# Multi-Criteria Analysis

*Teacher background information*

One of the challenges in environmental management is to make decisions which include environmental, social and economic aspects. These problems may benefit from multi-criteria analysis. Multi-criteria analysis (MCA) helps decision makers develop coherent preferences for a given problem so that decisions can be taken with more confidence.

This module explains the multi-criteria analysis (MCA) framework and allows student to apply this knowledge in a tutorial using a free spatial software tool (MCAS-S) developed by the MCAS-S Development Partnership. This module has been developed by the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES).

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The *ecoEd\_Multi-Criteria Analysis* folder includes the following documents:

* Multi-Criteria Analysis lecture (ppt): these slides provide an introduction to multi-criteria analysis. NB. The lecturer will need to install MCAS-S and download MCAS-S datapack ‘Where to live in Australia’.
* Multi-Criteria Analysis handout (both as PDF and Word document): this is a student handout with a step-by-step introduction on how to develop a multi-criteria analysis in MCAS-S.
* Multi-Criteria Analysis teacher background information: this document, which below outlines how to prepare a workshop and a suggested timeline for a workshop, as well as relevant literature and background information that help better understand the information presented in the lecture slides.
* Lantana data pack (zip file); this includes the data needed for the practical exercise. There is an associated Excel file that lists all the data license information for all data files in the zip file.
* Where to live data pack (zip file): this includes the data needed for the lecture. There is an associated Excel file that lists all the data license information for all data files in the zip file.

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## Overview of how to run a Multi-Criteria Decision workshop

### Introduction

It is most useful to run the workshop after presenting the Multi-Criteria Decision lecture to ensure students have a solid understanding of the different concepts discussed in the workshop. The lecture and workshop can also be combined in one so that the lectures are given with the students already in the computer room.

NB. This module requires installation of MCAS-S desktop software. This software is freely available but unfortunately can only run on Windows PC or virtual PC.

MCAS-S website<http://www.agriculture.gov.au/abares/aclump/multi-criteria-analysis>

MCAS-S Development Partnership (2018), *Multi-Criteria Analysis Shell for Spatial Decision Support MCAS-S version 3.2 User guide*, ABARES, Canberra, June. CC BY-ND 4.0.

### Workshop preparation

* Book a computer lab or ask people to bring their own laptop.

Ideally one computer to 1 or 2 people.

* Make sure MCAS-S is installed on computers/laptops prior to the workshop.
* Send around the Multi-Criteria Decision handout pdf file, so that people can follow the steps.
* Send around the Lantana zip file that contains all the data needed for the workshop.
* Run through the steps yourself so that you are familiar (if not already) with the MCAS-S software.

### Suggested timeline

To cover both the lecture slides and the steps in the handout, we suggest to allow 3 hours.

## 

## Relevant publications

* Australian Government (2014) *Reef Water Quality Protection Plan 2013 – prioritisation project report*, Canberra. <http://www.agriculture.gov.au/SiteCollectionDocuments/natural-resources/reef-water.pdf>
* Baker RHA, Benninga J, Bremmer J, Brunel S, Dupin M, Eyre D, Ilieva Z, Jaros V, Kehlenbeck H, Kriticos DJ, Makowski D, Pergl J, Reynaud P, Robinet C, Soliman T, Van der Werf W, Worner S (2012) A decision-support scheme for mapping endangered areas in pest risk analysis, *Bulletin OEPP/EPPO Bulletin*, 42(1): 65-73.<https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2338.2012.02545.x>
* CRC for Australian Weed Management 2003, *Weeds of National Significance, Weed Management Guide – Lantana camara*. <https://www.environment.gov.au/biodiversity/invasive/weeds/publications/guidelines/wons/pubs/l-camara.pdf>
* Department for Communities and Local Government UK (2009) *Multi-criteria analysis: a manual*, London. <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/7612/1132618.pdf>
* East IJ, Wicks RM, Martin PAJ, Sergeant ESG, Randall LA, Garner MG (2013) Use of a multi-criteria analysis framework to inform the design of risk based general surveillance systems for animal disease in Australia, *Preventive Veterinary Medicine*, 112(3-4): 230-247.

<https://doi.org/10.1016/j.prevetmed.2013.09.012>

* Esmail AB, Geneletti D (2018) Multi-criteria decision analysis for nature conservation: A review of 20 years of applications, *Methods in Ecology and Evolution*, 9(1): 42-53,<https://doi.org/10.1111/2041-210X.12899>
* Hirshfeld J, Hadley D, Mongruel R, D’Hernoncourt J (2011) *Multi-Criteria Analysis Specification Sheet and Supporting Material*, Report for Science Policy for Coastal Systems Assessment. <http://www.coastal-saf.eu/output-step/pdf/Specification%20sheet%20MCA_final.pdf>
* Hunter Councils (2013) *Mapping Important Agricultural Lands in the Lower Hunter Region of NSW*. <https://www.environment.gov.au/system/files/pages/25570c73-a276-4efb-82f4-16f802320e62/files/hc-important-agricultural-lands.pdf>
* Leys J Chappell, A, Mewett, J and Barson M (2017) Modelling wind erosion for Australia for prioritisation of national Landcare investment, 22nd International Congress on Modelling and Simulation, Hobart, Tasmania, Australia. <https://www.mssanz.org.au/modsim2017/G8/leys.pdf>
* Lobry de Bruyn LA (2013) *First Approximation: Evidence-based Soil Health Investment Prioritisation for NSW*, Report to the NSW Natural Resources Commission.<http://www.nrc.nsw.gov.au/_literature_177531/Funding_-_Evidence-based_soil_health_investment_prioritisation_for_NSW_(University_of_New_England)>

## Background information

One of the challenges in environmental management is to make decisions which include environmental, social and economic aspects. Environmental managers and policy makers often discover that problems are difficult to define, are still evolving, don’t have consensus about which inputs to include or their relative valuation, and have no ‘right’ answer. Instead you may be expected to meet multiple and competing objectives, compare scenarios and explore trade-offs. These ‘wicked’ problems may benefit from multi-criteria analysis.

### What is multi-criteria analysis?

Multi-criteria analysis (MCA) helps decision makers develop coherent preferences for a given problem so that decisions can be taken with more confidence. MCA is an assessment method that does not need to monetise all the inputs (unlike cost-effectiveness and cost-benefit analysis).

The basic stages of an MCA are to define the context, structure the problem, complete an analysis, come to a decision, and review. This can be considered as a 5-step process:

1. Define the problem and context, and identify the components for evaluation which can include the:
   1. Objective
   2. Criteria
   3. Inputs (data)
2. Assemble or collect data
3. Explore and combine data
   1. Rank or scale data
   2. Apply weights
4. Come to a decision: Calculate final score and develop options
5. Review and repeat the process to refine

The first step; defining the problem, is critical to a successful MCA and it is worth ensuring that sufficient time and effort is dedicated to this stage. In some cases, a satisfactory definition of the problem and the objective may only be reached via an iterative process by reviewing an incomplete MCA.

Common elements of an MCA are a performance matrix, weighting and a ranking process. Ranking methods include: linear additive, successive pairwise comparisons, multi-dimensional outranking methods, qualitative data, or fuzzy ranking procedures.

### What are the benefits of MCA and MCAS-S?

Multi-criteria analysis (MCA) is a process to assist decision-makers. An MCA does not do the decision-making, but it can be used to help define problems, identify data gaps, integrate inputs with different units, compare options, and explore trade-offs and potential outcomes.

The Multi-Criteria Analysis Shell for Spatial decision support (MCAS-S) software helps to answer 'where questions' when you have access to appropriate spatial input data, expert knowledge, an understanding of thresholds and linkages between the data. MCAS-S is a map viewer and a spatial-analysis tool. It can be used for spatial MCA and other applications. MCAS-S is particularly useful to show the relationship between data layers and objectives, look at alternative views quickly, produce statistical reports and explain your assumptions and decision process to stakeholders. These data discovery features give MCAS-S models a high level of transparency and help MCAS-S users and MCAS-S workshop participants to gain a deeper understanding of the problem and the data.

Leaving input data ‘raw’ or unclassified allows you flexibility when using MCAS-S to complete an MCA. For example you can compare the effect of different thresholds such as rainfall or temperature on an objective by dragging an input layer in twice and adjusting the class breakpoints.

MCAS-S provides a visual representation of decision matrices. For example Baker et al. (2012) have used the MCAS-S two-way viewer to define minimum, maximum and addition rule matrices.

### What are the problems with MCA and MCAS-S?

Limitations of multi-criteria analysis (MCA) and MCAS-S include:

* MCA results and the performance matrix can be complex and difficult to interpret
* MCAS-S may show an ‘answer’ when data is poor quality, missing, or used inappropriately. This may encourage users to think they have enough information to make a decision and not review the underlying assumptions.
* Aggregation and weighting relies heavily on assumptions and value judgements.
* Inputs may not be independent.
* Weighting preferences may not be independent.
* The way that inputs are categorized and aggregated will influence the outcome.
* It may take several sessions to agree on a performance matrix.
* It might be impossible to reach an agreement on the decision.

A literature review of MCA applications to conservation and planning over the last 20 years shows that very few of the analyses involved stakeholders other than the authors. While weighting was performed in almost all applications, sensitivity analysis was overlooked. Weighted linear combination was the most common aggregation method (Esmail 2018).

Therefore MCAs benefit from:

* Clear decision context
* Collaboration (such as focus groups, surveys, interviews, questionnaires)
* Transparent communication and discussion of methods
* Revisit and reformulate controversial steps
* Comprehensive sensitivity analysis
* Compare the results with cost effectiveness or cost benefit analysis (Hirschfield et al. 2011).
* Review or ‘reality checking’ by those who have good local knowledge or experiential knowledge of the study area that is the subject of the modelling exercise.

### How is multi-criteria analysis used in environmental management?

Multi-criteria analysis (MCA) is used for integrated assessments including ecological, economic and social concerns. MCA can be used where stakeholders do not accept a monetary value being placed on an input, such as potential species extinctions.

The flexibility of MCA is useful when the decision criteria are frequently changing. For example, priorities for the allocation of funding to protect and improve environmental values by governments can change on an annual basis. These funding priorities and related decision criteria, are also often different for different levels of government, such as federal, state and local government.

MCA can be a large or small component in the decision process. An MCAS-S project can be completed as an input to, or use outputs from other tools or systems including climate models or principle components analysis.

MCA applications include conservation prioritisation and planning; protected areas management and zoning; forest management and restoration; and mapping of biodiversity, naturalness and wilderness (Esmail 2018).

For example MCA (and/or MCAS-S) has been used:

* As part of a systems approach to improve water quality by presenting a set of indicators but NOT to weight or rank these against each other (Hirschfield et al. 2011).
* To define areas where economically important loss is likely by transparently displaying the methods for combining areas of potential pest establishment with areas at highest risk from pest impacts (Baker et al. 2012).
* To determine relative likelihood for key livestock diseases, by combining likelihood of disease introduction establishment and spread (East et al. 2013).
* To help target investment to improve soil quality in New South Wales by mapping areas that are most likely to experience irreversible damage to soil condition (Lobry de Bruyn 2013).
* To model wind erosion for Australia for prioritisation of national Landcare investment (Leys et al. 2017).
* To map important agricultural lands in the Low Hunter Region of NSW (Hunter Councils, 2013).
* To target investment to improve water quality in the Great Barrier Reef by combining information on the risk to marine assets (corals, sea grasses) from land-based contaminants, and the potential for improvement or solvability (Australian Government 2014).

### Applying the steps in the multi-criteria analysis framework

Applying the 5-step multi-criteria (MCA) process (informed by the Department for Communities and Local Government UK 2009):

**1. Define the problem and context, and identify the components for evaluation**

The decision context includes the administrative, political, historical and social structures that surround the decision being made. Who will be making the decision? Who will be affected? MCA is all about multiple conflicting objectives. There are ultimately trade-offs to be made. Deciding on how much time and effort to invest in the MCA process is also important. How will this activity make a difference to the decision?

a. Objective – what is the overall ambition?

b. Criteria – these are measures of performance by which the options will be judged. Grouping input data by criteria can help you check whether criteria are relevant to the objective, simplify the weighting process, create a hierarchy of importance, and broaden your view. If you don’t include many input data you may decide not to group them.

i. Start by asking ‘What would the difference be between a good choice and a bad choice for my objective?’

ii. Be specific – vague criteria are not useful in MCA.

iii. Keep the number of criteria low while ensuring a well-founded decision.

c. Inputs (data) – it may be tempting to try to include as much available data as possible or to be biased towards particular sources. Select data instead by relevance to the objective. Sometimes the exact data required may not be available and you will need to decide whether substitutes or surrogates are available or acceptable. This should be documented so that the MCA can be revised if/when new data becomes available.

**2. Assemble or collect data**

You may start with a large list of potential inputs criteria. You will need to refine this list and determine how each input will be ranked or classified to contribute to the objective. It can be useful to repeatedly ask ‘why do we care about that’ to obtain a list of fundamental inputs. Consider:

a. Completeness – is anything important still missing? How will you deal with missing information?

b. Redundancy – are any inputs unnecessary?

c. Contribution – can the contribution to the objective be shown? What units, scale or categories from each input contribute to the objective?

d. Mutual independence of preferences – most simple MCA approaches assume that preferences are independent, that is you can assign weighting to each criteria without

knowing the weight assigned to the others. If this is not true then more advanced MCA approaches may be needed.

e. Double counting – this will give some criteria more weight than they deserve.

f. Number of inputs – keep the number of inputs as low as practical to reach an informed decision. Don’t introduce unnecessary complexity as it will add a lot of time and confusion to the MCA.

g. Timing – what is the timeframe for the outcome? What are the implications of time on the outcome? Is the date of collection of the inputs relevant, consistent and appropriate? Are you considering future impacts? How far into the future?

**3. Explore and combine data**

To complete an MCA, inputs or criteria need to be compared to each other. The simplest way of doing this is by using a matrix.

The matrix can be a simple table with each option listed with ticks and crosses or positive and negative symbols indicating the influence of the input on the objective.

More complex MCAs enable inputs to be ranked, weighted and combined.

The MCAS-S tool applies MCA concepts to spatial data. For MCAS-S to analyse data inputs they must be classified. It is best to bring in data in a ‘raw’ unclassified format and complete the ranking in MCAS-S. This results in a flexible and transparent classification. More information about ranking, classifying assigning weights and combining spatial layers can be found in the [MCAS-S user guide](http://www.agriculture.gov.au/abares/aclump/multi-criteria-analysis/mcas-s-tool).

a. Rank or classify data – try to create a consistent classification system (for example, all inputs range from ‘suitable’ to ‘unsuitable’) and record how this has been decided. Where possible and relevant use reliable sources such as published scientific literature to set class thresholds, label classes and document these decisions. Once all data layers are classified, check the classifications against each other, and against their contribution to the objective. Do any inputs need to be classified in reverse order or have their maximum or minimum values adjusted?

b. Assign weights and combine – MCAS-S provides several different methods for comparing or combining layers. In choosing between these methods consider:

i. How can the input data best inform the objective

ii. Are any inputs critical or ‘deal breakers’

iii. How many inputs are being compared or combined

iv. What is the type of input data being used

v. What information already exists that can inform the combination and weighting method – for example principle components analysis

vi. Who should be involved in this process

vii. What type of answer do you want – for example, yes/no, suitability scale, count of conditions met, shortlist of options, etc.

viii. How will you assess whether the output is appropriate and useful?

**4. Come to a decision: Calculate final score and develop options**

What are the alternative options?

a. Is there a ‘dominant’ option, one which performs at least as well on all criteria and is strictly better on at least one criterion? Do spatial locations exist where all criteria are met? If so, is the area larger or smaller than practical for action?

b. Locations that do not meet all criteria can still show as ‘red’ or ‘suitable’ so it is important to be explicit about what the identified locations mean and check this against the objective.

What is the method for assessing surprising results, whether the analysis is sound, and what the consequences might be? What will happen if the message is unpleasant or unwelcome?

**5. Review; repeat the process to refine**

How was the result of the analysis used? Is any new data now available? Have any assumptions changed? Who should be involved in the review?

### Preparing data for MCAS-S using Geographic Information System (GIS)

MCAS-S version 3.2 comes with a limited number of ready-to-use Australian national map layers. A larger selection of layers is available on the [Australian national map layers web page](http://www.agriculture.gov.au/abares/aclump/multi-criteria-analysis/australian-national-map-layers), and [MCAS-S data portal](http://mcas.auscover.net.au/mcas-s/). MCAS-S users are also likely to want to prepare other data layers and or use a different analysis area.

The basic principles of data preparation are included in the [MCAS-S user guide](http://www.agriculture.gov.au/abares/aclump/multi-criteria-analysis/mcas-s-tool). MCAS-S spatial data must have consistent projection and extent. MCAS-S data for analysis (primary data) must be a raster or gridded data format. As well as primary data for analysis MCAS-S projects also include raster or gridded mask data for restricting the view and for regional reporting, and overlay vector lines and points for context.

Other tools that may be useful include scripts to automate MCAS-S data creation such as New South Wales Office of Environment and Heritage’s [Grid Garage](https://datasets.seed.nsw.gov.au/dataset/grid-garage-arcgis-toolbox) for ArcGIS.