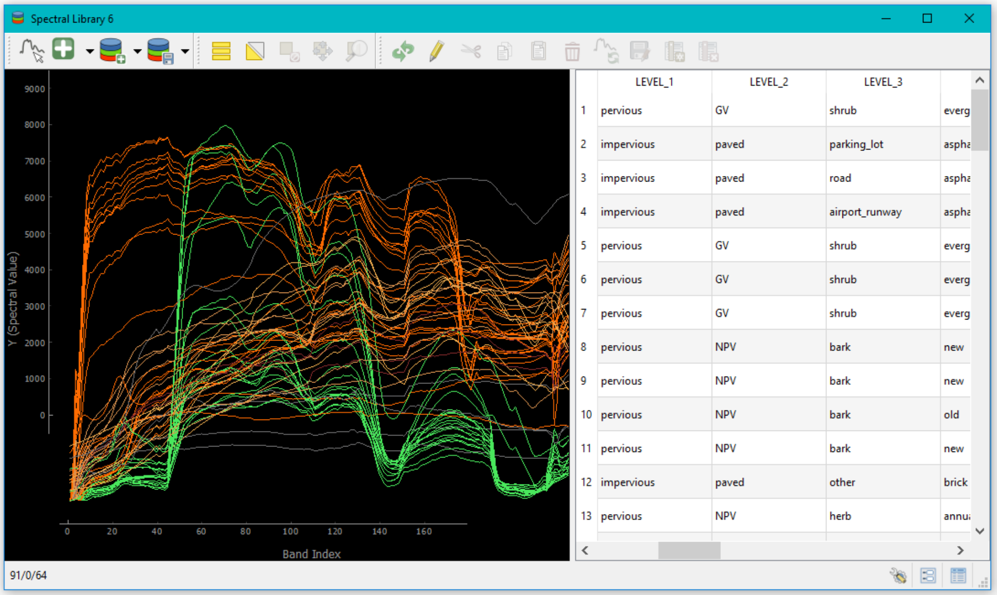
Spectral Library Tool

Release 1.1.3

Dec 13, 2020

Contents



	LEVEL_1	LEVEL_2	LEVEL_3	
1	pervious	GV	shrub	everg
2	impervious	paved	parking_lot	aspha
3	impervious	paved	road	aspha
4	impervious	paved	airport_runway	aspha
5	pervious	GV	shrub	everg
6	pervious	GV	shrub	everg
7	pervious	GV	shrub	everg
8	pervious	NPV	bark	new
9	pervious	NPV	bark	new
10	pervious	NPV	bark	old
11	pervious	NPV	bark	new
12	impervious	paved	other	brick
13	pervious	NPV	herb	annu

91/0/64

CHAPTER 1

Installation Instructions

For issues, bugs, proposals or remarks, visit the issue tracker.

1.1 Installation of QGIS Plugin

The plugin is available in the QGIS Python Plugins Repository:

```
Plugins menu > Manage and install plugins... > All > Search for 'Spectral Library Tool
↪'
```

Alternatively, you can download the latest stable distribution (*spectral-libraries-x-qgis.zip*) and install the plugin manually:

```
Plugins menu > Manage and install plugins... > Install from ZIP > Browse to the zip␣
↪file > Click *Install plugin*.
```

Note: The plugin is build for QGIS Version 3.6 and up. We recommend to use QGIS version 3.10. The plugin has been tested on Windows 10.0, Ubuntu 16.04 and Raspbian GNU/Linux 10 (buster)

1.2 Installation of the python package

Open a shell by running the following batch script (adapt to match with your installation):

```
::QGIS installation folder
set OSGEO4W_ROOT=C:\OSGeo4W64

::set defaults, clean path, load OSGeo4W modules (incrementally)
call %OSGEO4W_ROOT%\bin\o4w_env.bat
```

(continues on next page)

(continued from previous page)

```
call qt5_env.bat
call py3_env.bat

::lines taken from python-qgis.bat
set QGIS_PREFIX_PATH=%OSGEO4W_ROOT%\apps\qgis
set PATH=%QGIS_PREFIX_PATH%\bin;%PATH%

::make PyQGIS packages available to Python
set PYTHONPATH=%QGIS_PREFIX_PATH%\python;%PYTHONPATH%

:: GDAL Configuration (https://trac.osgeo.org/gdal/wiki/ConfigOptions)
:: Set VSI cache to be used as buffer, see #6448 and
set GDAL_FILENAME_IS_UTF8=YES
set VSI_CACHE=TRUE
set VSI_CACHE_SIZE=1000000
set QT_PLUGIN_PATH=%QGIS_PREFIX_PATH%\qtplugins;%OSGEO4W_ROOT%\apps\qt5\plugins

::enable/disable QGIS debug messages
set QGIS_DEBUG=1

::open the OSGeo4W Shell
@echo on
@if [%1]==[] (echo run o-help for a list of available commands & cmd.exe /k) else␣
↪(cmd /c "%*")
```

For command-line interface and stand-alone usage, install the python package with pip:

```
pip install spectral-libraries
```

For offline installation, you can download the latest stable distribution (*spectral-libraries-x.tar.gz*) and

```
C:\WINDOWS\system32>cd C:\Users\UserName\Downloads
C:\Users\UserName\Downloads>pip install spectral-libraries-x.tar.gz
```

CHAPTER 2

User Guide

The Spectral Library Tools can be used in several ways:

1. As a plugin in QGIS
2. As a command line interface in a terminal
3. Adapting the code to fulfil very specific needs

For the last option, we refer the user to the code repository and the API at the end of this document.

For issues, bugs, proposals or remarks, visit the issue tracker.

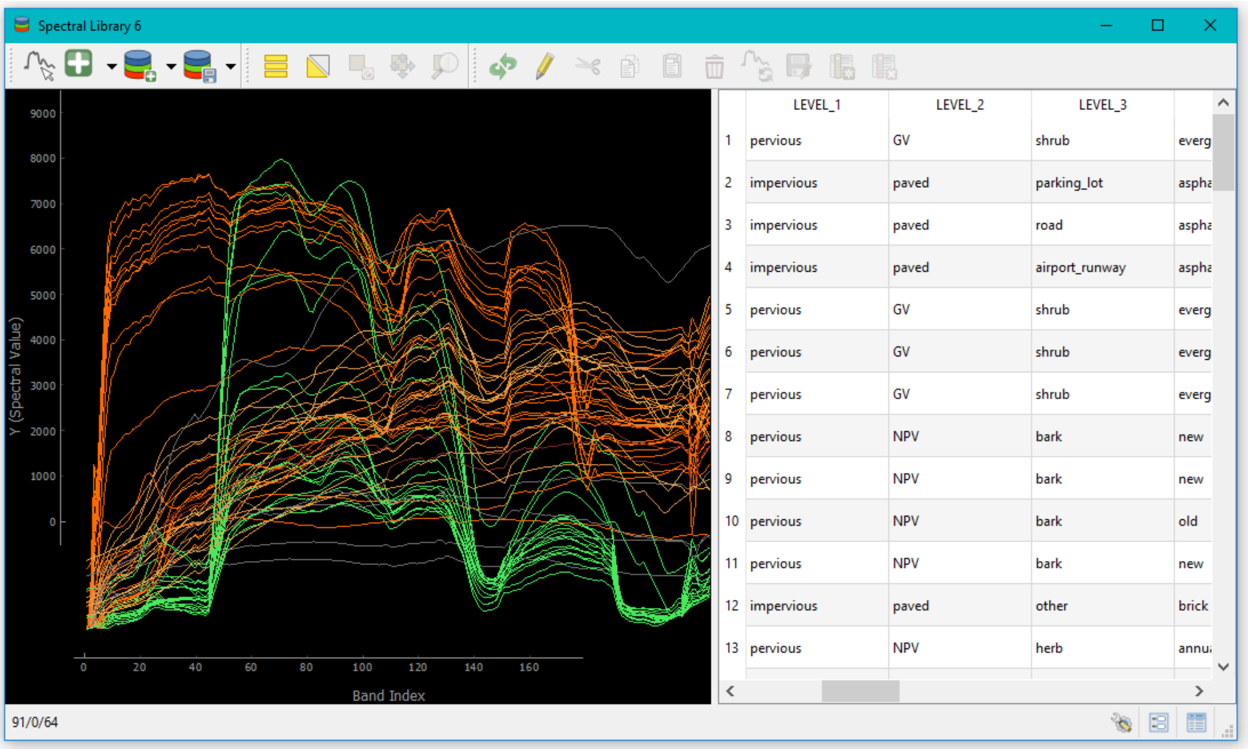
2.1 Creating/Editing a Spectral Library

So far, QGIS has no functionality for creating, viewing or editing spectral libraries. For that reason, we had to build this tool ourselves. It has several functions:

- Create a Spectral Library by manually selecting spectra from an image
- Create a Spectral Library by using Regions Of Interest (polygons/points)
- Open and inspect a Spectral Library
- Edit the metadata of a Spectral Library
- Remove profiles from the Spectral Library
- . . .

It speaks for itself that a thorough understanding of the research area is required to be able to build a Spectral Library from it.

The table below gives a short overview of all **Spectral Library specific buttons** and their function:



	LEVEL_1	LEVEL_2	LEVEL_3	
1	pervious	GV	shrub	everg
2	impervious	paved	parking_lot	aspha
3	impervious	paved	road	aspha
4	impervious	paved	airport_runway	aspha
5	pervious	GV	shrub	everg
6	pervious	GV	shrub	everg
7	pervious	GV	shrub	everg
8	pervious	NPV	bark	new
9	pervious	NPV	bark	new
10	pervious	NPV	bark	old
11	pervious	NPV	bark	new
12	impervious	paved	other	brick
13	pervious	NPV	herb	annu

91/0/64

	Select a new profile from a (hyperspectral) image
	Add the currently overlaid profiles to the **Spectral Library**
	Automatically add selected profiles to the Spectral Library
	Import Spectral Library
	Import profiles from **raster + vector source**
	Save the current Spectral Library to file
	Use **colors** from map vector symbology

All other buttons are inherent to QGIS, but here is a short overview:

	Toggle editing mode
	Toggle multi-edit mode
	Save edits
	Reload the table
	Add feature
	Delete selected features
	Cut selected rows to clipboard
	Copy selected rows to clipboard
	Paste features from clipboard
	Select features using an expression
	Select all
	Invert selection
	Deselect all
	Move selection to top
	Select/filter features using form
	Pan map to the selected rows
	Zoom map to the selected rows
	New field
	Delete field
	Conditional formatting
	Actions
	Form View
	Table View
	Show Spectral Library Properties

Note: This is a highly interactive tool and has **no command line** equivalent.

2.1.1 Create Spectral Library manually

In order to select spectra from an image, first load an hyperspectral image in QGIS.

- Toggle the **Select Profile** button .
- Click on a random pixel in the image to view a profile in the **plot window**. This profile is not automatically kept, and you can click as many times as you want in the image, until you find a good profile.
- Click on the **Add** button to add the last profile to your **Spectral Library**.
- If you check the **Auto** button all selected profiles are automatically added to the spectral library.
- To **remove** a profile, select it in the attribute table and use the **Delete** button . In order to do so, you must first toggle editing mode and afterwards save your edits by clicking again on .
- You can now edit the profile metadata, add or remove non-compulsory fields and zoom/pan to your selection on the image.
- Use the settings tool to change the colors of your profiles (according to a metadata element).

Hint: You can view a subset of your data by only setting layer properties for a subset of classes! The spectral library behaves like a point shape file and so the styling behaves accordingly.

2.1.2 Create Spectral Library from ROI's

To start with this step, you need a **ROI (Regions Of Interest)** file. This is a **QGIS Vector Layer**, with each feature representing an unmixing class (e.g. Pine trees). These classes, and other metadata, should be included in the attribute table.

- Make sure both the image and ROI file are open in QGIS.
- Click on *Import profiles from raster + vector source* : a small popup window will ask you to select the correct raster and vector files. The **All touched** options allows the user to choose between importing only pixels that lie completely within the ROI's, or also import pixels that are partly touched by the ROI's boundaries.
- You can now edit the profile metadata, add or remove non-compulsory fields and zoom/pan to the selection on the image.

Note: A Spectral Library will copy the attribute table of the ROI Vector Layer, it is therefore essential that it does not contain the following **protected fields**: 'fid', 'name', 'source', 'values' or 'style'.

The attribute table of the ROI Vector Layer **must contain an 'ID' field** (spelled with all capitals) with unique integer values.

2.1.3 Open existing Spectral Library

To open an existing Spectral Library, use the **Open Library** button .

2.1.4 Save Spectral Library to file

To save the current Spectral Library use the **Save Library** button .

Note: All changes made to the Spectral Library exist in memory only, until they are saved to file.

ACKNOWLEDGMENTS

This user guide is very loosely based on the VIPER Tools 2.0 user guide (UC Santa Barbara, VIPER Lab): Roberts, D. A., Halligan, K., Dennison, P., Dudley, K., Somers, B., Crabbe, A., 2018, Viper Tools User Manual, Version 2, 91 pp.

The Spectral Library tool was created for the most part at HU Berlin, by B. Jakimow. More information on the source code: https://bitbucket.org/jakimowb/qgispluginsupport.

For issues, bugs, proposals or remarks, visit the issue tracker.

2.2 Spectral Library Optimization

The Spectral Library Tool includes three basic library pruning techniques: **EMC**, **IES** and **CRES**. EMC and IES rely on a square array. This is implemented in the background, however the option is left to the user to explore this square array, in order to get a better understanding of the inner workings of IES and EMC.

2.2.1 Square Array

A **square array** is a way of storing how a specific endmember performs when used to unmix all other spectra in the same library.

A square array is an image of n by n pixels, with n being the number of spectra in the Spectral Library. In this square array, a row corresponds to a spectrum (row = model) used to unmix all other spectra in the library (columns).

The square array is used to store metrics needed for EAR, MASA, CoB and IES. The original format of the square array was proposed by Roberts et al. [Roberts1997] and included in several theses published at UCSB ([Gardner1997], [Halligan2002]).

Square arrays are stored as an ENVI image, with the following possible bands: RMSE, Spectral Angle, Endmember Fraction, Shade Fraction and a 'Constrained' band which indicates if the model met the constraints used.

The diagonal represents each spectrum modelling itself and is meaningless so it has been zeroed out for all output bands.

A detailed description of the Square Array Output Bands

RMSE

The RMSE at row A and column B is the root mean square error of spectrum A modelling spectrum B. RMSE is calculated using the following equation:

$$\text{RMSE} = \left(\sum_{k=1}^{\lambda} (\varepsilon_{i\lambda})^2 \Big/ \text{N} \right)^{1/2}$$

RMSE images are not symmetrical about the diagonal (see endmember fraction description below).

Note: The % RMSE is independent of the reflectance scale factor (1, 1000 or 10000), because all data is converted to values between 0 and 1 before Square Array calculations.

Spectral Angle

Spectral Angle at row A and column B is the angular distance, in radians, between spectrum A and spectrum B. This is the same metric used by ENVI's Spectral Angle Mapper (SAM) and is calculated as:

$$\text{spectral angle} = \cos^{-1} \sum \frac{A}{\sqrt{\sum A^2}} \times \frac{B}{\sqrt{\sum B^2}}$$

Where A and B are vectors containing the spectral data for spectrum A and B

For spectral angle, the square array will be symmetrical about the diagonal.

Endmember Fraction

The endmember fraction band at row A and column B is the SMA fraction for endmember A when used to model spectrum B.

These images are not symmetrical about the diagonal, because brightness differences contribute to differences in SMA fractions and model RMSE. When bright spectrum A models dark spectrum B the SMA fraction will be between 0 and 100%, and the RMSE will be calculated as the difference between the spectra at the brightness of the darker spectrum B. When dark spectrum B models bright spectrum A the SMA fraction will be greater than 100% and the RMSE will be calculated from the difference between the spectra at the brightness of the brighter spectrum A, and thus will be a larger RMSE than the previous case.

Shade Fraction

The shade fraction at row A and column B is the SMA shade fraction for endmember A when used to model spectrum B. It is calculated as 1 minus the endmember fraction, and is included to allow for shade thresholding in the EMC calculations.

Constraint Code

When calculating the fractions and RMSE, constraints can be used.

1. Unconstrained: It is allowed to have super positive (>100%) or negative (<0%) fractions or high RMSE values. There will be no 'constraints' band in the output.
2. Constrained, non-reset: Thresholds can be set for minimum and maximum fractions and for RMSE. When either the fractions or the RMSE are exceeded, a value is stored in the 'constraints' band (see below). The fractions and RMSE themselves stay unchanged.

   Default values of -0.05, 1.05 and 0.025 for minimum fraction, maximum fraction and RMSE threshold, respectively, represent values used in the literature ([Halligan2002], [Roberts2003]).

   The minimum fraction constraint cannot be set below -0.50, the maximum fraction constraint cannot exceed 1.50, and the maximum RMSE constraint cannot exceed 0.10.
3. Constrained, reset: When fractions exceed the constraint, the fractions in the output are reset to the threshold values. The RMSE is then calculated with these new fraction values instead of the original ones. The 'constraints' band now stores different values.

   This is useful for allowing models with very good fit to be included despite being slightly too dark. For example, spectrum A might be a well-fit spectrum for modelling spectrum B, but would produce a fraction of 106% (1.06) because it is darker than spectrum B. If running in non-reset mode with the maximum allowable fraction set to 105% (1.05), this model would be excluded completely because it exceeds the threshold. In reset mode this model would be run forcing the bright endmember to have a 105% fraction. The resulting RMSE would be slightly higher (due to a slight underestimate of the bright endmember fraction) but would not be excluded. It may even be possible that spectrum A will produce the lowest EAR value for the library, suggesting it is an optimal endmember despite the fact that it is fairly dark.

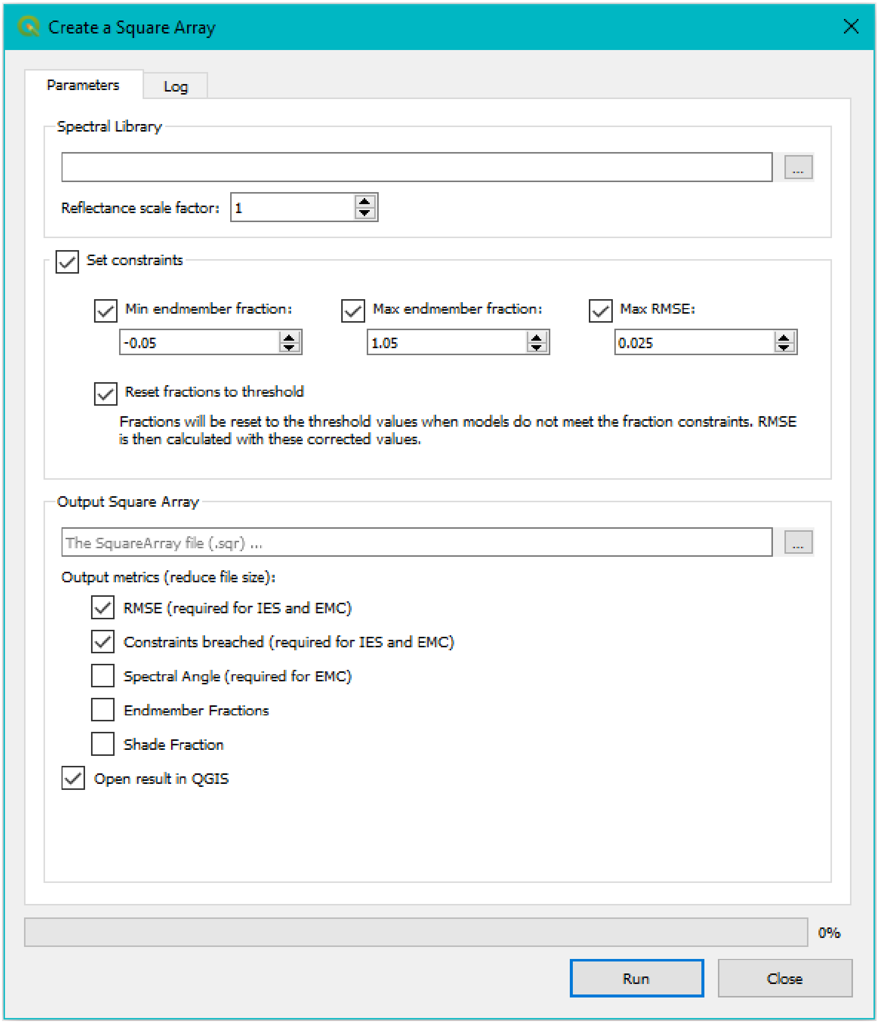
An overview of the possible values of the constraints band.

- 0 = no constraint breach
- 1 = fraction constraint breach + fraction reset + no RMSE constraint breach
- 2 = fraction constraint breach + no fraction reset + no RMSE constraint breach
- 3 = no fraction constraint breach + RMSE constraint breach
- 4 = fraction constraint breach + fraction reset + RMSE constraint breach
- 5 = fraction constraint breach + no fraction reset + RMSE constraint breach

QGIS GUI

Note: A square array is required for IES and EMC. EMC requires at least the RMSE and Spectral Angle bands. IES requires the RMSE and Constraints bands.

1. Select the input spectral library. Note that this library must have metadata attached to it and it is best sorted in a way to assist interpretation of the square array.
2. The reflectance scale factor is automatically detected.



Spectral Library

Reflectance scale factor: 1

☑ Set constraints

☑ Min endmember fraction: -0.05

☑ Max endmember fraction: 1.05

☑ Max RMSE: 0.025

☑ Reset fractions to threshold

Fractions will be reset to the threshold values when models do not meet the fraction constraints. RMSE is then calculated with these corrected values.

Output Square Array

The SquareArray file (.sqr) ...

Output metrics (reduce file size):

☑ RMSE (required for IES and EMC)

☑ Constraints breached (required for IES and EMC)

☐ Spectral Angle (required for EMC)

☐ Endmember Fractions

☐ Shade Fraction

☑ Open result in QGIS

> **Note:** Spectral data can be saved to file as **reflectance values** (i.e. values between 0 and 1) or the data can be multiplied by a **scale factor** (usually by 1000 or 10000). This is done to be able to store the data as integer values (no comma's), because integers require less memory. Although this is more efficient storage-wise, it has as a result we have to divide the data values again before processing.
>
> The software tries to **auto detect** this scale factor, but does not always succeed. Double check this value before continuing.

3. Select if you want to use constraints for the SMA algorithm or not.
   - Deselect the constraints-box to calculate the fraction and RMSE metrics without constraints. There will be no 'constraints' band in the output.
   - Select the constraints-box to calculate the fraction and RMSE metrics with constraints. Thresholds can be set for minimum and maximum fractions and for RMSE.
   - Select or deselect the 'reset' box to use the constraints in reset mode or non-reset mode.
4. Select an output filename. A default name is created for you with the structure *libraryName_sq.sqr*. Optionally, you can add the constraint parameters. Example: *name_-5_105_2pt5_sq.sqr* for constraints of -5%, 105% and 2.5%.
5. Select the output metrics of your choice: *RMSE*, *Fraction*, *Shade Fraction*, *Spectral Angle* and *Constraints*

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.

Command Line Interface

The main command is:

```
>square
```

Use `-h` or `--help` to list all possible arguments:

```
>square -h
```

Only the **spectral library** file is a **required argument**. An example:

```
>square "C:\Users\...\Data\spectral_library.sli"
```

All the other inputs are optional. Use `--reflectance-scale` to set the reflectance scale factor. It can also be automatically derived from the library image as 1, 1 000 or 10 000:

```
>square "C:\Users\...\Data\spectral_library.sli" --reflectance-scale 255
```

By default, the constraints are set at -0.05 (minimum fraction), 1.05 (maximum fraction) and 0.025 (maximum RMSE). Use `--min-fraction`, `--max-fraction` and `--max-rmse` arguments to change these values. To set no constraint for a given variable, use the value -9999. To use no constraints at all, use the argument `-u` or `--unconstrained`:

```
>square "C:\Users\...\Data\spectral_library.sli" --max-fraction 1.10 --max-rmse -9999
>square "C:\Users\...\Data\spectral_library.sli" -u
```

By default, the constraints are used in *reset mode* (see explanations before). To turn this option off, use the argument `-r` or `--reset-off`:

```
>square "C:\Users\...\Data\spectral_library.sli" -r
```

By default, the output file is stored in the same folder as the input file, with the extension '_sq.sqr'. To select another file or another location, use the argument `-o` or `--output`:

```
>square "C:\Users\...\Data\spectral_library.sli" -o "C:\Users\...\Desktop\square_
↪array.sqr"
```

By default, the following metrics are added to the output: RMSE and Constraints. The Fractions, Shade Fraction and Spectral Angle are not included by default. Use the following arguments are to reverse these settings: `--exclude-rmse`, `--exclude-constraints`, `--include-fractions`, `--include-shade`, `--include-angle`:

```
>square "C:\Users\...\Data\spectral_library.sli" --include-fractions --include-angle
```

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.

2.2.2 EAR, MASA, CoB (EMC)

We use the Square Array to determine which spectra within a group of spectra are most representative of their class while covering the range of variability within the class. There are three approaches to do this:

Count based Endmember selection (CoB) was first proposed by Roberts et al. [Roberts2003]. Optimal endmembers are selected as those members of a library that model the greatest number of spectra within their class. Candidate models are assessed by whether they meet fraction and RMSE constraints when unmixing other spectra in the library (stored in the Square Array *constraints* band).

- The metric *in_CoB* stores the total number of spectra modelled within the class.
- The metric *out_CoB* stores the total number of spectra modelled outside of the class

The optimum model is selected as the one that has the highest *in_CoB* value. Note that ties are not split in this process, so several spectra can have the same *in_CoB* value.

To determine additional CoB selections, the Spectral Library Tool implements the approach described by Clark [Clark2005]: once an initial optimal spectrum (or spectra, in the case of ties) is selected, all members of the spectral library that were successfully modelled by this spectrum/spectra are culled from the list of candidate CoB spectra. After culling, a second tier *in_CoB* is calculated and a second tier, optimal spectrum/spectra is selected. This process continues until all candidate spectra have been eliminated, either by being selected as an optimal spectrum or by being modelled by an optimal spectrum.

Out_CoB provides a measure of confusion between classes, with a high value suggesting significant confusion between classes. Ideally, the perfect spectrum will only model members of its class, and not model members outside of its class. This model would have a high *in_CoB*, but low *out_CoB*.

To assess the generality of a spectrum we include a third performance metric, the *Count Based Index (CoBI)* [Clark2005]. *CoBI* is the ratio of *in_CoB* to *out_CoB* with the denominator multiplied by the number of spectra within a class.

Thus a high *CoBI* and a high *in_CoB* represents an excellent choice (A specialist as described by Roberts et al. [Roberts1997]. A high *CoBI* and moderately low *in_CoB* may also be a good candidate because it captures a member of a class that is spectrally unique, even if it is not well represented in the library. Low values of *CoBI* would only be acceptable if they were paired with a high *in_CoB* (Generalists).

Endmember Average RMSE (EAR) was first proposed by Dennison and Roberts [Dennison2003] as a means of locating spectra within a class that provide the best fit when modelling that class. *EAR* is the average *RMSE* produced by a spectrum when it is used to model all other members of the same class. The optimum spectrum would be the one that produces the lowest average RMSE.

Minimum Average Spectral Angle (MASA) [Dennison2004] is similar to EAR in that it is designed to select spectra with the best average fit within a class. It differs from EAR in that the measure of fit used is the spectral angle, not the RMSE.

MASA within a class is calculated as the average spectral angle between a candidate model and all other spectra within the same class. The best MASA candidate produces the lowest average spectral angle.

EAR and **MASA** are conceptually very similar. However, the optimum endmember selected by each metric will depend on the overall brightness of the library. For example, for dark objects, subtle spectral differences between the reference and non-reference spectra could result in a fairly large spectral angle. At the same time, these subtle spectral differences would result in a small RMSE. The net result is that MASA will be far more sensitive to spectral differences for dark objects. For bright objects, the opposite is true. In this case, even a fairly large spectral feature may produce a small difference in spectral angle, but a large difference in RMSE, and EAR would be more sensitive to spectral differences. For further discussion of the differences between RMSE and spectral angle as metrics of spectral fit see Dennison et al [Dennison2004]. Despite differing sensitivities for darker and brighter endmembers, one endmember will frequently possess both the minimum EAR and MASA values.

Note: The strength of any particular selection technique will vary with the metadata field. For example, whereas EAR or MASA may outperform CoB for homogeneous selection criteria, such as dominant, CoB may outperform these measures for heterogeneous selection criteria, such as impervious/pervious. Calculating the EMC file is also critical when choosing the hierarchical level for your selections. For example, if a user were most interested in separating impervious from pervious surfaces, they might opt to sort on impervious/pervious when creating the EMC file. A different user might be interested in separating urban materials, and thus would sort on the material scale.

QGIS GUI

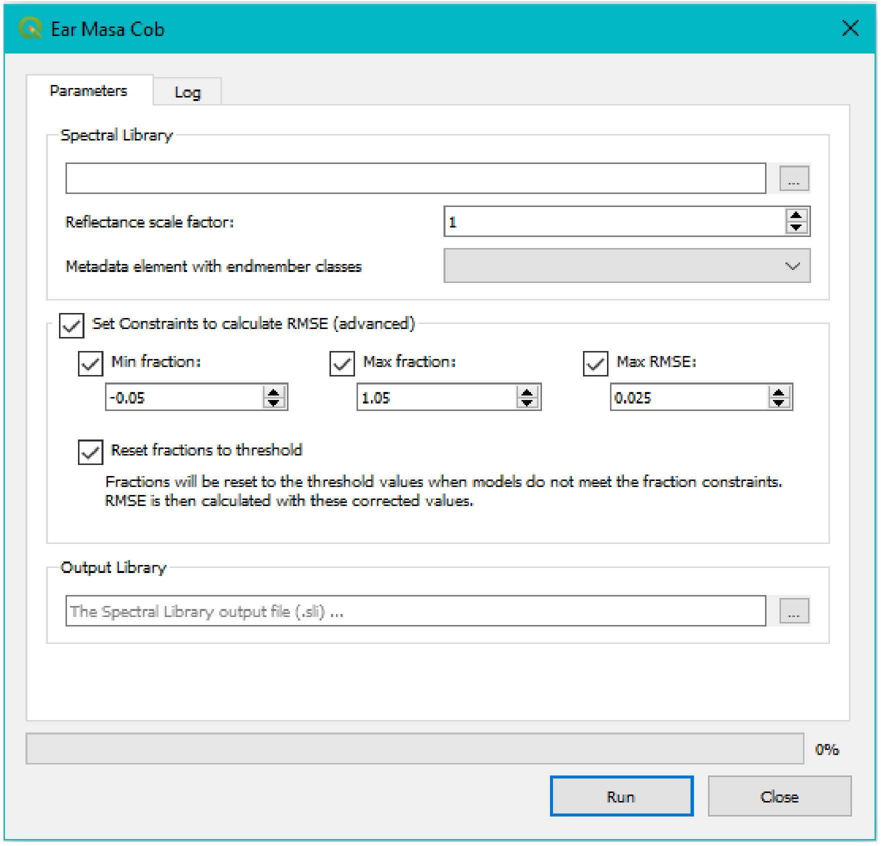
1. Select the input spectral library. Note that this library must have metadata attached to it and it is best sorted in a way to assist interpretation of the square array.
2. The reflectance scale factor is automatically detected.

   > **Note:** Spectral data can be saved to file as **reflectance values** (i.e. values between 0 and 1) or the data can be multiplied by a **scale factor** (usually by 1000 or 10000). This is done to be able to store the data as integer values (no comma's), because integers require less memory. Although this is more efficient storage-wise, it has as a result we have to divide the data values again before processing.
   >
   > The software tries to **auto detect** this scale factor, but does not always succeed. Double check this value before continuing.

3. Select the metadata element that divides the spectra in the library into classes.
4. Select if you want to use constraints for the SMA algorithm or not.
   - Deselect the constraints-box to calculate the fraction and RMSE metrics without constraints. There will be no 'constraints' band in the output.
   - Select the constraints-box to calculate the fraction and RMSE metrics with constraints. Thresholds can be set for minimum and maximum fractions and for RMSE.
   - Select or deselect the 'reset' box to use the constraints in reset mode or non-reset mode.
5. Select an output filename. A default name is created for you with the structure *libraryName_emc.sli*.

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.



Spectral Library

Reflectance scale factor: 1

Metadata element with endmember classes

☑ Set Constraints to calculate RMSE (advanced)

☑ Min fraction: -0.05

☑ Max fraction: 1.05

☑ Max RMSE: 0.025

☑ Reset fractions to threshold

Fractions will be reset to the threshold values when models do not meet the fraction constraints.
RMSE is then calculated with these corrected values.

Output Library

The Spectral Library output file (.sli) ...

0%

Command Line Interface

The main command is:

```
>emc
```

Use `-h` or `--help` to list all possible arguments:

```
>emc -h
```

Only the **spectral library** file and the **class name** are **required arguments**. An example:

```
>emc "C:\...\Data\spectral_library.sli" LEVEL_2
```

Use `-r` or `--reflectance-scale` to set the reflectance scale factor (only in case you calculate the square array on the fly). It can also be automatically derived from the library image as 1, 1 000 or 10 000:

```
>emc "C:\...\Data\spectral_library.sli" LEVEL_2 -q "C:\...\Data\square_array.sqr" -r␣
↪255
```

By default, the constraints are set at -0.05 (minimum fraction), 1.05 (maximum fraction) and 0.025 (maximum RMSE). Use `--min-fraction`, `--max-fraction` and `--max-rmse` arguments to change these values. To set no constraint for a given variable, use the value -9999. To use no constraints at all, use the argument `-u` or `--unconstrained`:

```
>emc "C:\...\Data\spectral_library.sli" LEVEL_2 --max-fraction 1.10 --max-rmse -9999
>emc "C:\...\Data\spectral_library.sli" LEVEL_2 -u
```

By default, the constraints are used in *reset mode* (see explanations before). To turn this option off, use the argument `-r` or `--reset-off`:

```
>emc "C:\...\Data\spectral_library.sli" LEVEL_2 -r
```

By default, the output file is stored in the same folder as the input file, with the extension '_emc.sli'. To select another file or another location, use the argument `-o` or `--output`:

```
>emc "C:\...\Data\spectral_library.sli" LEVEL_2 -q "C:\...\Data\square_array.sqr" -o
↪"C:\...\Data\emc_library.sli"
```

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.

2.2.3 Iterative Endmember Selection (IES)

Iterative Endmember Selection (IES) is a semi-automated approach for selecting optimal endmember subsets. IES was originally proposed by Schaaf et al. [Schaaf2011] then updated by Roth et al. [Roth2012]. The basic concept of IES is to identify the subset of spectra within a spectral library that provide the best class separability when MESMA is used as a two-endmember classifier. IES operates by first identifying the spectrum within a library that provides the highest classification accuracy as quantified using the kappa coefficient. This endmember would belong to the most commonly represented class in the library. Next, it identifies the endmember which, in combination with the first choice, generates the highest kappa. In the next iteration, it repeats, adding a third endmember. As it continues to iterate, it also tests all previous endmember selections to determine whether removing an endmember increases kappa. IES continues to iteratively add, and subtract spectra until the kappa coefficient no longer improves.

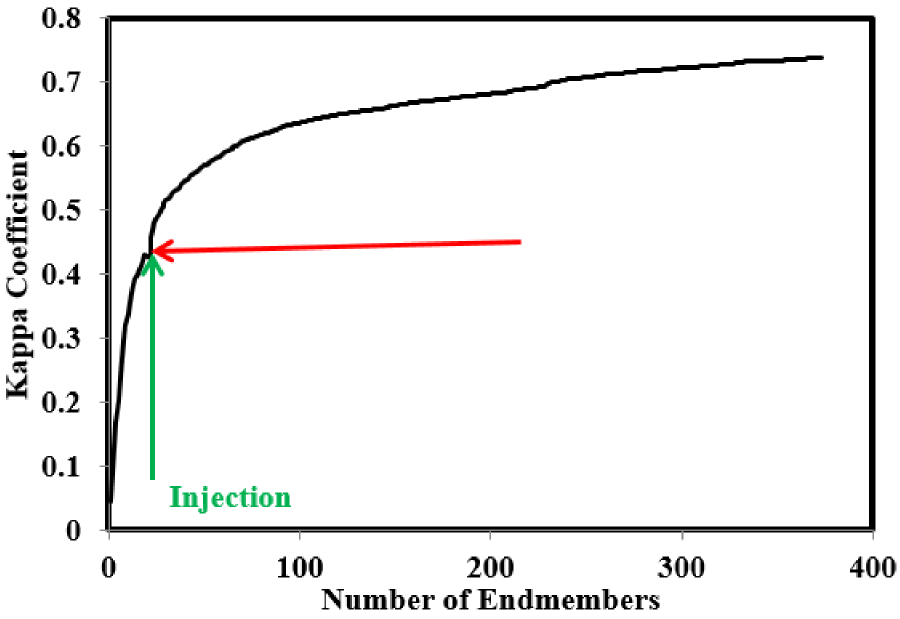
The Spectral Library Tool also includes a modified form of IES, called **Forced IES**, in which rare endmembers can be identified in a library. Forced IES, which was originally proposed by Roth et al. [Roth2012], is needed when an endmember class is rare, but also important. Because it is rare, IES does not identify an endmember belonging to the class if it results in a decrease in kappa. You can use another endmember selection tool, such as EMC, to identify the best representative spectra from the rare class. One or more of these user-selected endmembers is then injected into the endmember selection process after a set number of iterations, forcing IES to identify an optimal subset that also includes the forced endmembers. As shown below, initially forcing the endmember results in a decrease in Kappa, but IES rapidly identifies models that increase accuracy, iterating until accuracy no longer improves. IES tends to generate much larger spectral libraries than EMC, but also results in higher classification accuracies.

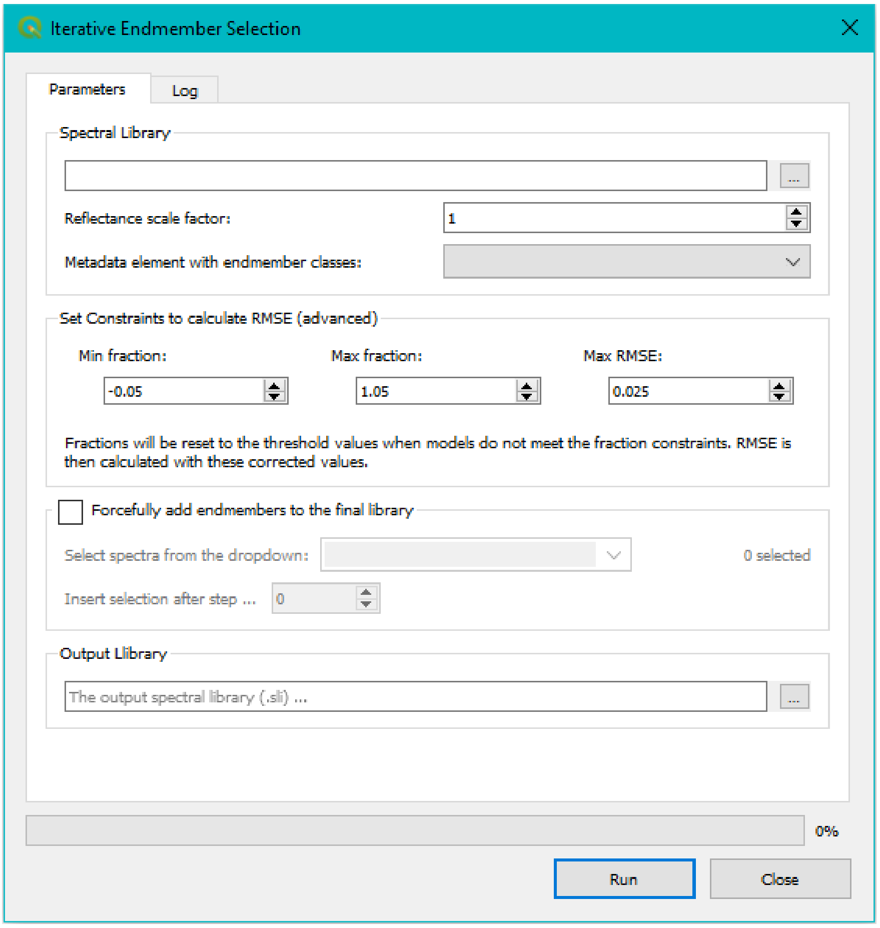
IES was used by Roberts et al. ([Roberts2012]; [Roberts2017]) to discriminate urban surface materials, map plant species and estimate fractional cover in the Santa Barbara area, using MASTER to evaluate the relationship between cover, species and land surface temperature ([Roberts2015]). Other applications of IES included creating multi-temporal libraries for mapping vegetation species ([Dudley2015]) and improved mapping of fire severity ([Fernandez2016]; [Quintano2017]). Roth et al. [Roth2015] evaluated the performance of IES across a diversity of North American ecosystems, finding that Linear Discriminant Analysis (LDA) using Canonical Discriminant Analysis (CDA) was a superior classifier, but MESMA classification results could be improved using dimensionality reduction, such as CDA.

QGIS GUI

1. Select the input spectral library. Note that this library must have metadata attached to it and it is best sorted in a way to assist interpretation of the square array.
2. The reflectance scale factor is automatically detected.

> **Note:** Spectral data can be saved to file as **reflectance values** (i.e. values between 0 and 1) or the data can be multiplied by a **scale factor** (usually by 1000 or 10000). This is done to be able to store




Iterative Endmember Selection

Parameters | Log

Spectral Library

Reflectance scale factor: 1

Metadata element with endmember classes:

Set Constraints to calculate RMSE (advanced)

Min fraction: -0.05

Max fraction: 1.05

Max RMSE: 0.025

Fractions will be reset to the threshold values when models do not meet the fraction constraints. RMSE is then calculated with these corrected values.

□ Forcefully add endmembers to the final library

Select spectra from the dropdown: 0 selected

Insert selection after step ... 0

Output Llibrary

The output spectral library (.sli) ...

0%

the data as integer values (no comma's), because integers require less memory. Although this is more efficient storage-wise, it has as a result we have to divide the data values again before processing.

The software tries to **auto detect** this scale factor, but does not always succeed. Double check this value before continuing.

3. Select the metadata element that divides the spectra in the library into classes.
4. Select the constraints for the fractions and the RMSE.
5. In case you want to use **Forced IES**:
   1. Select them from the drop-down menu.
   2. Indicate in which step you would like to include them. Mind that if the step larger than the final selection, the spectra might not be included in the final result.
6. Select an output filename. A default name is created for you with the structure *libraryName_ies.sli*.

While the IES algorithm is running, the user gets reports on the progress (adding and removing spectra) on the log screen.

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.

Command Line Interface

The main command is:

```
>ies
```

Use `-h` or `--help` to list all possible arguments:

```
>ies -h
```

Only the **spectral library** file and the **class name** are **required arguments**. An example:

```
>ies "C:\...\Data\spectral_library.sli" LEVEL_2
```

Use `-r` or `--reflectance-scale` to set the reflectance scale factor (only in case you calculate the square array on the fly). It can also be automatically derived from the library image as 1, 1 000 or 10 000:

```
>ies "C:\...\Data\spectral_library.sli" LEVEL_2 -q "C:\...\Data\square_array.sqr" -r␣
↪255
```

By default, the constraints are set at -0.05 (minimum fraction), 1.05 (maximum fraction) and 0.025 (maximum RMSE). Use `--min-fraction`, `--max-fraction` and `--max-rmse` arguments to change these values:

```
>ies "C:\...\Data\spectral_library.sli" LEVEL_2 --max-fraction 1.0 --max-rmse -0.015
```

In case you want to use **Forced IES**, use the argument `-f` or `--forced-selection` with an array with indices of the library spectra that should be forcefully added to the selection. Use the argument `-g` or `--forced-step` to indicate after which step the endmembers should be added to the selection:

```
>ies "C:\...\Data\spectral_library.sli" LEVEL_2 -q "C:\...\Data\square_array.sqr" -f␣
↪3 4 25 26 33 -g 1
```

By default, the output file is stored in the same folder as the input file, with the extension '_ies.sli'. To select another file or another location, use the argument `-o` or `--output`:

```
>ies "C:\...\Data\spectral_library.sli" LEVEL_2 -q "C:\...\Data\square_array.sqr" -o
↪"C:\...\Data\ies_library.sli"
```

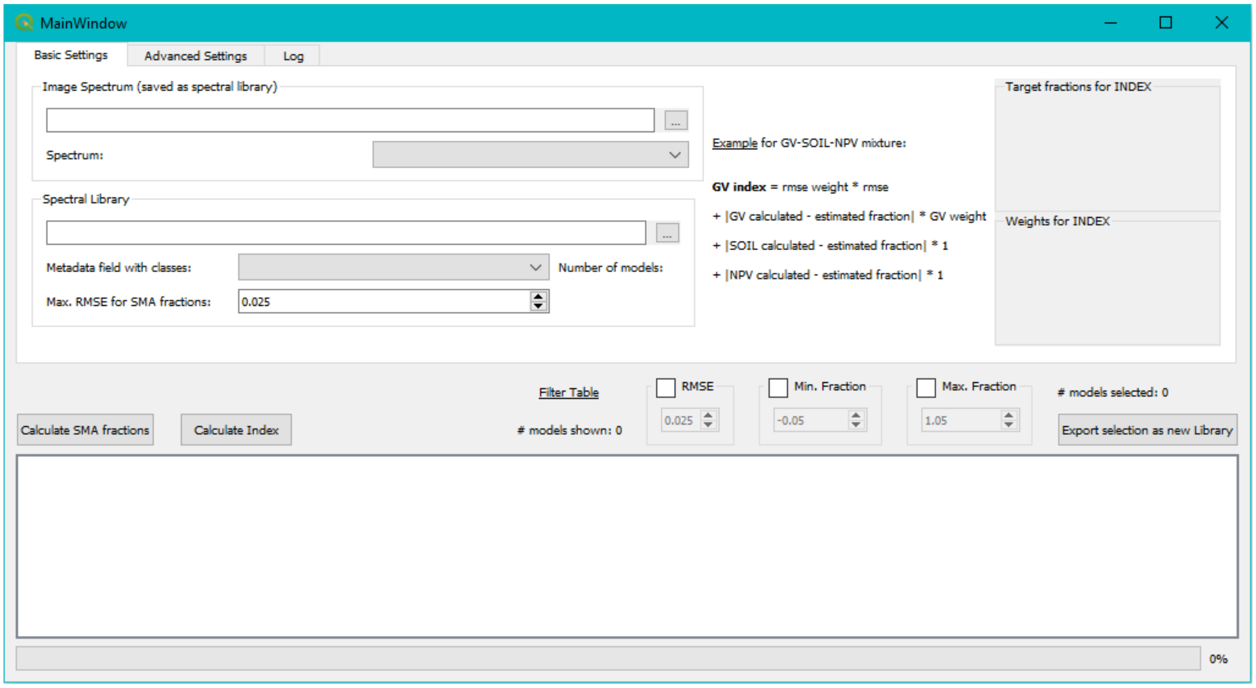
Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.

2.2.4 Constrained Reference Endmember Selection (CRES)

The CRES module represents an alternative approach to endmember selection. With CRES a user supplies expert knowledge on the expected SMA fractions at a particular location in order to select the optimal endmembers for that site. This approach was first described by Roberts et al. [Roberts1993] and later discussed in more detail in Roberts et al. [Roberts1998]. It has been used extensively in a number of papers published out of the VIPER group to select optimum endmembers for simple spectral mixture analysis ([Roberts2002], [Roberts2004]). CRES is a tool that aids the user to see which endmembers will produce SMA fractions that produce the closest match to the estimated fractions.

QGIS GUI



Max. RMSE for SMA fractions: 0.025

Example for GV-SOIL-NPV mixture:

GV index = rmse weight * rmse

+ |GV calculated - estimated fraction| * GV weight

+ |SOIL calculated - estimated fraction| * 1

+ |NPV calculated - estimated fraction| * 1

□ RMSE 0.025

□ Min. Fraction -0.05

□ Max. Fraction 1.05

models shown: 0

models selected: 0

1. Select the *spectral library* containing the spectra you would like to unmix. This library should consist of *image spectra* for which field estimates of fractional abundance of the known classes (e.g. green vegetation, soil, and non-photosynthetic vegetation) are available. The library can be of any size, but only one spectrum at a time will be assessed with CRES.
2. Once the library has been selected, select the spectrum to be assessed from the drop down list.
3. Select the input spectral library. Note that this library must have metadata attached to it.
4. Select the metadata element that divides the spectra in the library into classes.

5. The reflectance scale factor is automatically detected, but can be changed on the *Advanced* tab.
6. Select the unmixing RMSE constraint.
7. On the advanced tab, it is possible to include non-photometric shade.
8. To calculate SMA fractions and RMSE, click *Calculate SMA fractions*. Do this step only once.

   Note: The table will now be filled with the SMA results (fractions and RMSE) for all models that meet the RMSE constraint. Models are identified by the spectra names.

9. Enter estimates of the endmember fraction under the label *Target fractions for INDEX*.

   These estimated fractions may come from field data, expert knowledge or from some other ancillary data. These values are a critical component of CRES, as the main goal is to find the spectra that produce the closest fit to these endmember fraction estimates. Depending on the quality of your initial estimates, you are likely to adjust the fractions.

10. Enter weights for the indices calculations.

    Example for the GV-index in a GV-SOIL-NPV mixture:

    ```
    GV index = RMSE weight * RMSE
             + |GV calculated - estimated fraction| * GV weight
             + |SOIL calculated - estimated fraction|
             + |NPV calculated - estimated fraction|
             + |Shade calculated - estimated fraction|
    ```

    Some experimentation is needed to assess the best weighting factors. Increasing the endmember weight places the greater importance on matching the fraction of the target endmember. Increasing the RMSE constraint places greater importance on the fit of the model, or the spectral shape.

    Note: Because RMSE values (e.g., 0.025) are generally small relative to endmember fraction values (e.g., 0.3) an RMSE weight of 5 to 10 is generally helpful in ensuring that RMSE (model fit) is sufficiently weighted.

    Note: Extra index columns are now added to the table. Play around by changing the index weight values and re-calculating the index. **Smaller index numbers indicate better models.**

    The columns can be sorted by clicking on the headers.

11. Based on the results, the user can now select good spectra and export them as a new library.

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.

Command Line Interface

Because of the interactive nature of the CRES algorithm, no CLI is foreseen.

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.

2.2.5 MUSIC

Unlike IES, MUSIC by [Iordache2014] is an image-based library pruning method designed to select, from a large library, a subset of pure spectra that best represents the spectral variability of a given hyperspectral image and that, as a consequence, constitutes the best input for subpixel fractional abundance estimation.

MUSIC essentially comprises two steps. Firstly, the hyperspectral image is represented as a small set of eigenvectors that together define the image subspace, the n-dimensional space in which the data "live". This step is accomplished using the HySime algorithm ([BioucasDias2008]), which needs no input parameters and estimates the required number of eigenvectors (k) based on the signal- and noise correlation matrices of the original image.

Secondly, the Euclidean distances between each library spectrum and the estimated image subspace are calculated through orthogonal projection. The resulting projection errors, or distances between library members and image, are sorted and the spectra corresponding to the lowest distances are selected. The number of spectra to be retained can be adjusted by the user. In the complete absence of noise, the image is theoretically composed of k endmembers (as estimated by HySime). In practice however, this parameter is often set to 2 x k ([Iordache2014]).

In the current implementation, the user can set a minimum value for the number of eigenvectors to retain from the HySime algorithm.

MUSIC has already been successfully applied on both simulated and real hyperspectral datasets of mainly semi-natural environments (i.e., citrus orchards) and has been shown to increase the accuracy and computational efficiency of subpixel fraction mapping using sparse unmixing ([Iordache2014]). However, [Degerickx2016] showed that in more complex, urban environments MUSIC has some remaining redundancies in the final spectral libraries and revealed potential room for improvement.

MUSIC GUI

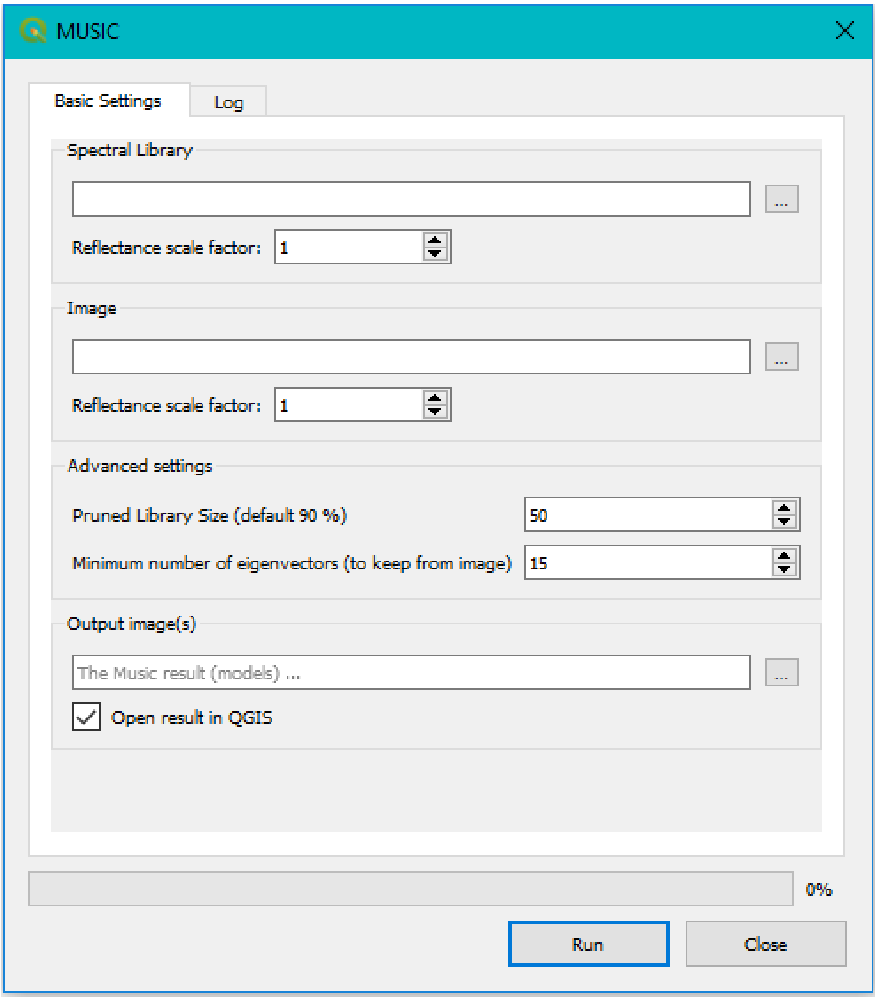
1. Select the input spectral library.
2. The reflectance scale factor is automatically detected.

> **Note:** Spectral data can be saved to file as **reflectance values** (i.e. values between 0 and 1) or the data can be multiplied by a **scale factor** (usually by 1000 or 10000). This is done to be able to store the data as integer values (no comma's), because integers require less memory. Although this is more efficient storage-wise, it has as a result we have to divide the data values again before processing.
>
> The software tries to **auto detect** this scale factor, but does not always succeed. Double check this value before continuing.

3. Select the input image. Again the reflectance scale factor is automatically detected. Double check it.
4. Advanced settings:
   - The size of the pruned library for MUSIC
   - The minimum number of eigenvectors to be retained from the image to calculate MUSIC distances
5. Select an output filename. A default name is created for you with the structure *libraryName_music.sli*.

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.



Spectral Library

Reflectance scale factor: 1

Image

Reflectance scale factor: 1

Advanced settings

Pruned Library Size (default 90 %) 50

Minimum number of eigenvectors (to keep from image) 15

Output image(s)

The Music result (models) ...

☑ Open result in QGIS

0%

2.2.6 AMUSES

AMUSES (*Automated MUsic and spectral Separability based Endmember Selection technique*) by [Degerickx2017] is an extension on MUSIC. It adds a spectral separability measure to further decrease the internal redundancy within the library subset produced by MUSIC.

[Degerickx2016] combined MUSIC and IES and showed that this approach results in smaller spectral libraries, in turn yielding more robust results.

In AMUSES, [Degerickx2017] opted for a spectral separability metric instead of IES to have more control over the entire procedure. A schematic overview of AMUSES is provided in the image below.

The method starts by applying brightness normalization to both the original spectral library and the image, to decrease the effect of brightness during the endmember selection process (step 1 in the figure below). This is accomplished by dividing the reflectance in each band by the average reflectance of the entire signal [Wu2004].

Then MUSIC is used to calculate the distance from each library spectrum to the image (step 2 in the figure below). [Degerickx2017] used a fixed minimum number of eigenvectors (15).The more eigenvectors are retained, the more spectra will be ranked as highly similar to the image and the harder it becomes to identify the true image endmembers.

After ranking all library spectra according to their distance to the image, a fraction of spectra ranked highest are retained and the lowest few are discarded (step 3 in the figure below).

All remaining spectra are assessed one by one using a spectral separability measure: only if a signature is sufficiently dissimilar from the already selected spectra, it will be included in the final selection.

[Degerickx2017] used a metric that combines the Jeffries Matusita distance and Spectral Angle (JMSA) by [Padma2014].

The JMSA threshold is systematically increased. This threshold is used to evaluate the similarity of a candidate spectrum with the already selected spectra (*thold parameter in the figure below) in function of the normalized distance of the candidate spectrum to the image as calculated by MUSIC (*nDist* in the figure below).

The higher the MUSIC distance, the lower the relevance of a library member to the image being analyzed. By using a high JMSA threshold for these spectra, their chance of ending up in the final selection is decreased. As input to the algorithm, the user needs to define a minimum and maximum threshold between which the thold parameter is allowed to vary.

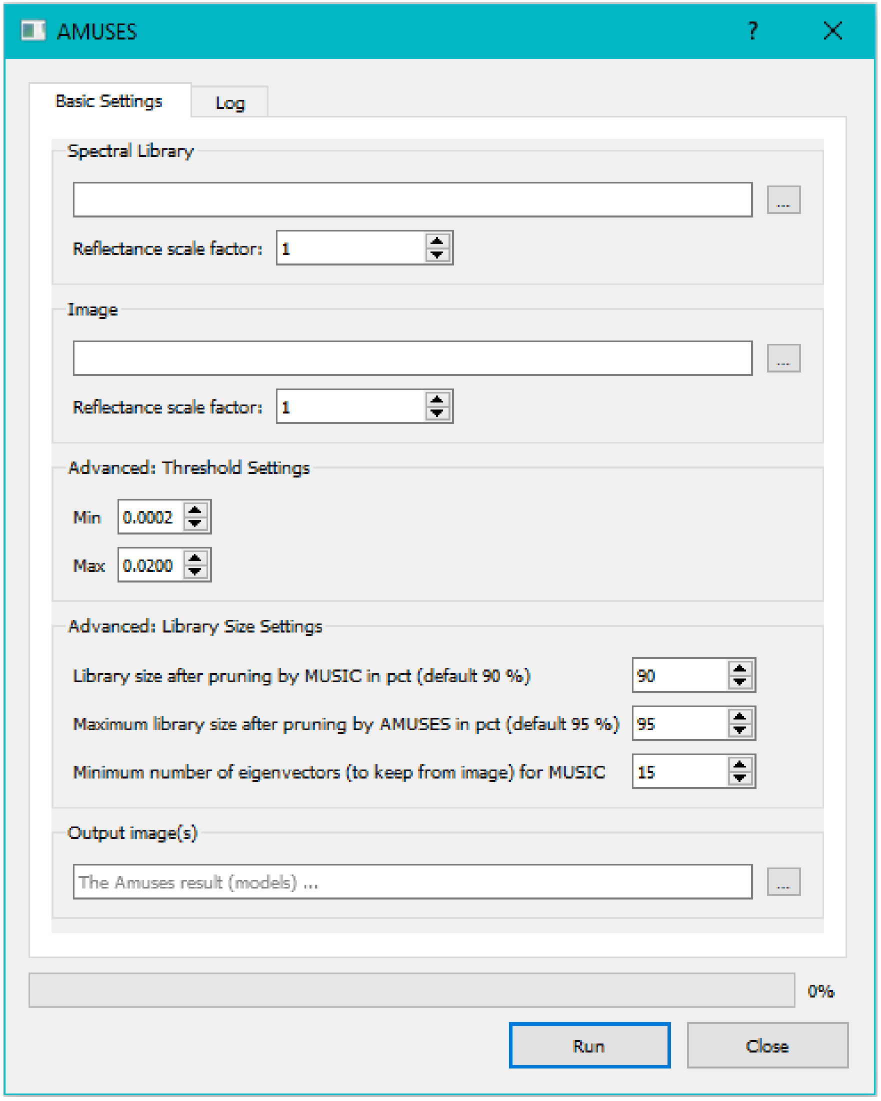
Using this approach, the pruning algorithm is highly automated as it now decides on the final number of spectra to be retained based on the distance to the image and the mutual similarity of the library spectra.

AMUSES GUI

1. Select the input spectral library.
2. The reflectance scale factor is automatically detected.

> **Note:** Spectral data can be saved to file as **reflectance values** (i.e. values between 0 and 1) or the data can be multiplied by a **scale factor** (usually by 1000 or 10000). This is done to be able to store the data as integer values (no comma's), because integers require less memory. Although this is more efficient storage-wise, it has as a result we have to divide the data values again before processing.
>
> The software tries to **auto detect** this scale factor, but does not always succeed. Double check this value before continuing.

3. Select the input image. Again the reflectance scale factor is automatically detected. Double check it.
4. Advanced settings:



Spectral Library

Reflectance scale factor: 1

Image

Reflectance scale factor: 1

Advanced: Threshold Settings

Min 0.0002

Max 0.0200

Advanced: Library Size Settings

Library size after pruning by MUSIC in pct (default 90 %) 90

Maximum library size after pruning by AMUSES in pct (default 95 %) 95

Minimum number of eigenvectors (to keep from image) for MUSIC 15

Output image(s)

The Amuses result (models) ...

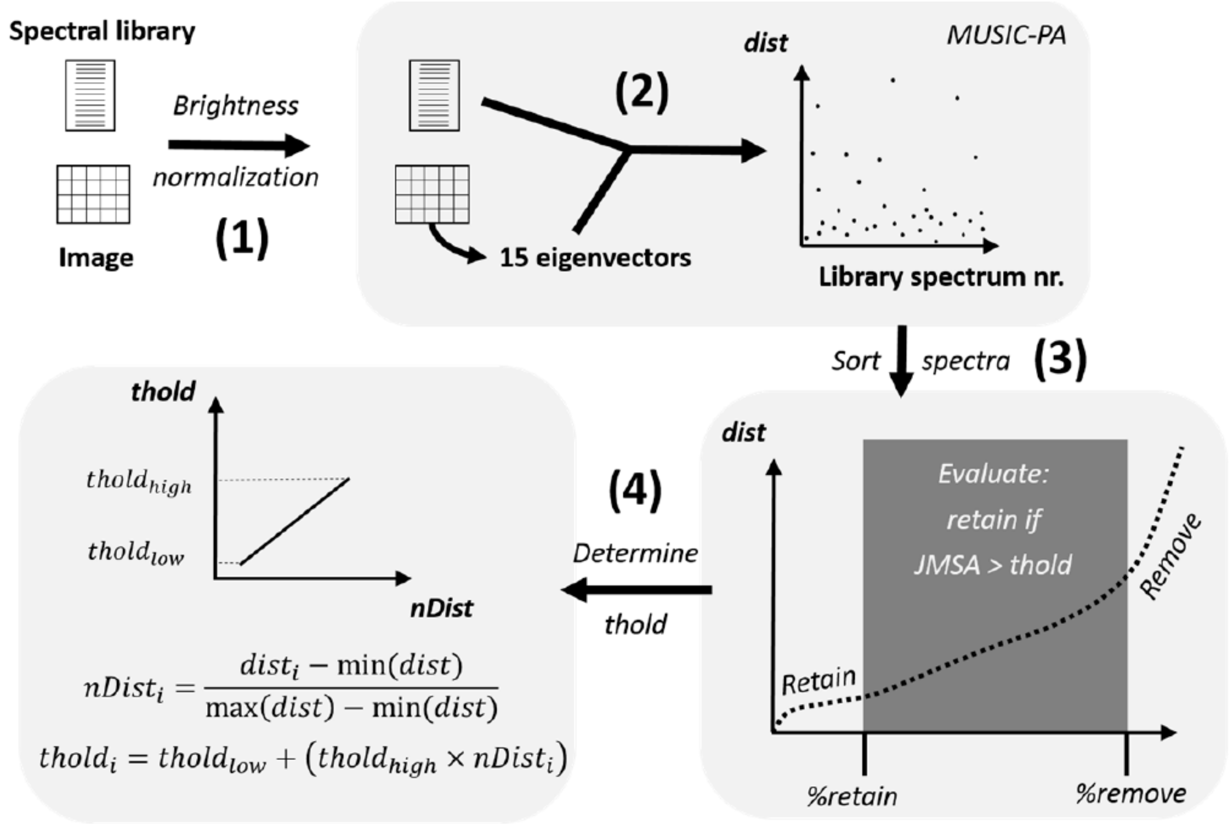
0%

- Threshold settings: see the in-depth explanation in the theoretical section
- The size of the pruned library by the MUSIC algorithm (in percentage)
- The maximum size of the pruned library by the AMUSES algorithm (in percentage)
- The minimum number of eigenvectors to be retained from the image to calculate MUSIC distances

5. Select an output filename. A default name is created for you with the structure *libraryName_amuses.sli*.

Issue Tracker:

For issues, bugs, proposals or remarks, visit the issue tracker.



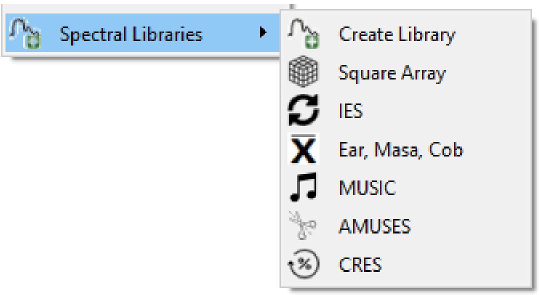
$$nDist_i = \frac{dist_i - \min(dist)}{\max(dist) - \min(dist)}$$

$$thold_i = thold_{low} + \left(thold_{high} \times nDist_i\right)$$

ACKNOWLEDGMENTS

This user guide is based on the VIPER Tools 2.0 user guide (UC Santa Barbara, VIPER Lab): Roberts, D. A., Halligan, K., Dennison, P., Dudley, K., Somers, B., Crabbe, A., 2018, Viper Tools User Manual, Version 2, 91 pp.

CITATIONS



CHAPTER 3

Exercises

For issues, bugs, proposals or remarks, visit the issue tracker.

We have developed two exercises. One with a data set in Brussels (Belgium), and one with a data set in Santa Barbara, CA (USA).

These exercises consist of two parts: creating and optimizing spectral libraries and MESMA and post-processing: the former you find here; for the latter visit http://mesma.readthedocs.io.

3.1 Exercise Brussels

For issues, bugs, proposals or remarks, visit the issue tracker.

3.1.1 Objectives

1. Learn to work with the Spectral Library Tool in QGIS
2. Get familiarized with spectral libraries:

- Build and edit them
- Prune libraries with optimization techniques like EMC or IES
- Analyse them with the Library Viewer

3. Use MESMA as a sub-pixel classification method

   Part 2 on http://mesma.readthedocs.be.

3.1.2 Tutorial Data Set

You can download the tutorial data set *tutorial_data_set_brussels* from https://bitbucket.org/kul-reseco/spectral-libraries/downloads/. The zip file contains the following data:

- Apex images from 2015 with numbers 014, 14 and 180 in ENVI format
- A spectral library in ENVI format
- A validation shape file for each image
- Note: images and library have been smoothed using Savitzky-Golay filter with window size 9

Acknowledgement for the data set:

Degerickx, Roberts, Somers; 2019; Enhancing the performance of Multiple Endmember Spectral Mixture Analysis (MESMA) for urban land cover mapping using airborne lidar data and band selection; Volume 221; P 260-273

Note: It is good practice to keep all files in the same folder - especially during the exercises. Files like *square arrays* often go looking for library information on which they are built.

3.1.3 Image Inspection

1. Try to visualize the images in QGIS.

   To recognize the surroundings, overlay them with a map from the OpenStreetMap project (QuickMapServices plugin and Google Satellite View).

2. Inspect the technical properties of the image.

- Why are the images black when first loading them into QGIS? Which bands would you use to visualize them for easy interpretation? Look-up the wavelengths of the RGB bands.
- What is the size of the image and of each pixel?
- Make a list of the land cover classes you expect to find in each image.

3.1.4 Creating Spectral Libraries

You will find some Spectral Libraries in your data folder. We will not use them for now. In this exercise, you are supposed to create your own Spectral Library by selecting *pure pixels* from your image.

Exercise: Create a Spectral Library

Data

Use the image *apex_2015_180_smooth*.

Exercise

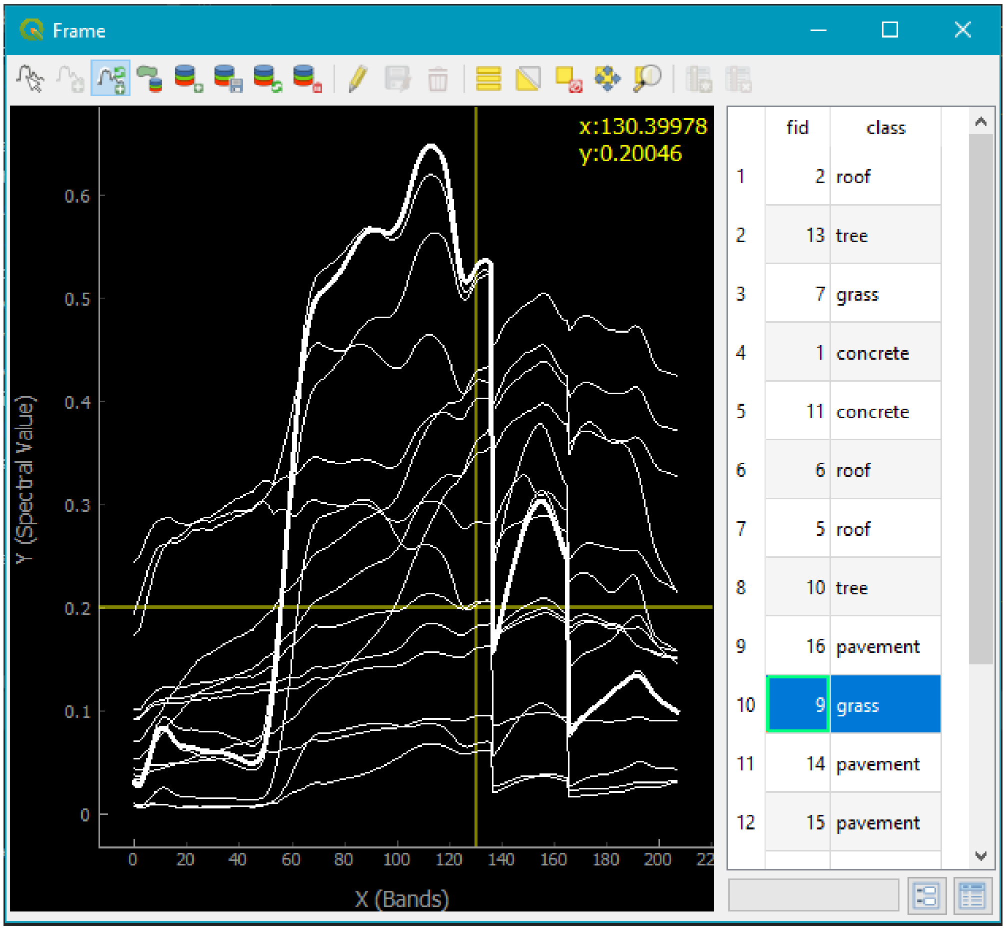
For each land cover class (see previous exercise), try to find several good spectra to add to the Spectral Library. Don't forget to **add a metadata class for each spectrum**. You won't remember afterwards!

- Turn off the OpenStreetMap layer in order not to get errors.
- Zoom to one of the images.
- Open the tool to build your own Spectral Library .
- Click on some random pixels and see the features appear on the plotting window. Add them to your spectral library by clicking on the Add button .

- Toggle the Auto button to automatically add profile to your spectral library.
- To remove a profile, select it in the attribute table and use the Delete button .
- You can now edit the profile metadata, add or remove non-compulsory fields and zoom/pan to selection on the image.
- Save the Spectral Library to the ENVI Spectral Library format (.sli) .

Result

The resulting Spectral Library can look like this:



	fid	class
1	2	roof
2	13	tree
3	7	grass
4	1	concrete
5	11	concrete
6	6	roof
7	5	roof
8	10	tree
9	16	pavement
10	9	grass
11	14	pavement
12	15	pavement

For issues, bugs, proposals or remarks, visit the issue tracker.

3.1.5 Spectral Library Optimization

The MESMA algorithm tests every model in your Spectral Library. Let's say you have 5 classes, with in each class 100 spectra. This leads to 500 2-EM Models, 100 000 3-EM Models, 10 000 000 4-EM Models, … as you can see, this can quickly get out of hand. Therefore it is good practice to prune your library, i.e. reduce it by removing spectra that are very similar.

In this exercise, we determine which spectra within a given class (e.g. Soil or Trees) are most representative of their class, while covering the range of variability within the class.

Exercise: Run AMUSES

Data used

We will use the Spectral Library (*library.sli*) from the testdata. To analyse this library first, use the spectral library tool . In this tool, use the Open Library button and browse to this file.

How many spectra does this library contain?

What are the different classes and subclasses in this library and how many are there?

To help you interpret the different classes, have a look at table 2 in the paper of Jeroen Degerickx (find it in your exercise folder):

Degerickx, Roberts, Somers; 2019; Enhancing the performance of Multiple Endmember Spectral Mixture Analysis (MESMA) for urban land cover mapping using airborne lidar data and band selection; Volume 221; P 260-273

We will also be using the image *apex_2015_180_smooth*. This is a hyperspectral Apex image from 2015 in ENVI format.

Exercise

Spectral Library:

- Select *library.sli*.
- The reflectance scale factor is automatically detected as 1. This is correct.

Image:

- Select *apex_2015_180_smooth*.
- The reflectance scale factor is automatically detected as 1. This is correct.

Advanced Settings:

- We will leave all settings as they are.

Output:

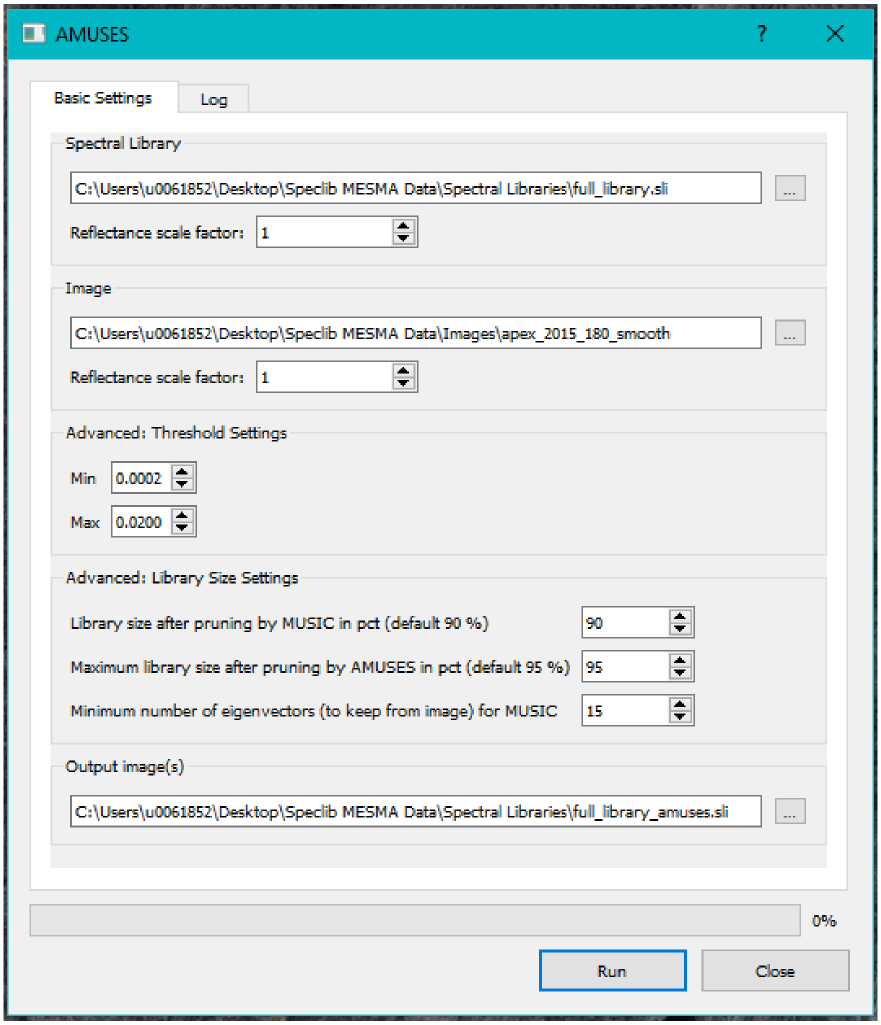
- The default output name is *library_amuses.sli*.

Click **RUN** to run AMUSES. The progress should be shown on the log-tab.

Result

The final library consists of 71 spectra.

For issues, bugs, proposals or remarks, visit the issue tracker.



Spectral Library

C:\Users\u0061852\Desktop\Speclib MESMA Data\Spectral Libraries\full_library.sli

Reflectance scale factor: 1

Image

C:\Users\u0061852\Desktop\Speclib MESMA Data\Images\apex_2015_180_smooth

Reflectance scale factor: 1

Advanced: Threshold Settings

Min 0.0002

Max 0.0200

Advanced: Library Size Settings

Library size after pruning by MUSIC in pct (default 90 %) 90

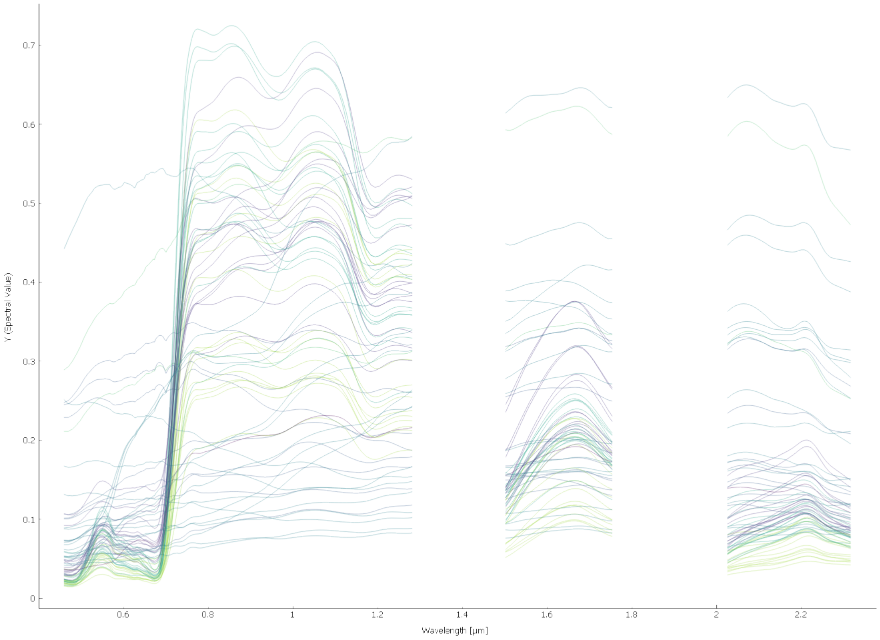
Maximum library size after pruning by AMUSES in pct (default 95 %) 95

Minimum number of eigenvectors (to keep from image) for MUSIC 15

Output image(s)

C:\Users\u0061852\Desktop\Speclib MESMA Data\Spectral Libraries\full_library_amuses.sli

0%



Exercise: Run IES

Data used

We will use the Spectral Library (*library.sli*) from the testdata. To analyse this library first, use the spectral library tool . In this tool, use the Open Library button and browse to this file.

How many spectra does this library contain?

What are the different classes and subclasses in this library and how many are there?

To help you interpret the different classes, have a look at table 2 in the paper of Jeroen Degerickx (find it in your exercise folder):

Degerickx, Roberts, Somers; 2019; Enhancing the performance of Multiple Endmember Spectral Mixture Analysis (MESMA) for urban land cover mapping using airborne lidar data and band selection; Volume 221; P 260-273

Exercise

Spectral Library:

- Select *library.sli*.
- The reflectance scale factor is automatically detected as 1. This is correct.
- The metadata element we are using for this analysis is **Meta2**.

Set **constraints**:

- We leave the constraints settings as they are.

Forced IES:

- We will not use this option in this exercise.

Output:

- The default output name is *library_ies.sli*.

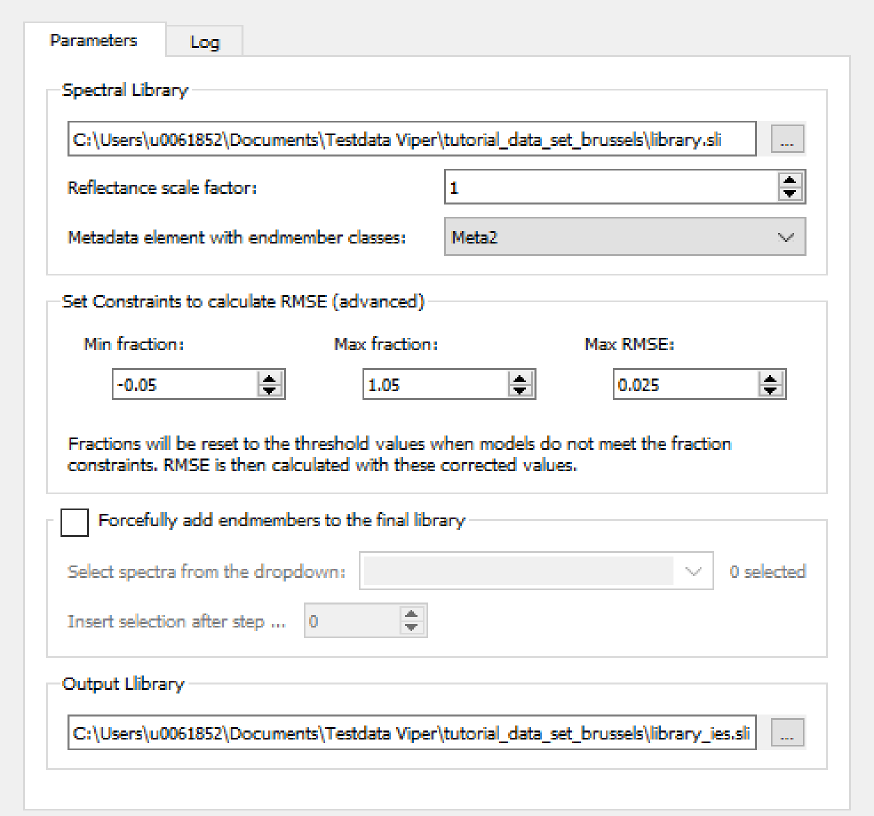
Click **RUN** to run IES. The progress should be shown on the log-tab. But since this is a very heavy process, QGIS might freeze for the duration of the process. IES is quite slow and might take a while.

Result

A summary of the algorithm's progress is saved as *library_ies_summary.txt* and automatically opens up on the screen. This summary file lists for each iteration the endmember name, kappa value and confusion matrix:

```
IES SUMMARY
----------------------------------------

Based on the spectral library: C:\Users\...\library.sli

Metadata
    Cass header: Meta2
    Unique classes: EXGR  LVEG  PAVEMENT  ROOF  SHRUB  SOIL  TREE

Used a forced library? No

...
```

(continues on next page)



Spectral Library

C:\Users\u0061852\Documents\Testdata Viper\tutorial_data_set_brussels\library.sli

Reflectance scale factor: 1

Metadata element with endmember classes: Meta2

Set Constraints to calculate RMSE (advanced)

Min fraction: -0.05

Max fraction: 1.05

Max RMSE: 0.025

Fractions will be reset to the threshold values when models do not meet the fraction constraints. RMSE is then calculated with these corrected values.

□ Forcefully add endmembers to the final library

Select spectra from the dropdown: 0 selected

Insert selection after step ... 0

Output Llibrary

C:\Users\u0061852\Documents\Testdata Viper\tutorial_data_set_brussels\library_ies.sli

(continued from previous page)

```

ITERATIVE PROCESS
----------------------------------------

Loop 0: new endmember: tiler598 (597)
 - Kappa at this point: 0.08008494
 - Confusion Matrix:
             EXGR      LVEG  PAVEMENT      ROOF     SHRUB      SOIL      TREE    ␣
↪Unclas
   EXGR         0         0         0         0         0         0         0         ␣
↪0
   LVEG         0         0         0         0         0         0         0         ␣
↪0
PAVEMENT        0         0         0         0         0         0         0         ␣
↪0
   ROOF         0         0        36        91         0         2         0         ␣
↪0
  SHRUB         0         0         0         0         0         0         0         ␣
↪0
   SOIL         0         0         0         0         0         0         0         ␣
↪0
   TREE         0         0         0         0         0         0         0         ␣
↪0
 Unclas        14        80       122       124        60        45        59         ␣
↪0

Loop 1: new endmember: dbt199 (198)
```

(continues on next page)

(continued from previous page)

```
 - Kappa at this point: 0.160418
 - Confusion Matrix:
             EXGR      LVEG  PAVEMENT      ROOF     SHRUB      SOIL      TREE    ␣
↪Unclas
   EXGR         0         0         0         0         0         0         0         ␣
↪0
   LVEG         0         0         0         0         0         0         0         ␣
↪0
PAVEMENT        0         0         0         0         0         0         0         ␣
↪0
   ROOF         0         0        36        91         0         2         0         ␣
↪0
  SHRUB         0         0         0         0         0         0         0         ␣
↪0
   SOIL         0         0         0         0         0         0         0         ␣
↪0
   TREE         0        11         0         0        32         0        55         ␣
↪0
 Unclas        14        69       122       124        28        45         4         ␣
↪0
```

From this file, we can see that the first endmember selected was *tiler598*. This is a *roof* spectrum that modeled 91 out of 215 roof spectra but also 36 pavement spectra and 2 soil spectra generating a *kappa* of 0.08. Thus, using this one spectrum our accuracy would be about 8% and a majority of the library would be unclassified.

Examine the second iteration. You should see *dbt199*. This is a *tree* spectrum that correctly classifies 55 out of 59 tree spectra, but also a majority of the shrub vegetation and some of the low vegetation. The *kappa* has increased to 0.16.

The final library consists of 92 spectra and the kappa value has reached 0.85. |

For issues, bugs, proposals or remarks, visit the issue tracker.

Exercise: Pruning the spectral library with EAR-MASA-COB

Data used

We will use the Spectral Library (*library.sli*) from the testdata. To analyse this library first, use the spectral library tool . In this tool, use the Open Library button and browse to this file.

How many spectra does this library contain?

What are the different classes and subclasses in this library and how many are there?

To help you interpret the different classes, have a look at table 2 in the paper of Jeroen Degerickx (find it in your exercise folder):

Degerickx, Roberts, Somers; 2019; Enhancing the performance of Multiple Endmember Spectral Mixture Analysis (MESMA) for urban land cover mapping using airborne lidar data and band selection; Volume 221; P 260-273

Exercise part 1 - EMC

Open the EMC tool X̄ .

Spectral Library:

- Select *library.sli*.

- The reflectance scale factor is automatically detected as 1. This is correct.
- The metadata element we are using for this analysis is **Meta1** (fine classes).

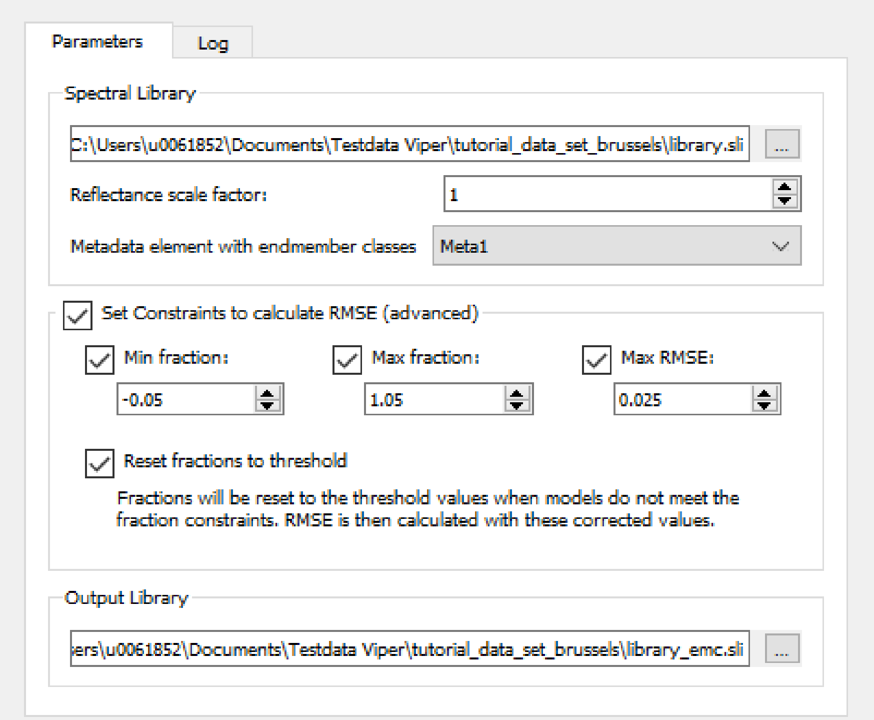
Set **constraints**:

- We leave the constraints settings as they are.

Output:

- Change the output name to your liking. It is good practice to keep the file in the same folder as the original library.

Click **RUN** to run EMC.



Spectral Library

C:\Users\u0061852\Documents\Testdata Viper\tutorial_data_set_brussels\library.sli

Reflectance scale factor: 1

Metadata element with endmember classes: Meta1

☑ Set Constraints to calculate RMSE (advanced)

☑ Min fraction: -0.05

☑ Max fraction: 1.05

☑ Max RMSE: 0.025

☑ Reset fractions to threshold

Fractions will be reset to the threshold values when models do not meet the fraction constraints. RMSE is then calculated with these corrected values.

Output Library

ers\u0061852\Documents\Testdata Viper\tutorial_data_set_brussels\library_emc.sli

Result

Open the new library in the Spectral Library Viewer.

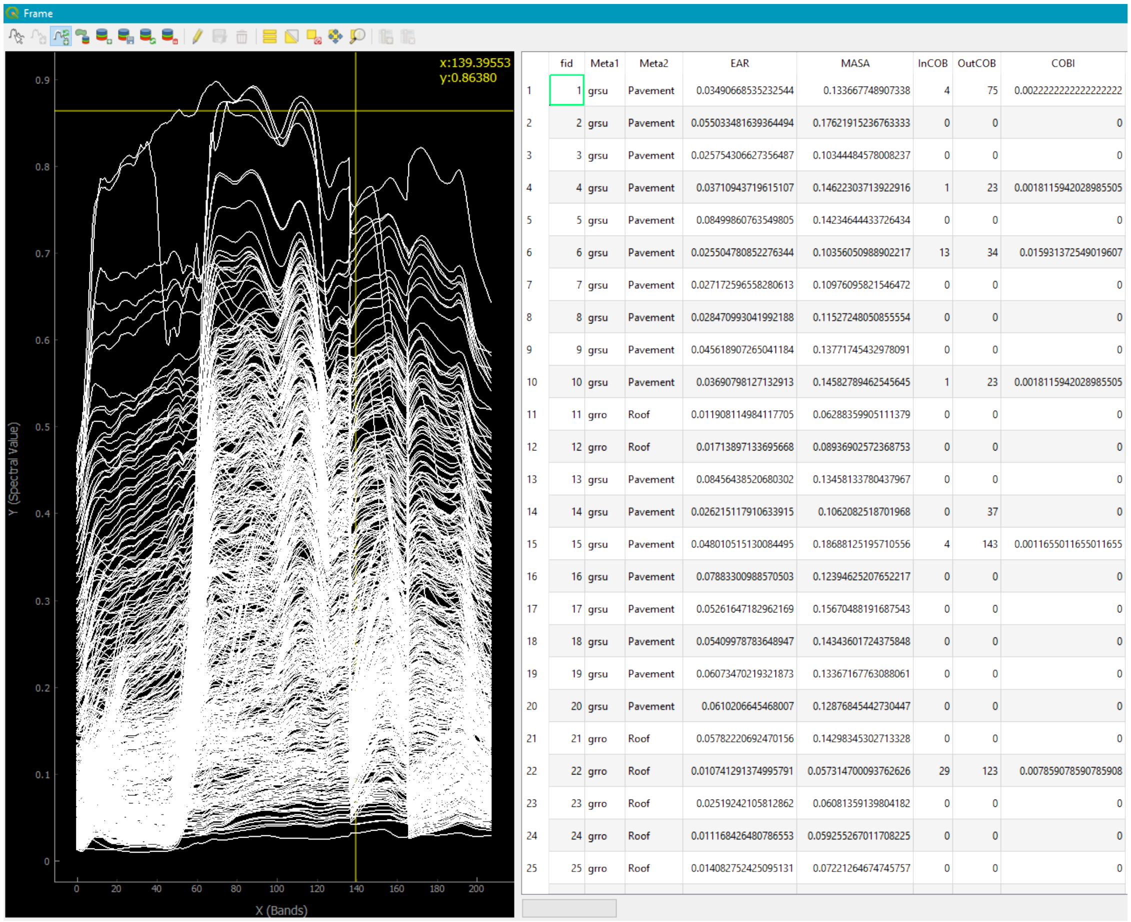
The following image shows the tabular output of the algorithm (partly).

Exercise part 2 - selecting a subset based on the EMC results

Now we will try to prune the library. Our aim is to keep approximately 4 spectra for each of the 28 classes.

Hint: Since these exercises were written, some features were added to the spectral library viewer in order to help the user distinguish between different classes. Think about using different colours for different classes, not displaying certain classes, and only showing selected features on the screen. These features will make this exercise easier to execute than indicated below.

Let's start with artu (artificial turf):



	fid	Meta1	Meta2	EAR	MASA	InCOB	OutCOB	COBI
1	1	grsu	Pavement	0.03490668535232544	0.133667748907338	4	75	0.00222222222222222
2	2	grsu	Pavement	0.055033481639364494	0.1762191523676333	0	0	0
3	3	grsu	Pavement	0.025754306627356487	0.10344484578008237	0	0	0
4	4	grsu	Pavement	0.03710943719615107	0.14622303713922916	1	23	0.0018115942028985505
5	5	grsu	Pavement	0.08499860763549805	0.14234644433726434	0	0	0
6	6	grsu	Pavement	0.025504780852276344	0.10356050988902217	13	34	0.015931372549019607
7	7	grsu	Pavement	0.027172596558280613	0.10976095821546472	0	0	0
8	8	grsu	Pavement	0.028470993041992188	0.11527248050855554	0	0	0
9	9	grsu	Pavement	0.045618907265041184	0.13771745432978091	0	0	0
10	10	grsu	Pavement	0.03690798127132913	0.14582789462545645	1	23	0.0018115942028985505
11	11	grro	Roof	0.011908114984117705	0.06288359905111379	0	0	0
12	12	grro	Roof	0.01713897133695668	0.08936902572368753	0	0	0
13	13	grsu	Pavement	0.08456438520680302	0.13458133780437967	0	0	0
14	14	grsu	Pavement	0.026215117910633915	0.1062082518701968	0	37	0
15	15	grsu	Pavement	0.048010515130084495	0.18688125195710556	4	143	0.0011655011655011655
16	16	grsu	Pavement	0.07883300988570503	0.12394625207652217	0	0	0
17	17	grsu	Pavement	0.05261647182962169	0.15670488191687543	0	0	0
18	18	grsu	Pavement	0.05409978783648947	0.14343601724375848	0	0	0
19	19	grsu	Pavement	0.06073470219321873	0.13367167763088061	0	0	0
20	20	grsu	Pavement	0.0610206645468007	0.12876845442730447	0	0	0
21	21	grro	Roof	0.05782220692470156	0.14298345302713328	0	0	0
22	22	grro	Roof	0.010741291374995791	0.057314700093762626	29	123	0.007859078590785908
23	23	grro	Roof	0.02519242105812862	0.06081359139804182	0	0	0
24	24	grro	Roof	0.011168426480786553	0.059255267011708225	0	0	0
25	25	grro	Roof	0.014082752425095131	0.07221264674745757	0	0	0

- The class has originally 22 spectra.
- We see that artu16 was successful in modelling all other spectra in the class (InCOB of 21).
- The EAR values range between 0.009 and 0.031. artu16 has an EAR value of 0.014, not the lowest but quite low. The lowest EAR values are for artu12, artu13, artu15, artu2, artu1 and artu10.
- The MASA values range between 0.090 and 0.210. artu16 has the highest MASA value! The lowest MASA values are for artu1, artu22, artu11, artu18, artu17, artu13 and artu21.
- The only similarities are artu13 and artu1.

How do we explain this?

- Remove all other spectra except for the artu class. Don't worry, this action does not affect the library saved on file.
- You can see that there are a lot of similar, dark spectra and a few very distinct bright ones.
- artu1 lies in the group of similar spectra, explaining the good MASA value.
- artu12 lies somewhere in the middle of everything, with a form similar to the dark spectra, explaining the good EAR value.
- artu16 is the brightest one with a very different shape – think about why this one would be selected.

We keep those three spectra.

Then we go on with dbt (deciduous broad leaf trees):

- Reload the full library and now remove all spectra except for the dbt class.
- This class contains 29 spectra.
- dbt199 was the only one able to model 27 other spectra (InCOB value of 27). Again this is the most bright spectrum in the class. Does this ring any bell?
- dbt199 also has the best EAR value.
- If you look at the top 5 of MASA values, you see that 4 of them are also in the top 5 of EAR values and vice versa: dbt199, dbt176, dbt189 and dbt198.
- Looking at dbt189 and dbt198 we see that they are (almost) identical.
- We keep the top 3.

Why are EAR and InCOB results so similar, but MASA less?

Go on and select the 3 or 4 best spectra for each class. You can skip the classes Extensive Green Roof, Meadow, Red Gravel, Green Surface, Tartan, Bare Soil and Sand. They are not part of our images.

For issues, bugs, proposals or remarks, visit the issue tracker.

Click on these links to find the theory behind AMUSES, IES and EMC.

For issues, bugs, proposals or remarks, visit the issue tracker.

3.2 Exercise Santa Barbara

For issues, bugs, proposals or remarks, visit the issue tracker.

3.2.1 Tutorial Data Set

You can download the tutorial data set *tutorial_data_set_santa_barbara* from https://bitbucket.org/kul-reseco/spectral-libraries/downloads/. The zip file contains the following data:

- Image 010614r4_4-5_clip

  A 2001 AVIRIS image (ENVI header format) with 20 m spatial resolution ([Roberts2003]).

- Image demo1.sub

  A 2011 AVIRIS image (ENVI header format) as 600x600 pixel subset of downtown Santa Barbara ([Roberts2015], [Roberts2017]. AVIRIS data were processed to apparent surface reflectance using ATCOR, as described in [Roberts2015], and scaled to reflectance times 10,000.

- Spectral Library: roberts2017_urban.sli

  This library was used in [Roberts2017] and consists of 3725 spectra. The spectra include a mixture of spectra extracted from the three AVIRIS flight lines acquired in 2011 merged with the urban spectral library described by [Herold2004]. The AVIRIS spectra, which originally consisted of over 60,000 spectra, were subsampled using code developed by Keely Roth as part of her dissertation. Following the protocols described in [Roth2012], spectra were sampled at the polygon level such that no polygon can contribute more than 10 spectra to the library, or more than 50% of the pixels for small polygons. The p9 in the file name, implies this was the 9th random pull out of 10 pulls. The 9th pull was selected because it produced the highest accuracy (based on IES) with the lowest number of spectra, as described in [Roberts2017].

- Spectral Library: 010627_westusa_all.sli

  Spectral Library for the CRES tutorial and for Simple SMA.

- Spectral Library: roberts_et_al_2017_final.sli.

  This is the same library that was used to generate the final fraction maps in Roberts et al. (2017). The library was created by merging 2,739 spectra extracted from the image with 986 spectra measured in the field. IES was run, generating a 497 spectral subset. This library was further pruned to remove poorly performing models to generate a 376 endmember subset, then all clearly mixed spectra (assessed visually), were removed to generate the *nomix* library, consisting of 259 spectra. Finally, a procedure, designed to remove spectrally degenerate spectra was used to generate a 91 endmember subset. The final culling was accomplished in 8 iterations.

- roi.shp

  This contains regions of interest for most dominant cover types in the region. This matches demo1.sub.

Acknowledgement for the data set:

Roberts, D. A., Halligan, K., Dennison, P., Dudley, K., Somers, B., Crabbe, A., 2018, Viper Tools User Manual, Version 2, 91 pp.

Note: It is good practice to keep all files in the same folder - especially during the exercises. Files like *square arrays* often go looking for library information on which they are built.

3.2.2 Creating Spectral Libraries

Exercise: Create a Spectral Library

Objective: In this exercise, we will build a Spectral Library, based on an image and it's ROI's (Regions Of Interest).

Data used

- Image: demo1.sub

To display the image as true color image, use RGB wavelengths 0.658, 0.560 and 0.443 μm.

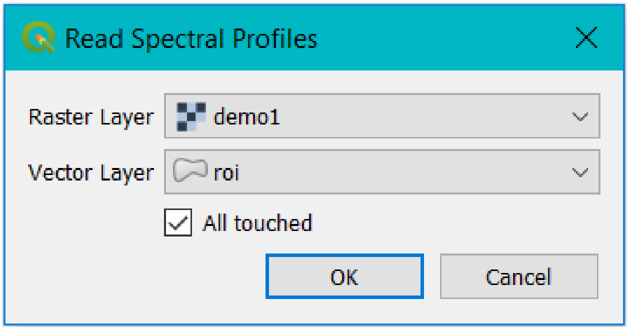
- Regions Of Interest: roi.shp

You might notice a lot of polygons in the ROI layer lie outside the image. This is no problem. Analyze the metadata: each ROI should have associated metadata like impervious/pervious, vegetation type, etc. The features represent a mix of natural and anthropogenic materials from needle-leaf shrubs (ADFA) and the invasive plant species Brassica nigra (BRNI), to asphalt surfaces, red tile roofs, concrete and golf courses. The metadata headers are generic because there is no hierarchical level common to a plant, a soil or an impervious surface (what is the species of asphalt, or its life form?).

Automatically build a Spectral Library from ROI's

- Open the *Create Library* tool and click on *Import profiles from raster + vector source*.
- In the pop-up window, select the shape file as ROI layer and the image as raster layer.
- Use the *All Touched* option to include all pixels that are partially covered by the ROIs.

Click **OK** to build the library. This might take a few moments.



Read Spectral Profiles

Raster Layer: demo1

Vector Layer: roi

☑ All touched

Result

The resulting Spectral Library contains 2557 profiles. Save the library to file.

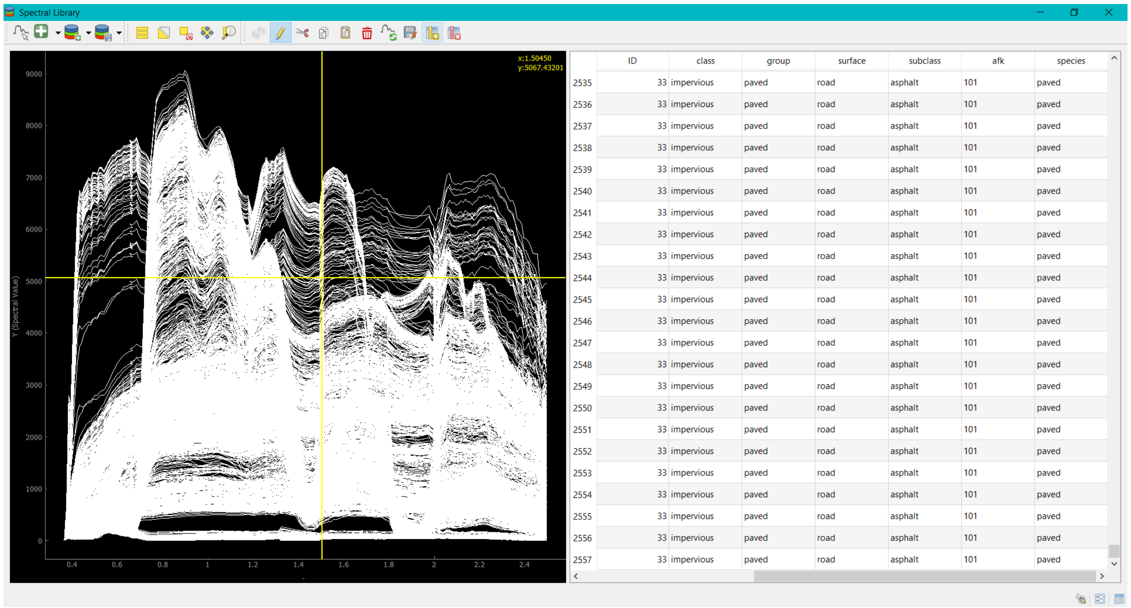
For issues, bugs, proposals or remarks, visit the issue tracker.

3.2.3 Spectral Library Optimization

Exercise: run EAR-MASA-COB in QGIS

Data used

- Spectral Library: roberts2017_urban.sli



	ID	class	group	surface	subclass	afk	species
2535	33	impervious	paved	road	asphalt	101	paved
2536	33	impervious	paved	road	asphalt	101	paved
2537	33	impervious	paved	road	asphalt	101	paved
2538	33	impervious	paved	road	asphalt	101	paved
2539	33	impervious	paved	road	asphalt	101	paved
2540	33	impervious	paved	road	asphalt	101	paved
2541	33	impervious	paved	road	asphalt	101	paved
2542	33	impervious	paved	road	asphalt	101	paved
2543	33	impervious	paved	road	asphalt	101	paved
2544	33	impervious	paved	road	asphalt	101	paved
2545	33	impervious	paved	road	asphalt	101	paved
2546	33	impervious	paved	road	asphalt	101	paved
2547	33	impervious	paved	road	asphalt	101	paved
2548	33	impervious	paved	road	asphalt	101	paved
2549	33	impervious	paved	road	asphalt	101	paved
2550	33	impervious	paved	road	asphalt	101	paved
2551	33	impervious	paved	road	asphalt	101	paved
2552	33	impervious	paved	road	asphalt	101	paved
2553	33	impervious	paved	road	asphalt	101	paved
2554	33	impervious	paved	road	asphalt	101	paved
2555	33	impervious	paved	road	asphalt	101	paved
2556	33	impervious	paved	road	asphalt	101	paved
2557	33	impervious	paved	road	asphalt	101	paved

Part 1 - EMC

Select the **input spectral library**.

- Select *roberts2017_urban.sli*.
- The reflectance scale factor is automatically detected as 10000. This is correct.
- The metadata element we are using for this analysis is **Level_7**.

Set **constraints**:

- Minimum fraction to 0.0, maximum to 1.0 and RMSE constraint at 0.025.
- Select the 'Reset fractions to threshold' mode.

Output:

- Select a name for the new library, e.g. *roberts2017_urban_emc.sli*.

Click **OK** to run EMC.

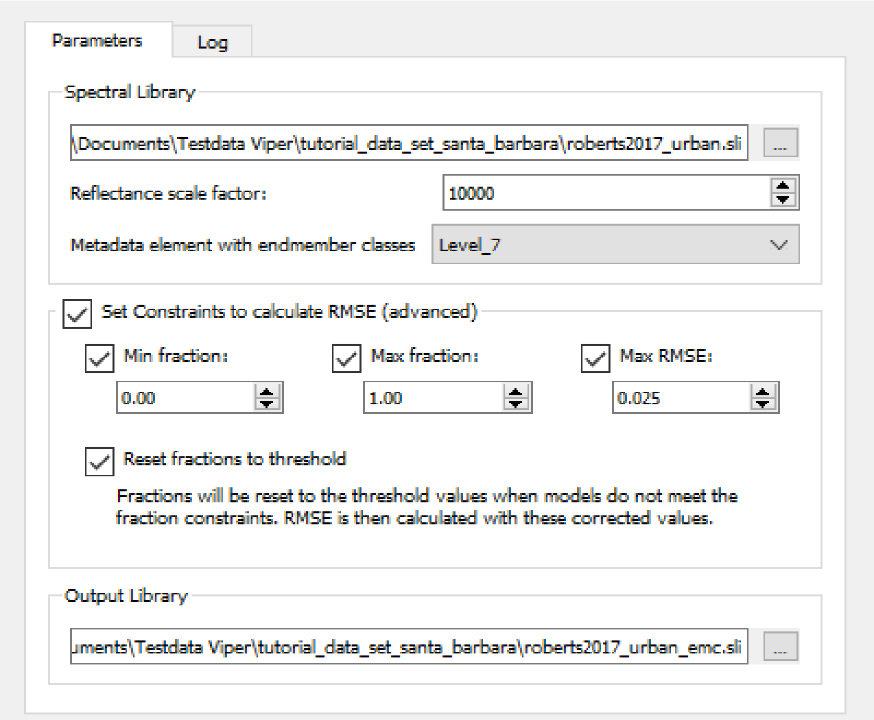
Result

The following image shows the tabular output of the algorithm (partly).

- When the metric of choice is *Cob*, sorting works very well.

  The best candidate per *Level_7* class is the class with the highest *InCob* value. In case of a tie, look to other measures (such as EAR) to make your choice.
- When the metric of choice is *EAR* or *MASA*, this technique is less efficient, as there are many similar RMSE or spectral angles values.

Part 2 - selecting a subset based on the EMC results



Spectral Library

\Documents\Testdata Viper\tutorial_data_set_santa_barbara\roberts2017_urban.sli

Reflectance scale factor: 10000

Metadata element with endmember classes: Level_7

☑ Set Constraints to calculate RMSE (advanced)

☑ Min fraction: 0.00

☑ Max fraction: 1.00

☑ Max RMSE: 0.025

☑ Reset fractions to threshold

Fractions will be reset to the threshold values when models do not meet the fraction constraints. RMSE is then calculated with these corrected values.

Output Library

uments\Testdata Viper\tutorial_data_set_santa_barbara\roberts2017_urban_emc.sli

Hint: Since these exercises were written, some features were added to the spectral library viewer in order to help the user distinguish between different classes. Think about using different colours for different classes, not displaying certain classes, and only showing selected features on the screen. These features will make this exercise easier to execute than indicated below.

Our objective will be to select the top candidates for each EMC-metric. **There are many criteria one could use.**

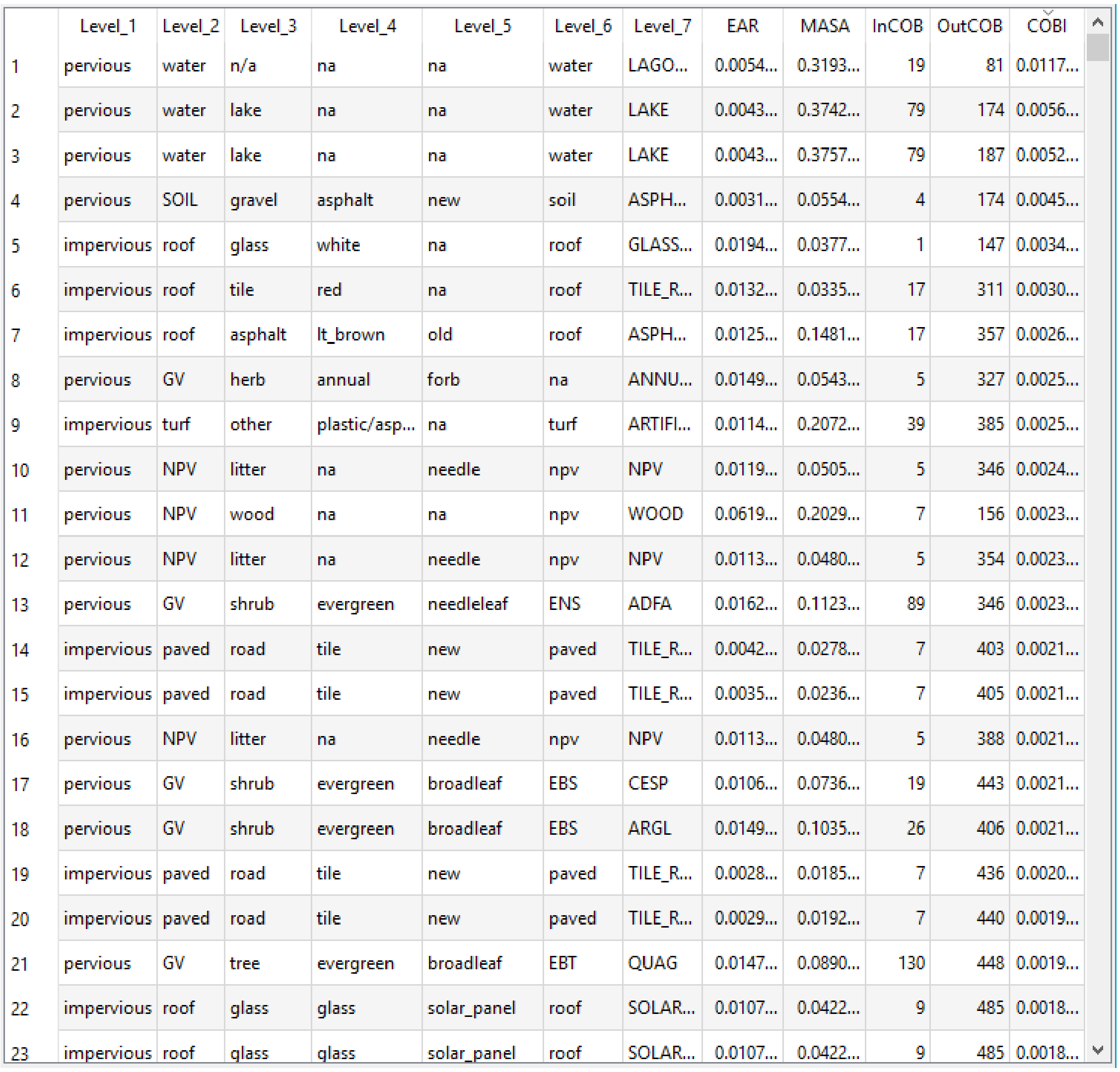
For example, one could **select the top three for each metric**. Using this approach we would, however, be best served by ensuring the top three all came from different polygons.

Another strategy would be to select the **top candidates for EAR, MASA and InCoB**. Where more than one *InCoB* is viable, we would add some until there are too few models left (say 1-3). Using this strategy, we would also remove any duplicates from the same metric, but would also potentially find a tie with *InCoB* and need another metric to break the tie.

There is no defined way to **break the tie**, but one option would be the select the one with the lower *EAR* (this would be the one that fits its class best). Another option would to select the one with the highest *EAR* (this is the one that is the most distinct from other spectra in the library, and might be a good choice if this were a second *InCoB*). A third option might be to select one with the lowest *OutCoB* (Most distinct from other classes).

In this example, we are going to use the strategy of using the **top metric for each class**, followed by multiple InCoBs. We will split ties by choosing the *InCoB* with the lowest *EAR*.

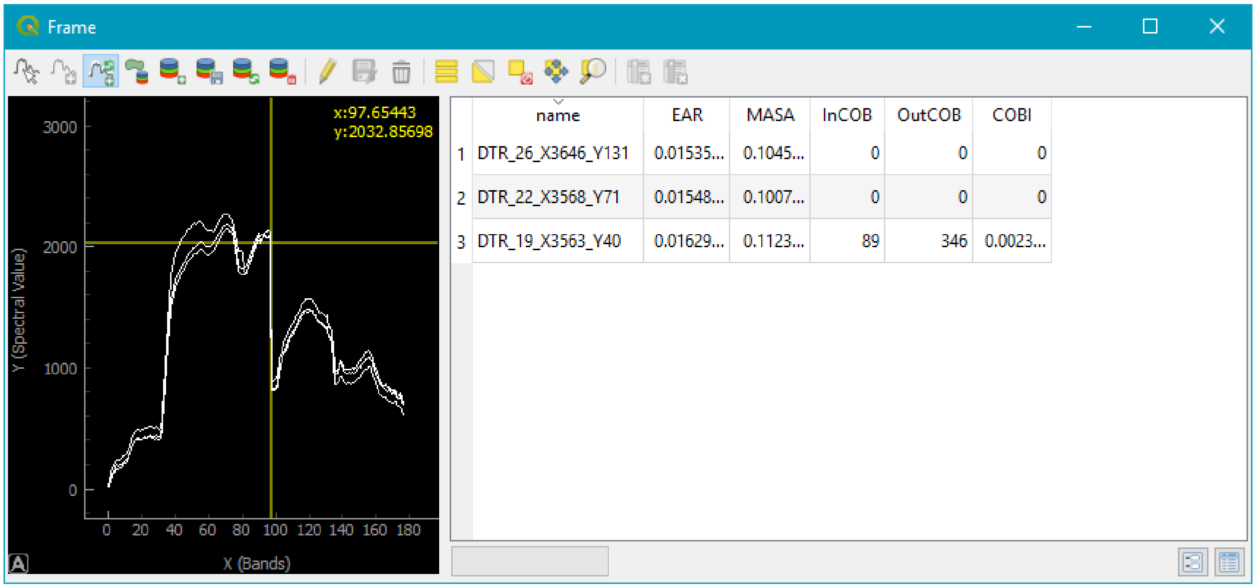
- Order the data according to column 7 and **only select ADFA** (remove all other spectra - this does not affect the EMC library saved to file).
- Sort by EAR: DTR_26_X3646_Y131 has the lowest EAR value.
- Sort by MASA: DTR_26_X3646_Y131 also has a low MASA value, but is not the best, that is DTR_22_X3568_Y71.
- Sort by InCob: DTR_19_X3568_Y37 and DTR_19_X3572_Y35 both have the highest value (85), but



	Level_1	Level_2	Level_3	Level_4	Level_5	Level_6	Level_7	EAR	MASA	InCOB	OutCOB	COBI
1	pervious	water	n/a	na	na	water	LAGO...	0.0054...	0.3193...	19	81	0.0117...
2	pervious	water	lake	na	na	water	LAKE	0.0043...	0.3742...	79	174	0.0056...
3	pervious	water	lake	na	na	water	LAKE	0.0043...	0.3757...	79	187	0.0052...
4	pervious	SOIL	gravel	asphalt	new	soil	ASPH...	0.0031...	0.0554...	4	174	0.0045...
5	impervious	roof	glass	white	na	roof	GLASS...	0.0194...	0.0377...	1	147	0.0034...
6	impervious	roof	tile	red	na	roof	TILE_R...	0.0132...	0.0335...	17	311	0.0030...
7	impervious	roof	asphalt	lt_brown	old	roof	ASPH...	0.0125...	0.1481...	17	357	0.0026...
8	pervious	GV	herb	annual	forb	na	ANNU...	0.0149...	0.0543...	5	327	0.0025...
9	impervious	turf	other	plastic/asp...	na	turf	ARTIFI...	0.0114...	0.2072...	39	385	0.0025...
10	pervious	NPV	litter	na	needle	npv	NPV	0.0119...	0.0505...	5	346	0.0024...
11	pervious	NPV	wood	na	na	npv	WOOD	0.0619...	0.2029...	7	156	0.0023...
12	pervious	NPV	litter	na	needle	npv	NPV	0.0113...	0.0480...	5	354	0.0023...
13	pervious	GV	shrub	evergreen	needleleaf	ENS	ADFA	0.0162...	0.1123...	89	346	0.0023...
14	impervious	paved	road	tile	new	paved	TILE_R...	0.0042...	0.0278...	7	403	0.0021...
15	impervious	paved	road	tile	new	paved	TILE_R...	0.0035...	0.0236...	7	405	0.0021...
16	pervious	NPV	litter	na	needle	npv	NPV	0.0113...	0.0480...	5	388	0.0021...
17	pervious	GV	shrub	evergreen	broadleaf	EBS	CESP	0.0106...	0.0736...	19	443	0.0021...
18	pervious	GV	shrub	evergreen	broadleaf	EBS	ARGL	0.0149...	0.1035...	26	406	0.0021...
19	impervious	paved	road	tile	new	paved	TILE_R...	0.0028...	0.0185...	7	436	0.0020...
20	impervious	paved	road	tile	new	paved	TILE_R...	0.0029...	0.0192...	7	440	0.0019...
21	pervious	GV	tree	evergreen	broadleaf	EBT	QUAG	0.0147...	0.0890...	130	448	0.0019...
22	impervious	roof	glass	glass	solar_panel	roof	SOLAR...	0.0107...	0.0422...	9	485	0.0018...
23	impervious	roof	glass	glass	solar_panel	roof	SOLAR...	0.0107...	0.0422...	9	485	0.0018...

DTR_19_X3568_Y37 has the lowest OutCOB of the two.

- Keep only these tree spectra and **save them as a separate library**. Afterwards, you can merge all libraries into one.



	name	EAR	MASA	InCOB	OutCOB	COBI
1	DTR_26_X3646_Y131	0.01535...	0.1045...	0	0	0
2	DTR_22_X3568_Y71	0.01548...	0.1007...	0	0	0
3	DTR_19_X3563_Y40	0.01629...	0.1123...	89	346	0.0023...

Repeat this process for all other major classes. As a word of warning, this process can be slow for large libraries.

To work faster, you might opt exporting as CSV and editing in another tool like Excel.

When you are done, merge all sub-libraries again into one by loading them one by one into the Spectral Library viewer and then saving them again to file, e.g. *roberts2017_urban_emc_opt.sli**. You should have around 150 spectra when you are done.

Other helpful hints:

Some indices will fail to produce markedly different spectra, even if they come from different polygons. This is particularly true of *MASA*. It may also not be possible to select more than one candidate from *InCoB*. If, for example, the third selection models far more of the wrong class than itself, it may be best left out. In addition, because *InCoB* automatically culls out all spectra from the first selection, even if the second best selection is from the same polygon, it still is likely to be quite different.

Also, keep in mind that you are working with a research tool. Optimal candidates are likely to differ between cover types and data sources. Thus, simply selecting the top three candidates may not be the best option for your study problem.

We do not know all of the answers, but have given you a tool to help you answer yours.

For issues, bugs, proposals or remarks, visit the issue tracker.

Exercise: Run IES in QGIS

Data used

- Spectral Library: roberts2017_urban.sli

Run IES

Select the **input spectral library**.

- Select *roberts2017_urban.sli*.
- The reflectance scale factor is automatically detected as 10000. This is correct.
- The metadata element we are using for this analysis is **Level_7**.

Set **constraints**:

- Minimum fraction to 0.0, maximum to 1.0 and RMSE constraint at 0.025.

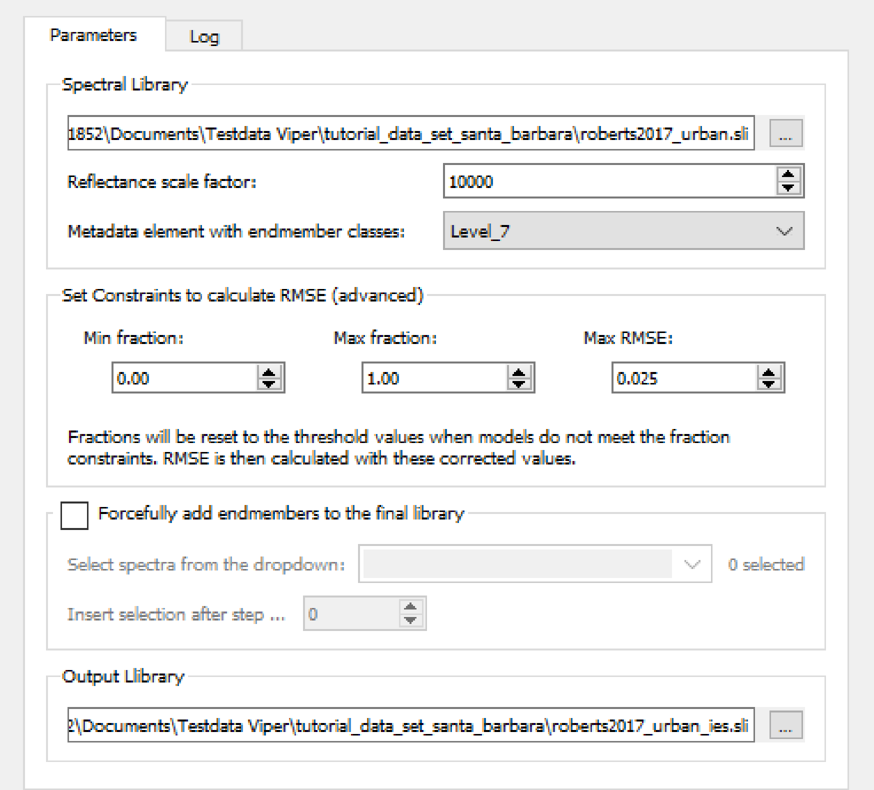
Forced IES:

- We will not use this option in this exercise.

Output:

- The default output name is *roberts2017_urban_ies.sli*.

Click **OK** to run IES. The progress should be shown on the log-tab. But since this is a very heavy process, QGIS might freeze for the duration of the process. IES is quite slow and might take a while.



Spectral Library

1852\Documents\Testdata Viper\tutorial_data_set_santa_barbara\roberts2017_urban.sli

Reflectance scale factor: 10000

Metadata element with endmember classes: Level_7

Set Constraints to calculate RMSE (advanced)

Min fraction: 0.00

Max fraction: 1.00

Max RMSE: 0.025

Fractions will be reset to the threshold values when models do not meet the fraction constraints. RMSE is then calculated with these corrected values.

□ Forcefully add endmembers to the final library

Select spectra from the dropdown: 0 selected

Insert selection after step ... 0

Output Llibrary

2\Documents\Testdata Viper\tutorial_data_set_santa_barbara\roberts2017_urban_ies.sli

Result

A summary of the algorithm's progress is saved as *roberts2017_urban_ies_summary.txt*. This summary file lists for each iteration the endmember name, kappa value and confusion matrix:

```
IES SUMMARY
----------------------------------------

Based on the spectral library: C:\Users\...\roberts2017_urban_subset.sli

Metadata
    Cass header: Level_7
    Unique classes: ADFA  ANNUAL_FORB  ARCA-SALE  ARGL  ARTIFICIAL_TURF  ...

Used a forced library? No

...

ITERATIVE PROCESS
----------------------------------------

Loop 0: new endmember: fscemm.015- (1431)
 - Kappa at this point: 0.061142445
 - Confusion Matrix:
       ...
Loop 1: new endmember: rpaeom.002- (475)
 - Kappa at this point: 0.098114274
 - Confusion Matrix:
       ...
```

From this file, we can see that the first endmember selected was *fscemm.015-*. This is a Composite Shingle spectrum that modeled 804 spectra in the library, of which 300 correct, generating a Kappa of 0.061142445. Thus, using this one spectrum our accuracy would be about 6%, but a majority of the library would be unclassified.

Examine the second iteration. You should see *rpaeom.002-*. This is a road asphalt spectrum that correctly classifies 166 spectra, resulting in an increase in kappa to 0.098114274.

Examining the Summary.txt file, we can see that kappa continues to increase until Loop 74. At this stage Kappa has risen to 0.5804497. In the next loop 75, the endmember *CEME04_X1566_Y99* was removed from the list.

The final library consists of 328 spectra (13 spectra were removed along the way).

For issues, bugs, proposals or remarks, visit the issue tracker.

Exercise: Run CRES in QGIS

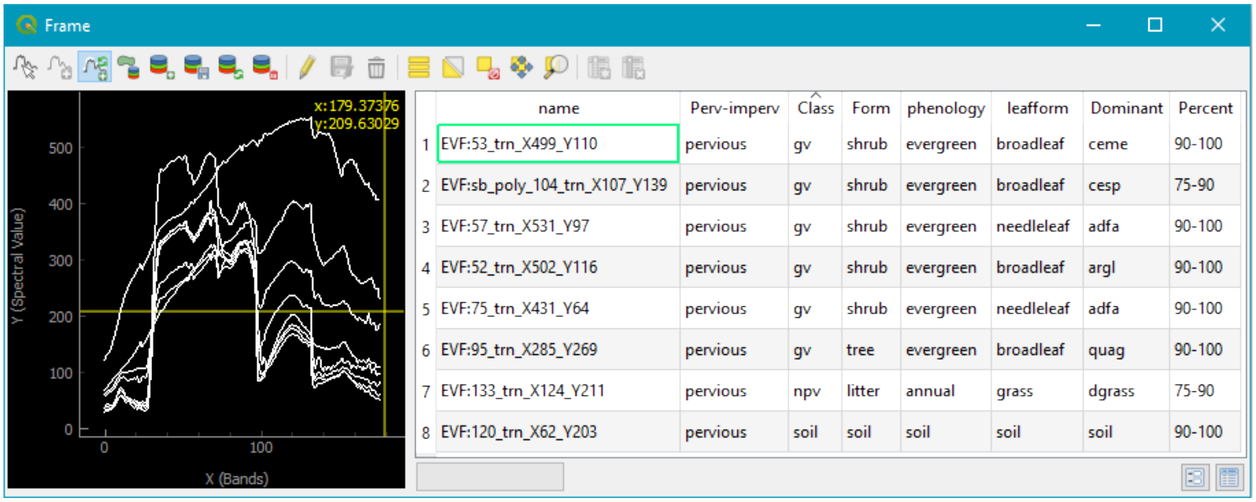
Objective: identify the best set of reference endmembers that unmix chamise, oak, manzanita, Ceanothus, soil and senescent grass with physically reasonable fractions.

Data used

We will start with a spectral library consisting of eight spectra to unmix. These spectra were selected to correspond to nearly pure stands of chamise (adfa: EVF75), big pod Ceanothus (ceme: EVF53), greenbark Ceanothus (cesp: EVF sb poly104), manzanita (argl: EVF52), coast live oak (EVF95) and soil (EVF120). Both senescent grass (EVF133) and senescent chamise (EVF57) are added, to see if we can locate an appropriate NPV that is not senescent grass.

- Library with Image Spectra: viper_tutorial_train_iem.sli

This library consists of laboratory and field spectra originally collected in southern California, Washington state and from libraries developed by the University of Washington. For this example, the library is convolved to the 2001 AVIRIS scene and further subsetted to include only spectra appropriate for Southern California.



	name	Perv-imperv	Class	Form	phenology	leafform	Dominant	Percent
1	EVF:53_trn_X499_Y110	pervious	gv	shrub	evergreen	broadleaf	ceme	90-100
2	EVF:sb_poly_104_trn_X107_Y139	pervious	gv	shrub	evergreen	broadleaf	cesp	75-90
3	EVF:57_trn_X531_Y97	pervious	gv	shrub	evergreen	needleleaf	adfa	90-100
4	EVF:52_trn_X502_Y116	pervious	gv	shrub	evergreen	broadleaf	argl	90-100
5	EVF:75_trn_X431_Y64	pervious	gv	shrub	evergreen	needleleaf	adfa	90-100
6	EVF:95_trn_X285_Y269	pervious	gv	tree	evergreen	broadleaf	quag	90-100
7	EVF:133_trn_X124_Y211	pervious	npv	litter	annual	grass	dgrass	75-90
8	EVF:120_trn_X62_Y203	pervious	soil	soil	soil	soil	soil	90-100

- Library for unmixing: 010627_westusa_all.sli

Part 1: Chamise

We will start with chamise (EVF75).

Image Spectrum:

- Select the library *viper_tutorial_train_iem.sli*.
- Select the spectrum *EVF:75_trn_X431_Y64*
- The reflectance scale factor is automatically detected as 10000 and can be left that way.

Spectral Library:

- Select the library *010627_westusa_all.sli*.
- The reflectance scale factor is automatically detected as 10000 and can be left that way.
- This should result in 1 042 695 models.
- Choose a RMSE threshold for the calculations. This can be left at 0.025.

Calculate SMA Fractions:

- Now the SMA fractions for each of the 1 042 695 models are calculated. This might take a while.
- This step has to be done only once per image spectrum.

You see now a table filed with models: the spectra names and fractions for each class, plus a shade fraction, plus the RMSE. There are 854 198 models in the table and not 1 042 695, because of the RMSE threshold we set earlier.

To limit the table even further, you can filter out absurd results by using the *RMSE*, *Minimum Fraction* and *Maximum Fraction* filters. Mind that with over 800 000 spectra, turning on a filter might also take a few moments. After turning all filters on, xxx models remain.

Calculate Index

Next, we need to *estimate the fractions* for chamise to allow CRES to search for models that will produce those fractions:

- We start with the following estimation: 50% GV, 0% Soil, 10% NPV and 40% Shade.

The we decide on the *weights for the index* calculations (see formula):

- Set the weights for the fractions to 1 and the RMSE to 10.
- Click *Calculate Index*.
- Sort by GV index.

Result for Chamise (adfa)

The best GV index (0.146) leads to a selections of *CCEOLSTCK* (52% GV, -1% Soil, 9% NPV, 40% Shade, RMSE of 0.014)

We can see that the fractions are nearly identical to our estimates, although the RMSE is a bit high. Given that *CCEOLSTCK* is an evergreen chaparral leaf spectrum from leaf stacks and *cadfa12671* is chamise stems, this is a very good first model.

If we **sort on RMSE**, we see our best fit is for *zsale42I6*, generating an RMSE of 0.009, but a physically unreasonable GV fraction of 1.10 (meaning the image endmember is brighter than the spectrum in the library.

Experiment with **changing the RMSE multiplier to 5**. We can see if we gave RMSE a smaller constraint, we get *QUDO1STCK* (GV 49%, NPV 10%, Shade 40% and RMSE of 0.016).

Part 2: big pod Ceanothus (ceme)

As a second example, we will see whether this spectrum might also work for ceme.

- **Image Spectrum**: change the spectrum to *EVF:53*
- **Calculate SMA Fractions**: redo the calculations

Looking at EVF53 several things stand out. First, it is much brighter than the other spectra, suggesting a lower shade fraction. Second, it has very low SWIR reflectance, suggesting a low NPV fraction and no soil.

- **Calculate Index**: fraction estimates: 65% GV, 0% Soil, 5% NPV and 30% Shade

Results for big pod Ceanothus (ceme)

Looking at our first estimate, we find a set of models that produces fractions that match our estimate. In addition, the RMSE is pretty high at 0.021.

We try **new fraction estimates**: 80% GV, 0% Soil, 0% NPV and 20% Shade

Using this model, we identify *CCEOLSTCK* as a viable model (78% GV, 1% soil, -3% NPV and 23% shade). However, we find that the RMSE is still poor at 0.024.

This may be our best model, given the library, but we will try one more test. We try **new fraction estimates**: 65% GV, 0% Soil, 0% NPV and 35% Shade

Our best selection is this case is *SASP12STCK* (64% GV, 0% soil, 2% NPV and 34% shade). The RMSE is still high at 0.02. This is probably the best we can do, given limitations in the reference library.

Part 3: coast live oak

We will conclude our GV search with coast live oak.

- **Image Spectrum**: change the spectrum to *EVF:95*
- **Calculate SMA Fractions**: redo the calculations

Looking at the spectrum, we can see that it is similar to the chamise spectrum in the NIR, but has lower visible and SWIR reflectance, suggesting lower NPV and slightly higher shade content.

- **Calculate Index**: fraction estimates: 50% GV, 0% Soil, 0% NPV and 50% Shade

Results for coast live oak

As our first choice, we find selected a *Quercus douglasii* spectrum. However, we also have several problems, including a high RMS (0.025) and 9% soil fraction.

Sifting down the list we actually see that *CCEOLSTK* gives better results, with 51% GV, 6% soil and 43% shade. The RMSE for model is better at 0.024 but still fairly high.

From these three experiments, we would **conclude that CCEOLSTCK is our best overall model**, but still not ideal for this scene because of a high RMSE.

Part 4: senescent grass

- **Image Spectrum**: change the spectrum to *EVF:133*
- **Calculate SMA Fractions**: redo the calculations

Looking at the spectrum, we would suggest a modest shade fraction (20%), minor soil (5%) and no GV.

- **Calculate Index**: fraction estimates: 0% GV, 5% Soil, 75% NPV and 20% Shade

Results for senescent grass

As our first selection we get *u9litt01-av*. This is a spectrum of senescent grass measured in the field using an ASD. This model has a very good fit (0.012 RMSE), but requires 17% soil and 20% shade.

While this may be an excellent model, we will try one more by changing the RMSE weight to 5 instead of 10. This has little impact, forcing us to conclude that the soil fraction was probably higher than the initial estimate of 5%.

Part 5: senescent chamise

Next, we will see if we can determine a more appropriate NPV for chamise.

- **Image Spectrum**: change the spectrum to *EVF:57*
- **Calculate SMA Fractions**: redo the calculations

We Looking at this spectrum we can see it is obviously highly mixed, including GV, shade, NPV and probably rock or soil.

Calculate Index: fraction estimates: 25% GV, 15% Soil, 30% NPV and 30% Shade. Keep the RMSE weight at 5.

Results for senescent chamise

As our first pass, we select a fairly reasonable model, consisting of stems from Artemisia calfornica, a soil from the Santa Monica Mountains and leaves from Eriogonum cinarium (an evergreen shrub).

We also see that *u9litt01* produces a reasonable model for this spectrum (33% NPV, 22% GV, 15% soil and 30% shade). Given this result, we stick with *u9litt01*.

Part 6: Soil

We will conclude with a search for a soil spectrum.

- **Image Spectrum**: change the spectrum to *EVF:120*
- **Calculate SMA Fractions**: redo the calculations

Given that this soil is fairly bright, we will start with a low shade fraction of 5%. There is also very little evidence of any senescent material, so we will set the NPV to 0%.

Calculate Index: fraction estimates: 0% GV, 95% Soil, 0% NPV and 5% Shade. Keep the RMSE weight at 5.

Results for Soil

Our first model turns out to be pretty good. We select *DCSMM68.DAT* (4% shade, 3% NPV and 92% soil). The only negative is a higher RMSE of 0.019.

We can try a **second model** setting the RMSE weight to 10.

In this case we select *J9009181*. However, this model also requires a slight negative GV fraction, 105% soil and no shade. *DCSMM68.DAT* is the better model.

Conclusion

To summarize, we have one GV, NPV and Soil that appear to be reasonable for all of the image endmembers: - CCEOLSTCK (GV) - u9litt01-av (NPV) - DCSMM68.DAT (Soil)

For issues, bugs, proposals or remarks, visit the issue tracker.

For issues, bugs, proposals or remarks, visit the issue tracker.

CITATIONS

CHAPTER 4

Spectral Library Tool API

Source code: https://bitbucket.org/kul-reseco/spectral-libraries/src.

For issues, bugs, proposals or remarks, visit the issue tracker.

4.1 Spectral Library Optimization

4.1.1 EAR MASA COB Module

———————————————————————————————————————-

Date : August 2018
Copyright : © 2018 - 2020 by Ann Crabbé (KU Leuven)
Email : acrabbe.foss@gmail.com
Acknowledgements : Translated from VIPER Tools 2.0 (UC Santa Barbara, VIPER Lab).
Dar Roberts, Kerry Halligan, Philip Dennison, Kenneth Dudley, Ben Somers, Ann Crabbé

This file is part of the Spectral Libraries QGIS plugin and python package.

———————————————————————————————————————-

class `spectral_libraries.core.ear_masa_cob.`**`EarMasaCob`**

Bases: `object`

Calculate EAR, MASA, and CoB values from a spectral library.

- EAR = Endmember Average RMSE
- MASA = Minimum Average Spectral Angle
- CoB = Count based Endmember selection (CoB)

Citation EAR:

Dennison, P.E., Roberts, D.A., 2003, Endmember Selection for Multiple Endmember Spectral Mixture Analysis using Endmember Average RMSE, Remote Sensing of Environment, 87, p. 123-135.

Citation MASA:

Dennison, P.E., Halligan, K. Q., Roberts, D.A., 2004, A Comparison of Error Metrics and Constraints for Multiple Endmember Spectral Mixture Analysis and Spectral Angle Mapper, Remote Sensing of Environment, 93, p. 359-367.

Citations CoB:

Roberts, D.A., Dennison, P.E., Gardner, M.E., Hetzel, Y., Ustin, S.L., Lee, C.T., 2003, Evaluation of the potential of Hyperion for fire danger assessment by comparison to the Airborne Visible/Infrared Imaging Spectrometer, IEEE Transactions on Geoscience and Remote Sensing, 41, p. 1297-1310.

Clark, M., 2005, An assessment of Hyperspectral and LIDAR Remote Sensing for the Monitoring of Tropical Rain Forest Trees, PhD Dissertation, UC Santa Barbara, 319 p.

static execute(*library: numpy.array*, *class_list: numpy.array*, *constraints: tuple = (-0.05*, *1.05*, *0.025)*, *reset: bool = True*, *log: callable = <built-in function print>*)

Calculate EAR, MASA and COB parameters.

Beware of the square array used as input! Ideally it is built in 'reset' mode. The constraints band has 6 possible values indicating which constraint was breached:

- 0 = no breach
- 1/2 = a fraction constraint breached (reset/no reset)
- 3 = RMSE constraint breached
- 4/5 = 1/2 (fractions reset/no reset) + 3 (RMSE)

Parameters

- **`library`** – spectral library [spectra as columns], scaled to reflectance values, without bad bands
- **`class_list`** – str array with the class for each spectrum (e.g. GV or SOIL)
- **`constraints`** – min fraction, max fraction and max RMSE. Use (-9999, -9999, -9999) for unconstrained.
- **`reset`** – fractions are reset to threshold values in case of breach, BEST TURNED ON
- **`log`** – log function

Returns ear, masa, cob_in, cob_out, cob_ratio: all 1-D arrays complementing the original library's metadata.

4.1.2 IES Module

Date : August 2018

Email : acrabbe.foss@gmail.com

Acknowledgements : Translated from VIPER Tools 2.0 (UC Santa Barbara, VIPER Lab).
Dar Roberts, Kerry Halligan, Philip Dennison, Kenneth Dudley, Ben Somers, Ann Crabbé

This file is part of the Spectral Libraries QGIS plugin and python package.

---

class `spectral_libraries.core.ies.`**`Ies`**

Bases: `object`

Iterative Endmember Selection (IES) is used to identify the spectral library subset that provides the best class separability. The basis for this is a RMSE-based kappa coefficient. In an iterative manner, endmembers are added and removed from the subset until the kappa coefficient no longer improves.

Citations:

Schaaf, A.N., Dennison, P.E., Fryer, G.K., Roth, K.L., and Roberts, D.A., 2011, Mapping Plant Functional Types at Multiple Spatial Resolutions using Imaging Spectrometer Data, GIScience Remote Sensing, 48, p. 324-344.

Roth, K.L., Dennison, P.E., and Roberts, D.A., 2012, Comparing endmember selection techniques for accurate mapping of plant species and land cover using imaging spectrometer data, Remote Sensing of Environment, 127, p. 139-152.

`execute`(*library: numpy.array*, *class_list: numpy.array*, *constraints: tuple = (-0.05, 1.05, 0.025)*, *forced_list: numpy.array = None*, *forced_step: int = None*, *multiprocessing: bool = True*, *summary: bool = False*, *set_progress: callable = None*, *log: callable = <built-in function print>*)

Execute the IES algorithm. The result is a 1-D numpy array of selected endmembers. In case a summary is requested, it is delivered as a second output variable.

Parameters

- **`library`** – spectral library [spectra as columns], scaled to reflectance values, without bad bands
- **`class_list`** – int array with the *numerical* class for each spectrum (e.g. GV = 1, SOIL = 2)

- **constraints** – min fraction, max fraction and max RMSE.
- **forced_list** – int array with indices of the endmembers that should be forcefully included
- **forced_step** – the loop in which the forced_list should be included (starting from 0)
- **multiprocessing** – use multiprocessing or not (option is deactivated)
- **summary** – return a summary of the process or not
- **set_progress** – communicate progress (refer to the progress bar in case of GUI; otherwise print to console)
- **log** – communicate messages (refer to the print_log tab in the GUI; otherwise print to the console)

Returns numpy array with the indices of the selected endmembers [+ summary as a dict in case requested]

`spectral_libraries.core.ies.`**`printProgress`**`(`*value: int*`)`

Replacement for the GUI progress bar

4.1.3 Cres Module

———————————————————————————————————————-

Date : August 2018

Copyright : © 2018 - 2020 by Ann Crabbé (KU Leuven)

Email : acrabbe.foss@gmail.com

Acknowledgements : Translated from VIPER Tools 2.0 (UC Santa Barbara, VIPER Lab).

Dar Roberts, Kerry Halligan, Philip Dennison, Kenneth Dudley, Ben Somers, Ann Crabbé

This file is part of the Spectral Libraries QGIS plugin and python package.

This program is free software: you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or any later version.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied
warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License (COPYING.txt). If not see www.gnu.org/licenses.

———————————————————————————————————————-

class `spectral_libraries.core.cres.`**`Cres`**

Bases: `object`

Constrained Reference Endmember Selection. Unmix a given signal with all models in a library. Then create an index to see which models are a close match to estimated fractions.

Citations:

Roberts, D.A., Smith, M.O., Adams, J.B., 1993, Green vegetation, non-photosynthetic vegetation and soils in AVIRIS data, Remote Sensing of Environment, 44, p. 255-270.

Roberts, D.A., Batista, G., Pereira, J., Waller, E., and Nelson, B., 1999, Change Identification using Multitemporal Spectral Mixture Analysis: Applications in Eastern Amazonia, Remote Sensing Change Detection: Environmental Monitoring Methods and Applications, Edited by Elvidge, C. and Lunetta R., Chapter 9, p. 137-161.

execute(*signal: numpy.array*, *library: numpy.array*, *classes: list*, *spectrum_names: list*, *rmse_constraint: float = 0.025*, *shade: numpy.array = array([], dtype=float64)*)

Unmix a given signal with a library and create fractions and RMSE values for each endmember in that library.

Parameters

- **signal** – The signal to unmix, without bad bands and scaled to reflectance values.
- **library** – The library used for unmixing, without bad bands and scaled to reflectance values.
- **classes** – The class of each spectrum in the library (e.g. GV, SOIL, . . .) [list-of-str]
- **spectrum_names** – The name of each spectrum in the library [list-of-str]
- **rmse_constraint** – Only keep models that fulfill this constraint.
- **shade** – Shade-spectrum in case of non-photometric shade.

get_fractions() → list

Get the calculated fractions (and RMSE) as a list of dictionaries, specifically designed for a QTableModel. In the list, each dictionary represents one endmember combination from the library (=one model). Assuming we have n classes in the library, each model's dictionary has n key-value pairs with the spectra names, n key-value pairs with the fractions, one key-value pair with the shade fraction and one key-value pair with the RMSE.

The dictionary keys match the table header names.

Example for gv-soil mixture:

```
{gv_name: tree1, soil_name: clay4, gv_fraction: 0.25, soil_fraction: 0.55,␣
↪shade_fraction: 0.20, rmse: 0.01}
```

Returns A list of dictionaries, one per model, containing the spectra names, fractions and RMSE.

get_header() → list

Get the header for the QTableModel. It has header names for the spectra names, fractions and RMSE. The header names match the keys in the table dictionaries.

Example for gv-soil mixture:

```
['gv_name', 'soil_name', 'gv_fraction', 'soil_fraction', 'shade_fraction',
↪'RMSE']
```

Returns The header for the GUI QTableModel.

index(*target_fractions: list*, *weight_per_target: list*, *weight_rmse: int*) → dict

Calculate the CRES indices based on input from the user.

Example for GV-SOIL-NPV mixture:

```
GV index = rmse weight * rmse
+ |GV calculated - estimated fraction| * GV weight
+ |SOIL calculated - estimated fraction|
+ |NPV calculated - estimated fraction|
+ |Shade calculated - estimated fraction|
```

Parameters

- **target_fractions** – The estimated fractions of the spectrum that is being unmixed (list-of-floats).
- **weight_per_target** – The weights per class for calculating the indices (list-of-ints between 1 and 10).
- **weight_rmse** – The weight attached to the RMSE for calculating the indices (int between 1 and 10).

Returns Indices for each endmember and each class. The unique classes from the library metadata are the keys.

4.1.4 MUSIC Module

—————————————————————————————————-

Date : June 2020

Email : acrabbe.foss@gmail.com

Acknowledgements : Jeroen Degerickx (KU Leuven). Documentation: https://doi.org/10.3390/rs9060565.

This file is part of the Spectral Libraries QGIS plugin and python package.

—————————————————————————————————-

class spectral_libraries.core.music.**Music**

Bases: object

MUSIC (multiple signal classification) is a library pruning technique that operates on a full image.

This technique reduces the dimensionality of an image to kf eigenvectors, and prunes a library according to the smallest distances to this subspace.

Citation: Iordache, M.D., Bioucas-Dias, J.M., Plaza, A., Somers, B., 2014, MUSIC-CSR: Hyperspectral unmixing via multiple signal classification and collaborative sparse regression, IEEE Transactions on Geoscience and Remote Sensing, 52, p. 4364–4382.

estimate_noise(*image*)

Hyperspectral noise estimation, by assuming that the reflectance at a given band is well modelled by a linear regression on the remaining bands.

Parameters **image** – 2D hyperspectral data set (m bands x n pixels)

Returns the noise estimates for every pixel (m x n)

execute(*library: numpy.array*, *image: numpy.array*, *library_size: int*, *min_eig: int = 15*, *log: callable = <built-in function print>*) → dict

This technique reduces the dimensionality of an image to kf eigenvectors, and select library spectra according to the smallest distances to this subspace.

Parameters

- **library** – the original spectral library to be pruned (bands x spectra), reflectance, no bad bands
- **image** – image used for pruning (bands x rows x columns) reflectance, no bad bands
- **library_size** – pruned library size
- **min_eig** – minimum number of eigenvectors to be retained from the image to calculate MUSIC distances
- **log** – communicate messages (point to the print_log tab in the GUI; otherwise print to the console)

Returns

dictionary with each output metric as a numpy array in a key-value pair - music_indices: indices of the pruned library - eigenvectors: first kf eigenvectors of image subspace (needed for sparse unmixing)

kf = estimated number of eigenvectors in the image estimated by Hysime algorithm

- music_distances: MUSIC distances of the pruned library spectra to the image, sorted from low to high

static flatten_image(*image: numpy.array*) → numpy.array

Store the image as a line (2D array).

Parameters **image** – 3D image (m bands x n rows x p columns)

Returns 2D image (m bands x n.p spectra

hysime2(*image*, *min_eig*)

Hysime2 algorithm

Parameters

- **image** – 2D hyperspectral data set (m bands x n pixels)
- **min_eig** – minimum number of eigenvectors to be retained from the image to calculate MUSIC distances

Returns signal subspace dimension (tuple), eigenvectors that span the signal subspace (in the columns)

static normalize_brightness(*spectra: numpy.array*) → numpy.array

Brightness normalization of spectral library or 2D-image

Parameters **spectra** – array with m bands x n spectra

Returns array with normalized spectral

4.1.5 AMUSES Module

Date : June 2020

Email : acrabbe.foss@gmail.com

Acknowledgements : Jeroen Degerickx (KU Leuven). Documentation: https://doi.org/10.3390/rs9060565.

This file is part of the Spectral Libraries QGIS plugin and python package.

---

class `spectral_libraries.core.amuses.`**`Amuses`**

Bases: `object`

AMUSES Prunes a spectral library with regard to an image and internal redundancy.

Degerickx, J.; Okujeni, A.; Iordache, M.-D.; Hermy, M.; van der Linden, S.; Somers, B. A Novel Spectral Library Pruning Technique for Spectral Unmixing of Urban Land Cover. Remote Sens. 2017, 9, 565.

static execute(*image: numpy.array*, *library: numpy.array*, *music_pct: float = 0.9*, *amuses_pct: float = 0.95*, *min_eig: int = 15*, *thresholds: tuple = (0.0002, 0.02)*, *log: callable = <built-in function print>*, *set_progress: callable = None*) → dict

AMUSES Prunes a spectral library with regard to an image and internal redundancy.

Parameters

- **image** – image used for pruning (bands x rows x columns), reflectance, no bad bands
- **library** – the original spectral library to be pruned (bands x spectra), reflectance, no bad bands
- **music_pct** – final pruned library size for the MUSIC algorithm (in pct)
- **amuses_pct** – library size for the AMUSES algorithm (in pct)
- **min_eig** – minimum number of eigenvectors to be retained from the image to calculate MUSIC distances,
- **thresholds** – low and high threshold for the AMUSES algorithm
- **log** – log function
- **set_progress** – communicate progress (refer to the progress bar in case of GUI; otherwise print to console)

Returns

dictionary with each output metric as a numpy array in a key-value pair - music_indices: library indices after pruning with the MUSIC algorithm - music_eigenvectors: first kf eigenvectors of image subspace (needed for sparse unmixing)

kf = estimated number of eigenvectors in the image estimated by Hysime algorithm

- music_distances: MUSIC distances of the pruned library spectra to the image, sorted from low to high
- amuses_indices: library indices after pruning with the AMUSES algorithm

`spectral_libraries.core.amuses.`**`printProgress`**(*value: int*)

Replacement for the GUI progress bar

See the User Guide for instructions on using the **Command Line Interface**.

CHAPTER 5

About The Spectral Library Tool

The Spectral Library Tool software package is both a QGIS plugin and stand-alone python package that provides a suite of processing tools for multi- and hyperspectral spectral libraries.

The software is based on VIPER Tools: code written for ENVI/IDL and released in 2007. Several updates have been released since and now it has been ported to PyQGIS in the period 2017 - 2020. The original VIPER Tools is now split over two python/QGIS tools: Spectral Library Tools and MESMA.

Spectral Library Tool provides the following:

- Creating spectral libraries interactively (selecting spectra from an image or using regions of interest) and managing the metadata (developed by HU Berlin)
- Optimizing spectral libraries with Iterative Endmember Selection, Ear-Masa-Cob, CRES, MUSIC or AMUSES
- Website: <https://spectral-libraries.readthedocs.io>
- Repository: https://bitbucket.org/kul-reseco/spectral-libraries

MESMA provides the following:

- Running SMA and MESMA (with multi-level fusion, stable zone unmixing, . . .)
- Post-processing of the MESMA results (visualisation tool, shade normalisation, . . .)
- Website: <https://mesma.readthedocs.io>
- Repository: https://bitbucket.org/kul-reseco/mesma

The software has now been developed in the open source environment to encourage further development of the tool.

PLEASE GIVE US CREDIT

When using The Spectral Library Tool, please use the following citation:

Crabbé, A. H., Jakimow, B., Somers, B., Roberts, D. A., Halligan, K., Dennison, P., Dudley, K. (2020). Spectral Library QGIS Plugin (Version x) [Software]. Available from https://bitbucket.org/kul-reseco/spectral-libraries.

ACKNOWLEDGEMENTS

The software and user guide are based on VIPER Tools 2.0 (UC Santa Barbara, VIPER Lab): Roberts, D. A., Halligan, K., Dennison, P., Dudley, K., Somers, B., Crabbe, A., 2018, Viper Tools User Manual, Version 2, 91 pp.

The software also makes use of the QGISPluginSupport python packages developed by Benjamin Jakimow (HU Berlin): https://bitbucket.org/jakimowb/qgispluginsupport.

The MUSIC and AMUSES algorithms are based on work and code by Jeroen Degerickx (KU Leuven): https://doi.org/10.3390/rs9060565.

This revision is funded primarily through BELSPO (the Belgian Science Policy Office) in the framework of the STEREO III Programme – Project LUMOS - SR/01/321.

Logo's were created for free at https://logomakr.com.

SOFTWARE LICENSE

5.1 Indexes

- genindex
- modindex

Bibliography

[BioucasDias2008] Bioucas-Dias JM, Nascimento JMP. 2008. Hyperspectral Subspace Identification. IEEE Transactions on Geoscience and Remote Sensing, volume 46, p. 2435-2445.

[Clark2005] Clark M. 2005. An assessment of Hyperspectral and Lidar Remote Sensing for the Monitoring of Tropical Rain Forest Trees. University of California, Santa Barbara, 319 pp.

[Degerickx2016] Degerickx J, Iordache MD, Okujeni A, Hermy M, van der Linden S, Somers B. 2016. Spectral unmixing of urban land cover using a generic library approach. In Proceedings of the SPIE 10008, Remote Sensing Technologies and Applications in Urban Environments, Edinburgh, UK, 26 September 2016.

[Degerickx2017] Degerickx J, Okujeni A, Iordache M-D, Hermy M, van der Linden S, Somers B. 2017. A Novel Spectral Library Pruning Technique for Spectral Unmixing of Urban Land Cover. Remote Sensing, volume 9, 565.

[Dennison2003] Dennison PE, Roberts DA. 2003. The Effects of Vegetation Phenology on Endmember Selection and Species Mapping in Southern California Chaparral. Remote Sensing of Environment, volume 87, p. 295-309.

[Dennison2004] Dennison PE, Halligan KQ and Roberts DA. 2004. A Comparison of Error Metrics and Constraints for Multiple Endmember Spectral Mixture Analysis and Spectral Angle Mapper. Remote Sensing of Environment, volume 93, p. 359-367.

[Dudley2015] Dudley KL, Dennison PE, Roth KL, Roberts DA and Coates AR. 2015. A Multitemporal Spectral Library Approach for Mapping Vegetation Species Across Spatial and Temporal Phenological Gradients. Remote Sensing of Environment, volume 167, p. 121-134.

[Fernandez2016] Fernandez-Manso A, Quintano C and Roberts DA. 2016. Burn severity influence on post-fire vegetation cover resilience from Landsat MESMA fraction images time series in Mediterranean forest ecosystems. Remote Sensing of Environment, volume 184, p. 112-123.

[Gardner1997] Gardner M. 1997. Mapping chaparral with AVIRIS using Advanced Remote Sensing Techniques. University of California, Santa Barbara, 58 pp.

[Halligan2002] Halligan KQ. 2002. Multiple Endmember Spectral Mixture Analysis of Vegetation in the Northeast Corner of Yellowstone National Park. University of California, Santa Barbara, 64 pp.

[Iordache2014] Iordache MD, Bioucas-Dias JM, Plaza A, Somers B. 2014. MUSIC-CSR: Hyperspectral unmixing via multiple signal classification and collaborative sparse regression. IEEE Transactions on Geoscience and Remote Sensing, volume 52, p. 4364-4382.

[Padma2014] Padma S, Sanjeevi S. 2014. Jeffries Matusita based mixed-measure for improved spectral matching in hyperspectral image analysis. International Journal of Applied Earth Observation and Geoinformation, volume 32, p. 138-151.

[Quintano2017] Quintano C, Fernandez-Manso A and Roberts DA. 2017. Burn severity mapping from Landsat MESMA fraction images and Land Surface Temperatures. Remote Sensing of Environment, volume 190, p. 83-95.

[Roberts1993] Roberts DA, Adams JB and Smith MO. 1993. Discriminating Green Vegetation, Non-Photosynthetic Vegetation and Soils in AVIRIS Data. Remote Sensing of Environment, volume 44, p. 255-270.

[Roberts1997] Roberts DA, Gardner ME, Church R Ustin SL and Green RO. Optimum Strategies for Mapping Vegetation using Multiple Endmember Spectral Mixture Models. Proceedings of the SPIE, volume 3118, p. 108-119.

[Roberts1998] Roberts DA, Gardner M, Church R, Ustin S, Scheer G and Green RO. 1998. Mapping Chaparral in the Santa Monica Mountains using Multiple Endmember Spectral Mixture Models, Remote Sensing of Environment, volume 65, p. 267-279.

[Roberts2002] Roberts DA, Numata I, Holmes KW, Batista G, Krug T, Monteiro A, Powell B and Chadwick O. 2002. Large area mapping of land-cover change in Rondônia using multitemporal spectral mixture analysis and decision tree classifiers. Journal of Geophysical Research: Atmospheres, volume 107, p. 40-1 to 40-18.

[Roberts2003] Roberts DA, Dennison PE, Gardner M, Hetzel Y, Ustin SL and Lee C. 2003. Evaluation of the Potential of Hyperion for Fire Danger Assessment by Comparison to the Airborne Visible/Infrared Imaging Spectrometer. IEEE Transactions on Geoscience and Remote Sensing, volume 41, p. 1297-1310.

[Roberts2004] Roberts DA, Ustin SL, Ogunjemiyo S, Greenberg J, Dobrowski SZ, Chen J and Hinckley TM. 2004. Spectral and structural measures of Northwest forest vegetation at leaf to landscape scales, Ecosystems, volume 7, p. 545-562.

[Roberts2015] Roberts DA, Dennison PE, Roth KL, Dudley K and Hulley G. 2015. Relationships Between Dominant Plant Species, Fractional Cover and Land Surface Temperature in a Mediterranean Ecosystem. Remote Sensing of Environment, volume 167, p. 152-167.

[Roth2012] Roth KL, Dennison PE and Roberts DA. 2012. Comparing endmember selection techniques for accurate mapping of plant species and land cover using imaging spectrometer data. Remote Sensing of Environment, volume 127, p. 139-152.

[Roth2015] Roth KL, Roberts DA, Dennison PE, Alonzo M, Peterson SH and Beland M. 2015. Differentiating Plant Species within and across Diverse Ecosystems with Imaging Spectroscopy. Remote Sensing of Environment, volume 167, p. 135-151.

[Schaaf2011] Schaaf AN, Dennison PE, Fryer GK, Roth KL and Roberts DA. 2011. Mapping Plant Functional Types at Multiple Spatial Resolutions using Imaging Spectrometer Data. GIScience Remote Sensing, volume 48, p. 324-344.

[Wu2004] Wu C. 2004. Normalized spectral mixture analysis for monitoring urban composition using ETM+ imagery. Remote Sensing of Environment, volume 93, p. 480-492.

[Herold2004] Herold M, Roberts DA, Gardner ME and Dennison PE. 2004. Spectrometry for urban area remote sensing – Development and analysis of a spectral library from 350 to 2400 nm. Remote Sensing of Environment, volume 91, p. 304-319.

[Roberts2003] Roberts DA, Dennison PE, Gardner M, Hetzel Y, Ustin SL and Lee C. 2003. Evaluation of the Potential of Hyperion for Fire Danger Assessment by Comparison to the Airborne Visible/Infrared Imaging Spectrometer. IEEE Transactions on Geoscience and Remote Sensing, volume 41, p. 1297-1310.

[Roberts2015] Roberts DA, Dennison PE, Roth KL, Dudley K and Hulley G. 2015. Relationships Between Dominant Plant Species, Fractional Cover and Land Surface Temperature in a Mediterranean Ecosystem. Remote Sensing of Environment, volume 167, p. 152-167.

[Roberts2017] Roberts DA, Alonzo M, Wetherley E, Dudley K and Dennison P. 2017. Scale in Remote Sensing and GIScience Applications. Chapter: Multiscale Analysis of Urban Areas using Mixing Models, p. 247-282.

[Roth2012] Roth KL, Dennison PE and Roberts DA. 2012. Comparing endmember selection techniques for accurate mapping of plant species and land cover using imaging spectrometer data. Remote Sensing of Environment, volume 127, p. 139-152.

Python Module Index

Index