previous case study analyses (see Oliver et al. 2023) suggest that 5 or fewer reference sites may result in highly variable estimates of the acceptable range of variation, but on average will underestimate the acceptable range of variation. These analyses suggested a minimum of 10 reference sites per reference ecosystem are required when performance indicator data approximate a normal distribution, or a minimum of 15 when data are highly skewed.

The number of reference sites required is likely to vary among ecosystems and performance indicators. Oliver et al. (2023) recommends a simulation approach to guide reference site replication sufficiency. The following 4 questions will help stakeholders reach agreement on the number of reference sites required to calculate a reliable estimate of the acceptable range of variation.

Question 7. Does the project team have the skills or resources to undertake or outsource data simulation analyses?

- If yes:
  - go to Question 8.
- If no:
  - although each case will differ, previous case study analyses suggest a minimum of 10 reference sites per reference ecosystem when data approximate a normal distribution, or a minimum of 15 when data are highly skewed (see Oliver et al. 2023).
  - accept this guidance and implement the study.

Question 8. Are data available from the literature or from your own studies from sites that Step 1 and Step 2 suggest might be considered suitable reference sites?

- If yes:
  - use data from these sites to calculate sample mean and standard deviation and define an underlying data distribution
  - pool data among reference ecosystems if distributions are similar (see Oliver et al. 2023)
  - undertake simulation analyses according to Oliver et al. (2023) to assess reference site replication sufficiency for each performance indicator
  - then go to Question 10.
- If no:
  - go to Question 9.

Question 9. Is there sufficient time and resources to undertake a pilot study?

- If yes:
  - sample 10–15 reference sites in each reference ecosystem (after following Steps 1 and 2)
  - use these data to calculate sample mean and standard deviation and define an underlying data distribution
  - pool data among reference ecosystems if distributions are similar
  - undertake simulation analyses according to Oliver et al. (2023) to assess reference site replication sufficiency for each performance indicator
  - then go to Question 10.
- If no:
  - although each case will differ, previous case study analyses (Oliver et al. 2023) suggest a minimum of 10 reference sites per reference ecosystem when data approximate a normal distribution, or 15 when data are highly skewed
  - accept this guidance and implement the study.

Question 10. Do simulation analyses suggest sufficient reference site replication has been reached?

- If yes:
  - implement study based on these findings.
- If no:
  - sample additional sites and go back to Question 9.

At the completion of Step 4, stakeholders will have either accepted recommendations on the default minimum number of reference sites required or undertaken simulation analyses to support study-specific replication sufficiency.

Step 5. Monitor restoration progress and measure restoration success

For each performance indicator in each reference ecosystem, compare measures made at restoration sites with the measure of acceptable range of variation agreed at Step 3 and calculated from a sufficient number of reference sites (from Step 4) located according to Steps 1 and 2.

By following these practical steps and the analytical approaches described in more detail in Oliver et al. (2023), restoration ecologists and practitioners will make a significant contribution to delivering practical, scientifically robust, socially acceptable and economically feasible methods for the assessment of restoration success.

More information

DPIE (Department of Planning, Industry and Environment) (2020) ‘Biodiversity assessment method’, DPIE, NSW Government, Sydney, Australia.

NSW Resources Regulator (2021) *Guideline: Restoration objectives and rehabilitation completion criteria* [PDF 782KB], NSW Resources Regulator, Department of Primary Industries, NSW Government, Sydney, Australia.

Oliver I, Dorrough J and Travers SK (2023) ‘The acceptable range of variation within the desirable stable state as a measure of restoration success’, *Restoration Ecology*, 31(1), doi.org/10.1111/rec.13800.

See Oliver et al. (2023) for further references.