



# Introduction to the IUCN Red List of Ecosystems Categories and Criteria

Course Manual

Version 1.0



International Union for Conservation of Nature





# Introduction to the IUCN Red List of Ecosystems Categories and Criteria

Course Manual

## **IUCN Red List of Ecosystems**

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# 1. RLE Training Course

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Welcome to the training course for the introduction of the IUCN Red List of Ecosystems Categories and Criteria. We will work through a range of exercises supported by lectures over the next few days, with the aim of providing an in-depth introduction to all aspects of the IUCN Red List of Ecosystems required to complete an assessment of one or more ecosystems. This training course is intended to be accompanied by the [Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria](#), which is the definitive source for all information required to ensure consistent application of the criteria (Bland *et al.*, 2016).

## 1.1 Structure of this course

The training course and course manual are intended as a self-learning exercise which is supported by experts in ecosystem risk assessment. Our course will follow the general process for assessing ecosystems as depicted in Figure 1. We will begin with a series of introductory lectures that provides the history, background and purpose of the IUCN Red List of Ecosystems (RLE). Following this, we will develop the theoretical basis for assessing ecosystems under the RLE categories and criteria, allowing us to (i) define an ecosystem type under assessment, (ii) identify and describe the key features and processes of the ecosystem, (iii) map the distribution of the ecosystem type and (iv) collect the data necessary for submitting to the IUCN for publication.

The remainder of the course will follow a series of lectures and practical exercises to ensure a thorough understanding of the application of the categories and criteria. Using a case study provided by the course instructors, we will then work through each of the criteria, enabling us to assess the ecosystem type with a range of tools and resources. You may wish to use your own dataset to complete these exercises. If you move quickly or have no access to ArcGIS, we provide extra material at the end of each chapter which can be worked through in your own time.

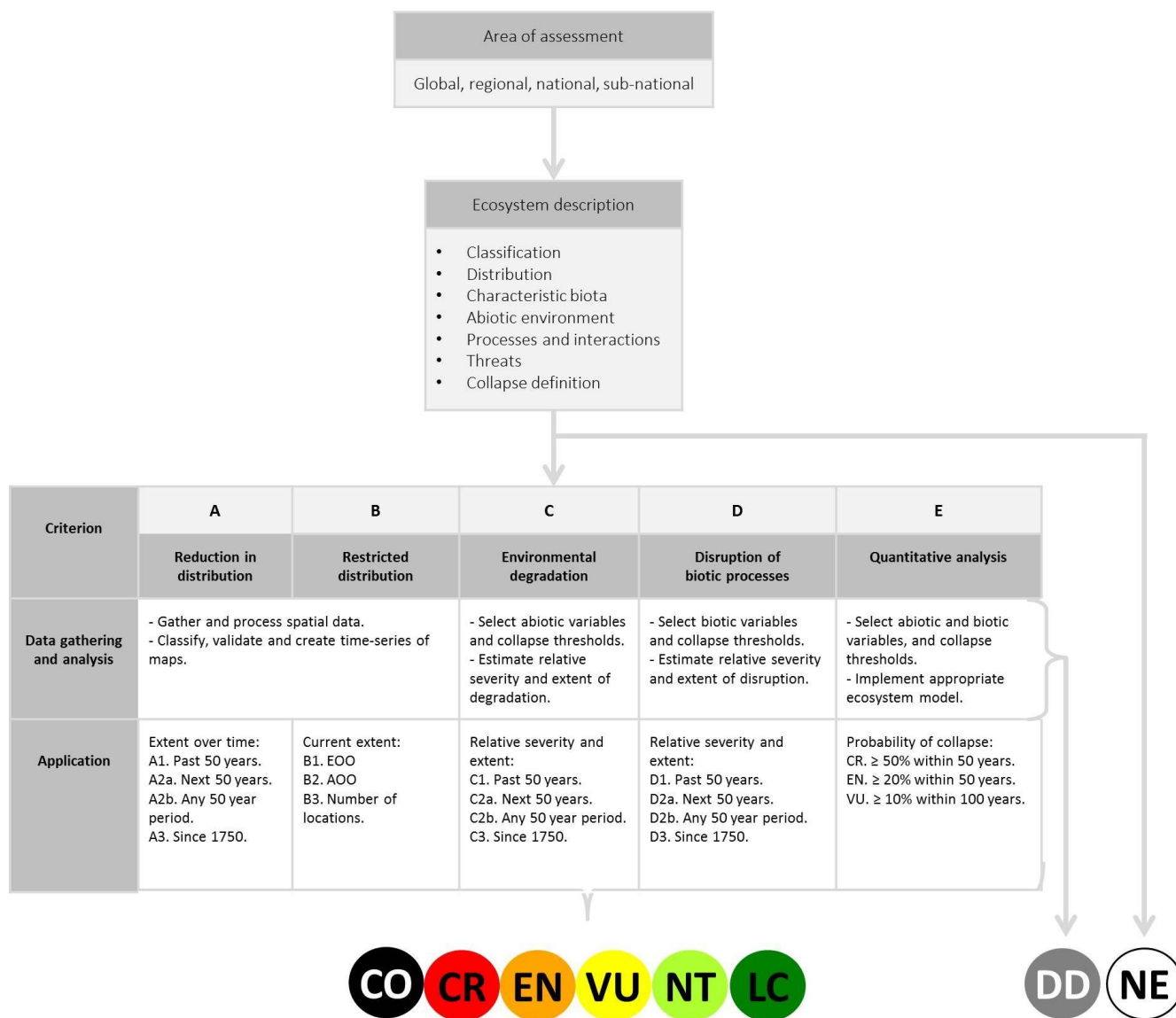
Lastly, we will determine the final outcome of the ecosystem risk assessment, enabling a final classification of the status of the focal ecosystem. At all times we will allow time for questions, discussion and you can feel free to contact us by email.

## 1.2 Tools and resources

In this course we provide a range of tools and resources for completing a Red List of Ecosystems assessment (available from [iucnrle.org](http://iucnrle.org)). The main tools we will use include:

1. ArcGIS. Optional to use QGIS, Grass or some other open source software. We are working towards extending our documentation to include open-source software.
2. Microsoft Excel or Google Spreadsheets.
3. We also use R and Python for many of the analyses. For analytical tools and functions written in these programming languages please go to:

<https://github.com/nick-murray>



**Figure 1.** Process for assessing the risk of collapse of an ecosystem type.

Red List of Ecosystems Assessment Criteria						
Criterion	A	B	C	D	E	Overall
Subcriterion 1	A1:	B1a:	C1:	D1:	E:	
		B1b:				
		B1c:				
Subcriterion 2	A2a:	B2a:	C2a:	D2a:		
	A2b:	B2b:	C2b:	D2b:		
		B2c:				
Subcriterion 3	A3:	B3:	C3:	D3:		

**Table 1.** Overall assessment table. Fill this table out as you work through the exercises in this book.



## 2. Exercises: Day 1

---

We will begin the exercises with a preliminary analysis of a dataset depicting the spatial distribution of an ecosystem type. This assumes that we have fully defined our focal ecosystem type, its characteristic native biota and abiotic environment, and have a good understanding of the key drivers that influence the ecosystem type. As we have discussed in the first lectures of the course, much of this information will be based on your own expertise of the ecosystem type, a detailed literature review of published and grey literature, discussion with experts, and clarification with experts on ecosystem risk assessment.

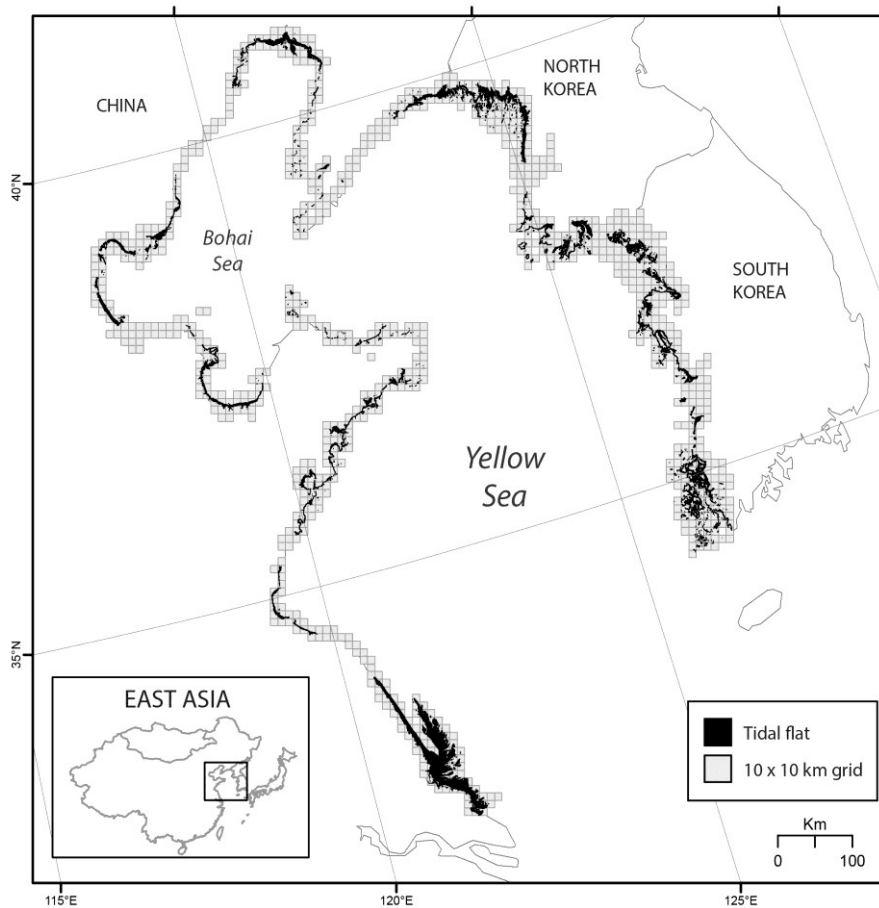
### 2.1 Mapping an ecosystem

In this course we will not undertake any remote sensing, vegetation classifications, map digitization or any other work required for mapping an ecosystem type. Instead, we will use a time series dataset that was the foundation of the RLE assessment of the *Tidal Flats of the Yellow Sea* (Murray *et al.*, 2015). The details of the mapping methods have been reported in several scientific publications (Murray *et al.*, 2014a, Murray & Fuller, 2015, Murray *et al.*, 2015, Murray *et al.*, 2012) and the datasets are available in an online data repository (Murray *et al.*, 2014b).

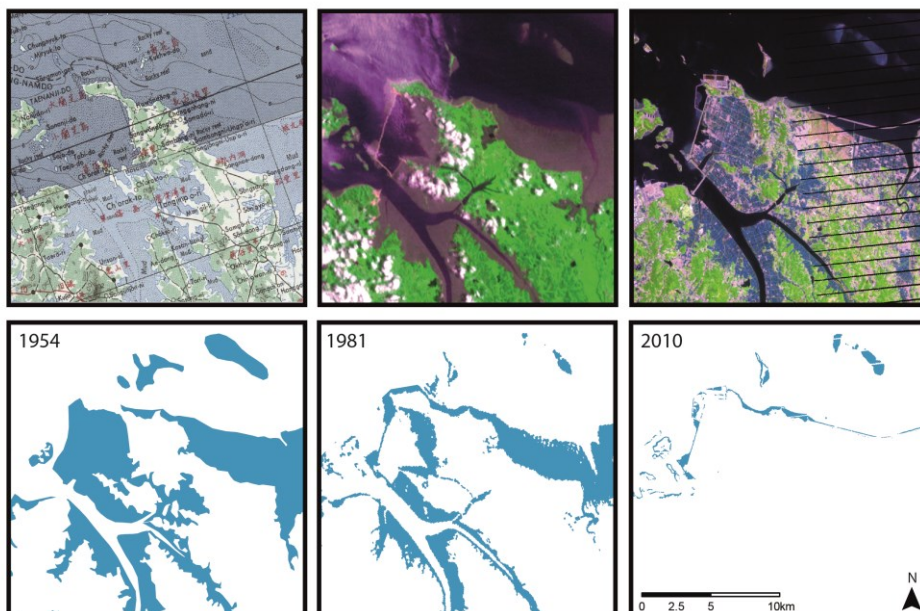
The datasets are provided as shapefiles and raster format, but in this course we will use shapefiles only. If you have raster data for an ecosystem type, feel free to visit our tools website for a range of workflows that enable similar analyses of raster data (<https://github.com/nick-murray>). Alternatively, it is possible to convert a raster data to polygon (shapefile) format and follow the same workflow.

The three maps (Figure 3) that have been provided are:

1. A 1950s map of intertidal areas developed from US Army topographic maps (1:100000)
2. A 1980s map of intertidal areas developed from Landsat TM data (originally 30m spatial grain, generalised to 100m pixel size and converted to shapefile).
3. A 2000s map of intertidal areas developed from Landsat ETM+ data (originally 30m spatial grain, generalised to 100m pixel size and converted to shapefile). Note that this dataset contains stripes from a malfunction of the Landsat 7 satellite, so will only be used for demonstration purposes only.



**Figure 2.** The spatial distribution of the Yellow Sea tidal flat ecosystem.



**Figure 3.** Example of the time-series data we will use in this course. Here, historical topographic maps (1954) and Landsat Archive satellite imagery (1981, 2010) allowed a standardised time-series of the area of the Yellow Sea tidal flat ecosystem to be developed for assessment under criterion A (Murray *et al.*, 2014a, Murray *et al.*, 2015, Murray *et al.*, 2012).



## 2.2 Some caution required

As with all mapping exercises, it is essential to fully understand:

1. Where does the data come from?
2. How are the data mapped?
3. What is the resolution of the map?
4. How accurate are the maps? If the maps are inaccurate then this must be accounted for to ensure our estimates of change are comparable over time, rather than an artefact of mapping inaccuracies.

Here, we note a few key considerations to ensure the data are directly comparable for time-series mapping:

1. A masking procedure was applied to the three datasets to ensure all areas were mapped with the same effort. Masks of areas afflicted with clouds and ice-cover, as well as stripes in the post 2000 dataset (caused by a malfunction on Landsat 7), have been applied to all three datasets, ensuring we have complete coverage for all three time periods.
2. The datasets were generalised to a common spatial grain (resolution) of 100m pixel size to ensure the three datasets are directly comparable.
3. The minimum patch size of each dataset was considered. As the dataset contains maps from two different sources (topographical maps and satellite data), it is important to understand whether one data source is able to map smaller patches than others. In our case, a post-processing procedure ensured that very small patches (such as single pixels) were removed (Murray & Fuller, 2012, Murray *et al.*, 2014b).
4. All datasets are in the same equal area projection.
5. The datasets have accuracy assessments indicating that the remote sensing derived data are highly accurate (Murray *et al.*, 2014a).
6. The data have been published in several peer-reviewed publications. Therefore, we assume the methods and analysis of these datasets are to the highest standard.

After checking for these important factors, we are satisfied that the dataset is suitable for our purposes, avoiding some common mistakes with time-series mapping (see Section 5, guidelines). For further consideration of these common mistakes and how to avoid them, refer to these papers:

Fuller, R. M., Smith, G. M. & Devereux, B. J. 2003. The characterisation and measurement of land cover change through remote sensing: problems in operational applications? *International Journal of Applied Earth Observation and Geoinformation*, 4, 243-253.

Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E. & Wulder, M. A. 2014. Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, 42-57.

Olofsson, P., Foody, G. M., Stehman, S. V. & Woodcock, C. E. 2013. Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment*, 129, 122-131.

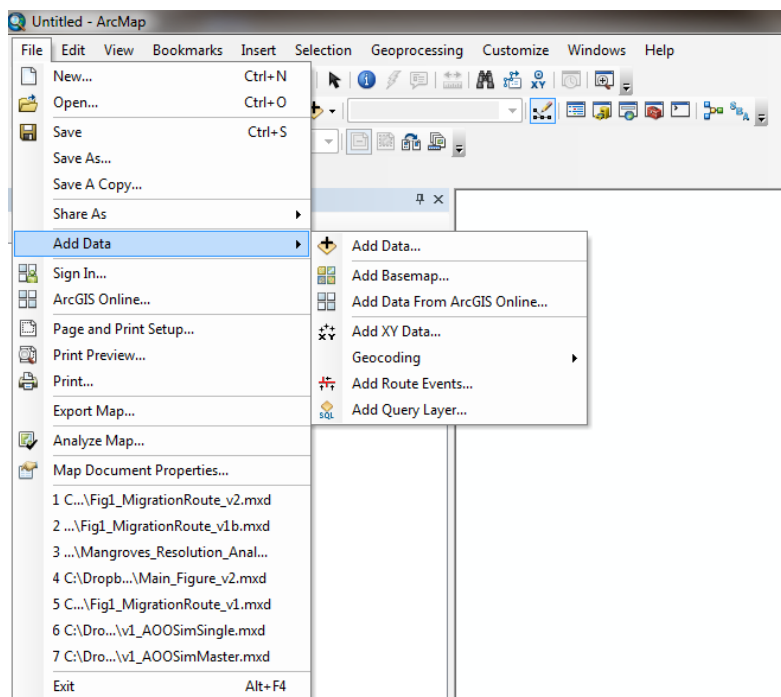
## 2.3 Importing data

Import datasets into ArcGIS:

1. Unzip and save the provided datasets to a simple working folder, such as C:\RLE.
2. Open ArcMap. If an automatic window opens for selecting an existing project, choose cancel to begin with an untitled project.
3. Use *Add Data* to add the two datasets (1950s\_TidalFlat.shp and 1980s\_TidalFlat.shp) using the toolbar button or via the file menu



OR

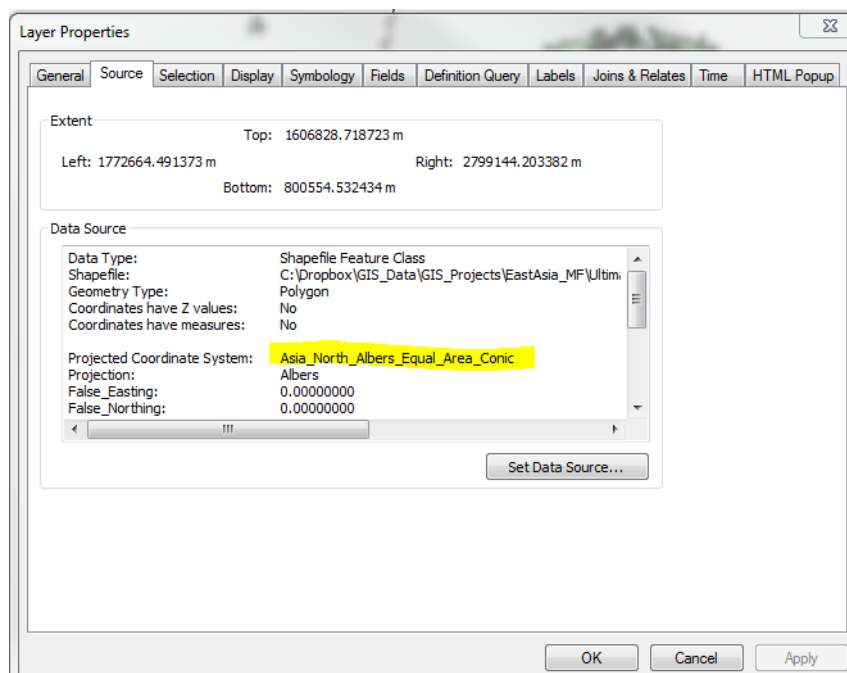


4. You can now check the datasets in detail, ideally against satellite imagery or other high resolution data suitable for the purpose. This can be achieved in ArcGIS using *Add Basemap* in the Add Data menu and selecting *imagery*, as long as you have the necessary license. If your ArcGIS doesn't have a license for this however, consider using Google Maps, Bing Maps, USGS Landsat Look or another online satellite imagery source.

## 2.4 Projection

To ensure consistency across all of the datasets, we must first check that the two datasets have the same projection.

1. Right click the shapefile in the table of contents and select properties (if table of contents is not visible, click the Windows menu and select Table of Contents). Click the *Source* tab.
2. Ensure that both datasets are in the same projection. In this case it should be: *Projected Coordinate System: Asia\_North\_Albers\_Equal\_Area\_Conic*
3. If they are not the same, then reproject one or both of the datasets to a common projection suitable for the region. This can be achieved by selecting *Search For Tools* from the Geoprocessing menu. Search for “project” and select a reproject tool (*Project, Project Raster, Batch Project*). If the dataset has no projection you will need to define the projection (*Define Projection*) after you have first discovered which projection the data was originally collected in.
4. In our case, our datasets have a common Albers Equal Area projection, which is suitable for determining areas, mapping the EOO and assessing the AOO as required for assessing against Criteria A and B of the RLE.



## 2.5 Assessing an ecosystem

A summary table for each ecosystem type reports the assessment outcome for all criteria (and subcriteria) as well as the overall status. Results for all four subcriteria of criteria A, C, and D must be reported during the assessment process.

To account for uncertainty in the outcome of an RLE assessment, we primarily use bounded estimates. The lower bound of the overall status is the highest lower bound (or the most plausible value) across any of the subcriteria that return the same category as the overall status. The upper bound of the overall status is the highest upper bound across any of the subcriteria that return the same category as the overall status. Please see the Guidelines for more information.

Throughout this course please complete for each example the final assessment (with plausible bounds if required) for each ecosystem type. Please note that these examples do not distinguish subcriteria 2a and 2b in their reporting (Tables 2 and 3).

*Overall assessment table of Caribbean coral reefs*

Criterion	A	B	C	D	E	Overall
Subcriterion 1	DD	LC	NE	EN (VU-CR)	NE	EN(VU-CR)
Subcriterion 2	DD	LC	NE	DD		
Subcriterion 3	DD	LC	NE	EN		

*Overall assessment table of Coastal Sandstone Upland Swamps of South-Eastern Australia*

Criterion	A	B	C	D	E	Overall
Subcriterion 1	LC	EN	LC	NT(NT-VU)	DD	EN(EN-CR)
Subcriterion 2	EN(EN-CR)	EN	EN(EN-CR)	DD		
Subcriterion 3	LC	LC	DD	DD		

## 3. Criterion A. Reduction in geographic distribution

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Criterion A focuses on the decline of the geographic distribution over time. We define geographic distribution as all spatial occurrences of an ecosystem type, which we typically determine with an ecosystem map. When the area of an ecosystem distributions falls to zero—when no occurrences of the ecosystem type remains—the ecosystem is considered collapsed (Bland *et al.*, 2016).

### 3.1 Calculating ecosystem areas

The RLE allows assessment of ecosystems over a range of timeframes. Owing to a failure of a sensor on Landsat 7 (ETM+) in 2002, the mapping exercise for the 2000s is more difficult and required use of data masks and several processing steps to achieve robust change estimates (Murray *et al.*, 2014a). Therefore, in this course we will demonstrate area calculations on the 1950s and 1980s dataset only, and provide you with the area obtained from the 2000s dataset.

As described in Section 2.2, we should first check that the datasets are fit-for-purpose in making comparisons of area (see suggested reading from section 2).

1. What resolution is each dataset recorded at? Record it
  - a. Read the metadata if it is a shapefile to understand the source of the data. This has been provided for the 1950s dataset.
  - b. For raster data (.tif, .img, etc), use *Get Raster Properties* tool in ArcGIS for raster data.
2. If the data is of different pixel resolution, we must generalise it to a common resolution to ensure our analysis is not biased. There are many ways to achieve this, but most commonly used are resampling methods. Some precautions should be made with this and, if this is a problem with your datasets, we ask you to refer to the guidelines for more information on the various ways that this can be achieved (Bland *et al.*, 2016).
3. In our case, our two shapefiles are considered suitable for use, since we have read the scientific papers and metadata that accompany the datasets.

We can now determine the area of the ecosystem at each point in time, recording the area (in km<sup>2</sup>) as well as the specific year that the ecosystem was mapped.

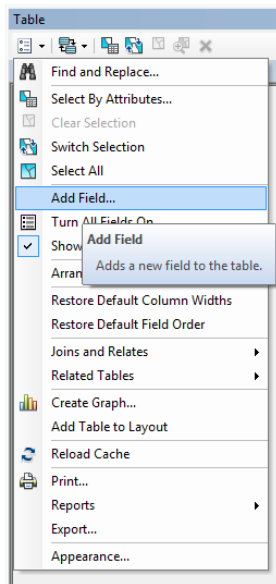
As we are using shapefiles, we will determine the area of each dataset using tools in ArcGIS:

1. Two methods can be used to calculate areas of shapefiles in ArcGIS:
2. First we can use the *Calculate Areas (spatial statistics)* tool, which outputs a new shapefile where each polygon is given an area.
3. However, a simpler method is to use the attribute table tools as follows:
  - a. Right click the shapefile, select *Open Attribute Table*

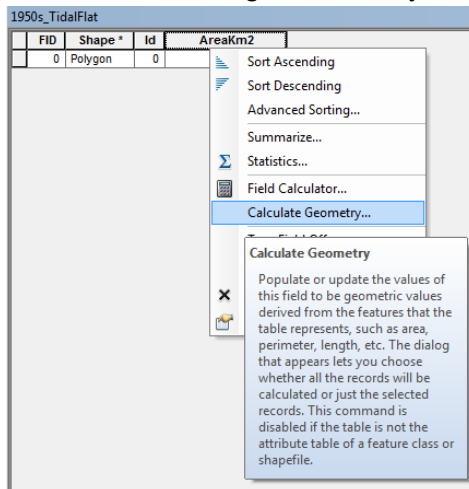
- b. Select the *Table Options* button



- c. Click *Add Field*



- d. Give the *Name* “AreaKm2”, and change the *Type* to “Float”. Select *OK*.
- e. Now, right click the new column in the table and select *Calculate Geometry*. Review the warning, then click yes.



- f. Choose *Area* as the *Property*, change *Units* to *Square Kilometers [sq km]* and select *OK*. Again you can ignore the warning.
  - g. You will now see that the area of the ecosystem is provided in square kilometres within the attribute table.
4. Record the data in the table below.
  5. Always double check area estimates. You can use other methods to do this, such as using the Python and R tools provided on N. Murray’s GitHub (see supplementary material if you wish to use these tools).



If we were using raster data, the area of ecosystems distributions can be determined by counting the number of pixels and multiplying by their area. (see N. Murray's GitHub).

Year	Area (km <sup>2</sup> )	Notes
1958		
1988		
2008	3893.03	Provided in Murray <i>et al</i> (2014)

### 3.2 Calculating rates of declines

The RLE guidelines suggest two methods to determine the rate of decline of an ecosystem, each of which assumes a different functional form of the decline (Bland *et al.*, 2016). In a proportional rate of decline (PRD), the decline is a fraction of the previous year's remaining area ( $0.02 \times$  last year's area), while in an absolute rate of decline (ARD) the area subtracted each year is a constant fraction of the area of the ecosystem at the beginning of the decline ( $0.02 \times 1000 = 20 \text{ km}^2/\text{year}$ ) (Bland *et al.*, 2016). Calculating these rates of decline allow extrapolation to the full timeframe of an assessment (50 years in past, present or future).

The rates of decline can be calculated using our Excel spreadsheet, in R (see the resources sections of iucnrle.org), Python (see GitHub), or simply with a calculator. Here we use the 1988 (year.t2) area estimate (area.t2) against the 1958 (year.t1) area estimate (area.t1):

1. Calculate absolute rate of decline between 1958 and 1988:

$$\begin{aligned} \text{ARD} &= - (\text{Area.t2} - \text{Area.t1}) / (\text{year.t2} - \text{year.t1}) \\ &= - (5448.5 - \text{A.t1}) / (1988 - 1958) \\ &= ? \end{aligned}$$

2. Calculate proportional rate of decline:

$$\begin{aligned} \text{PRD} &= 100 \times (1 - (\text{Area.t2} / \text{Area.t1})^{1/(\text{year.t2} - \text{year.t1})}) \\ &= 100 \times (1 - (5448.5 / \text{A.t1})^{1/(1988 - 1958)}) \\ &= ? \end{aligned}$$

### 3.3 Making an assessment under Criterion A

Now we have an estimate of the extent of decline of our ecosystem type. We can assess the ecosystem against the RLE thresholds. *An ecosystem may be listed under criterion A if it meets the thresholds for any of four subcriteria (A1, A2a, A2b or A3), quantified as a reduction in geographic distribution over the following time frames:*

Subcriterion	Time frame	CR	EN	VU
A1	Past (over the past 50 years)	≥ 80%	≥ 50%	≥ 30%
A2a	Future (over the next 50 years)	≥ 80%	≥ 50%	≥ 30%
A2b	Future (over any 50 year period including the past, present and future)	≥ 80%	≥ 50%	≥ 30%
A3	Historical (since approximately 1750)	≥ 90%	≥ 70%	≥ 50%

However, we only have our estimates of declines in terms of absolute areas lost for a given timeframe. We can adjust these to a percentage reduction in area using the following equations:

1. Calculate % area lost between time 1 and time 2:

$$\begin{aligned} \text{\% lost} &= ((\text{Area.t1} - \text{Area.t2})/\text{Area.t1}) \times 100 \\ &= ? \end{aligned}$$

Thus, as our data fits exactly a 50 year period we can use this percentage area lost to assess under the categories and criteria to determine the status of our ecosystem under Criterion A.

In many cases, our time frames will not fit the exact 50 year period for an assessment. In these cases, we can use our observed absolute and proportional rates of decline to estimate the area at a future date, equating to 50 years since our first observed data point. It will be interesting to compare our very simple forecast with the empirical data provided in Murray *et al.* (2014a).

2. Estimate area of ecosystem 50 years into the future using proportional rate of decline assumption. Recall that area.t1 is the area in km<sup>2</sup> of tidal flats in year.t1 (1958):

$$\begin{aligned} \text{Area.2008.PRD} &= \text{Area.t1} \times (1 - (\text{PRD}/100))^{n\text{Years}} \\ &= \text{Area.t1} \times (1 - (\text{PRD}/100))^{50} \\ &= ? \end{aligned}$$

3. Estimate area of ecosystem 50 years into the future using the assumption of an absolute rate of decline:

$$\text{Area.2008.ARD} = \text{Area.t1} - (\text{ARD} \times n\text{Years})$$

$$= \text{Area.t1} - (\text{ARD} \times 50)$$

$$= ?$$

Compare these results with those published in Murray *et al.* (2014a). We note that the observed area of tidal flats from remote sensing data in 2008 (3893.03 km<sup>2</sup>) are incredibly close to those estimated with a Proportional Rate of Decline assumption. For further information on the functional forms of decline refer to the guidelines (Bland *et al.*, 2016).

Now, calculate the percentage area lost between 1958 and 2008:

4. Calculate % area lost between 1958 (t1) and your estimate of 2008 (t3) area derived from the equations above (Area.2008.PRD):

$$\% \text{ lost} = ((\text{Area.t1} - \text{Area.2008.PRD}) / \text{Area.t1}) \times 100$$

$$= ?$$

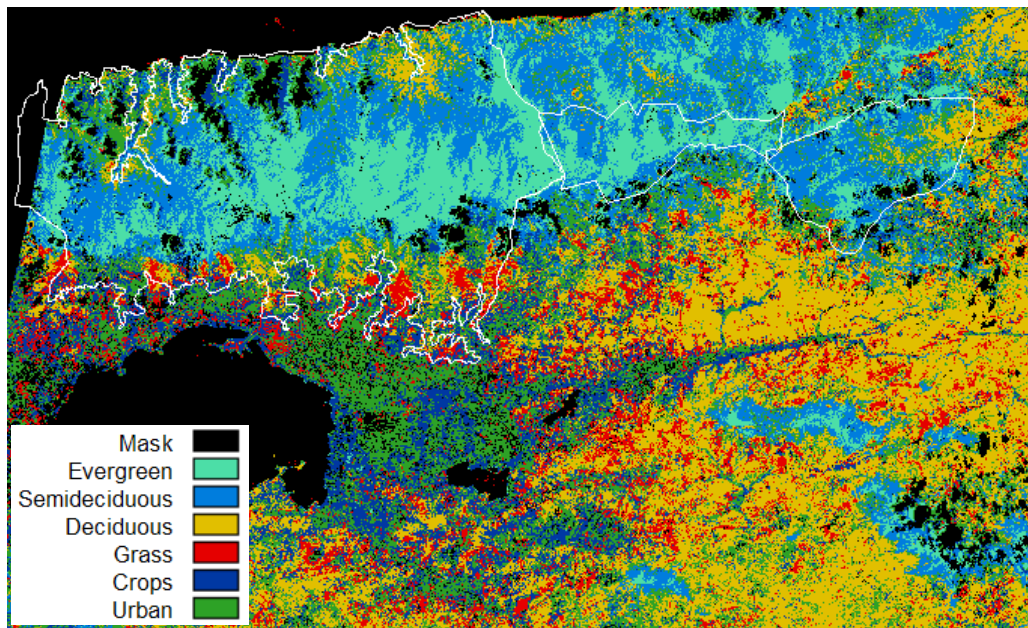
Again, note how similar this estimate is to the empirical estimate of the loss of tidal flats (Murray *et al.*, 2014a).

Record the outcome of the assessment.

When there are more than two data points it is possible to apply far more advanced and suitable statistical analysis methods to the time-series area data. We encourage assessors to fit statistical models to the time-series data where possible, allowing full use of all data available to achieve better estimates of the time-series area changes. Such models also allow incorporation of further information, such as accuracy of the datasets at each time point and covariate information that can improve model fit, and will generally result in more accurate predictions than the methods provided here. In all cases, information on the type of models used, the assumptions of the functional form of the decline and any other relevant information should be included in the RLE assessment.

### 3.4 Extra exercise

Two maps of land cover, which we will consider are ecosystems mapped according to the Guidelines, have been produced around the cities of Maracay and Valencia (Figure 1), adjacent to Lake Valencia, Venezuela (large black area at the bottom left). The land cover maps were produced using Landsat Archive satellite images, and the area of each ecosystem type was determined (Table 1). The ecosystem types have changed rapidly in the last decades, and we are interested in classifying the risk of collapse of each ecosystem type using the RLE criteria.



*Change in extent of six land cover types between 1986 and 2001 in north-central Venezuela*

Year	1986 (km <sup>2</sup> )	2001 (km <sup>2</sup> )	ARD	PRD	2051 Area Estimate (PRD)	% Change	Assessment outcome
Evergreen forest	397	385					
Semi-deciduous forest	1190	1037					
Deciduous forest	2227	1563					
Grasslands	1249	2001					

Using these area estimates, estimate the risk of collapse of the different land covers according to Criterion A.

## 4. Criterion B. Restricted Geographic Distribution

Criterion B uses measures of the geographic distribution of an ecosystem type to identify ecosystems that are at risk from catastrophic disturbances. In general, ecosystems that are widely distributed or exist across multiple independent patches are at lower risk from catastrophes, disturbance events or any other threats that exhibit a degree of spatial contagion (e.g. invasions, pollution, fire, forestry operations, and hydrological or regional climate change). The primary role of criterion B is to identify ecosystems whose distribution is so restricted that they are at risk of collapse from the chance occurrence of single or few interacting threatening events (Rodríguez *et al.*, 2015). Criterion B also includes an approximation for an estimate of occupied habitat for component biota, which is positively related to population viability irrespective of exposure to catastrophic events

### 4.1 Standardised measures of geographic distribution

The geographic distribution of an ecosystem type is assessed under criterion B with two standardized metrics: the extent of occurrence (EEO) and the area of occupancy (AOO) (Gaston & Fuller, 2009, Keith *et al.*, 2013). It must be emphasised that EEO and AOO are not used to estimate the mapped area of an ecosystem like the methods we used in Criterion A; they are simply spatial metrics that allow us to standardise an estimate of risk spreading. Thus, it is critical that these measures are used consistently across all assessments, and the use of non-standard measures invalidates comparison against the thresholds. Refer to the guidelines for more information on AOO and EEO (Bland *et al.*, 2016).

As we are only interested in the risk of collapse of an *extant* ecosystem, we will use only the latest spatial distribution map available for this exercise (the 2008 distribution of Yellow Sea tidal flats).

Measure of Distribution	Area (km <sup>2</sup> )	Notes
AOO	?	
AOO (1 per cent rule)		
EEO	?	

### 4.2 Measuring the EEO

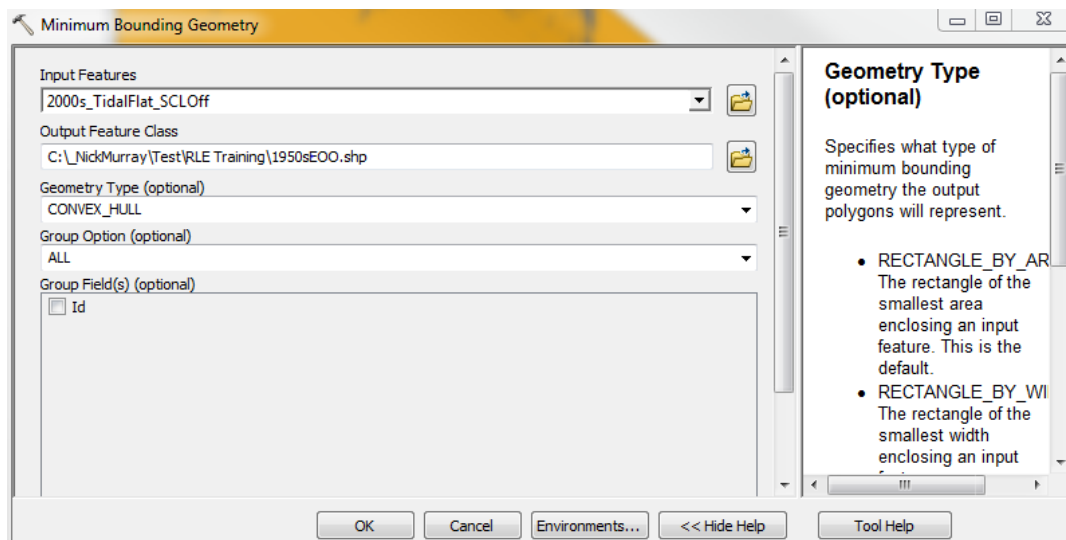
The RLE guidelines defines the EEO as:

The EEO of an ecosystem is measured by determining the area (km<sup>2</sup>) of a minimum convex polygon—the smallest polygon that encompasses all known occurrences of a focal ecosystem in which no internal angle exceeds 180 degrees— fitted to an ecosystem distribution. The minimum convex polygon (also known as a convex hull) must not exclude any areas, discontinuities or disjunctions, regardless of whether the ecosystem can occur in those areas or not. Regions such as oceans (for terrestrial ecosystems), land (for coastal or marine ecosystems), or areas outside the study

area (such as in a different country) must remain included within the minimum convex polygon to ensure that this standardized method is comparable across ecosystem types. In addition, these features contribute to spreading risks across the distribution of the ecosystem by making different parts of its distribution more spatially independent (Bland *et al.*, 2016).

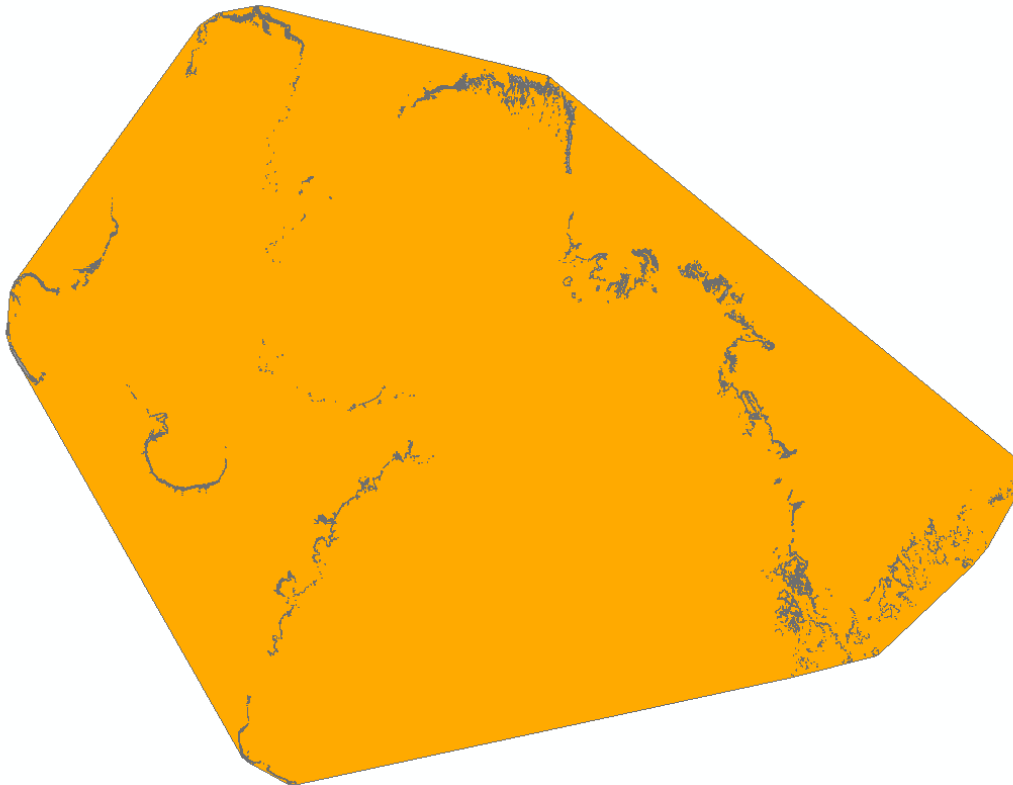
Thus, to accurately measure the EOO of an ecosystem we must apply a minimum convex polygon to our ecosystem data, which can be easily achieved using ArcGIS:

1. Load the 2000's tidal flat shapefile into ArcGIS using the procedure above, if not already completed.
2. From the Geoprocessing menu, select Search For Tools
3. In the search box, search for *Minimum Bounding Geometry*.
4. Open the Minimum Bounding Geometry tool
5. As the input feature, select your 2000s tidal flat shapefile.
6. Save the output feature class to your working folder as EOO.shp
7. Under Geometry Type, select CONVEX\_HULL
8. Group Option should be set as ALL



We now have a minimum convex polygon (convex hull) that encompasses all known occurrences of the ecosystem type. Note that under no circumstances can the MCP be modified, despite the inclusion of unsuitable areas, as it is a standardized measure of distribution.





We must now determine the area of the minimum convex polygon, which allows us to assess Criterion B. We use the same method as in the first exercise to determine the area of the shapefile.

- a. Right click the shapefile, select *Open Attribute Table*
- b. Select the *Table Options* button
- c. Click *Add Field*
- d. Give the *Name* AreaKm2, and change the *Type* to "Float". Select *OK*.
- e. Now, right click the new column in the table and select *Calculate Geometry*. Click yes to ignore the warning.
- f. Choose Area as the *Property*, change *Units* to Square Kilometers [sq km] and select *OK*. Again you can ignore the warning.
- g. You will now see that the area of the ecosystem is provided in square kilometres within the attribute table.

Record the area of the EOO in the table above.

### 4.3 Measuring the AOO

As the primary source of all information on the RLE, the guidelines have a detailed section on the theory, background and methods for measuring the AOO of an ecosystem type:

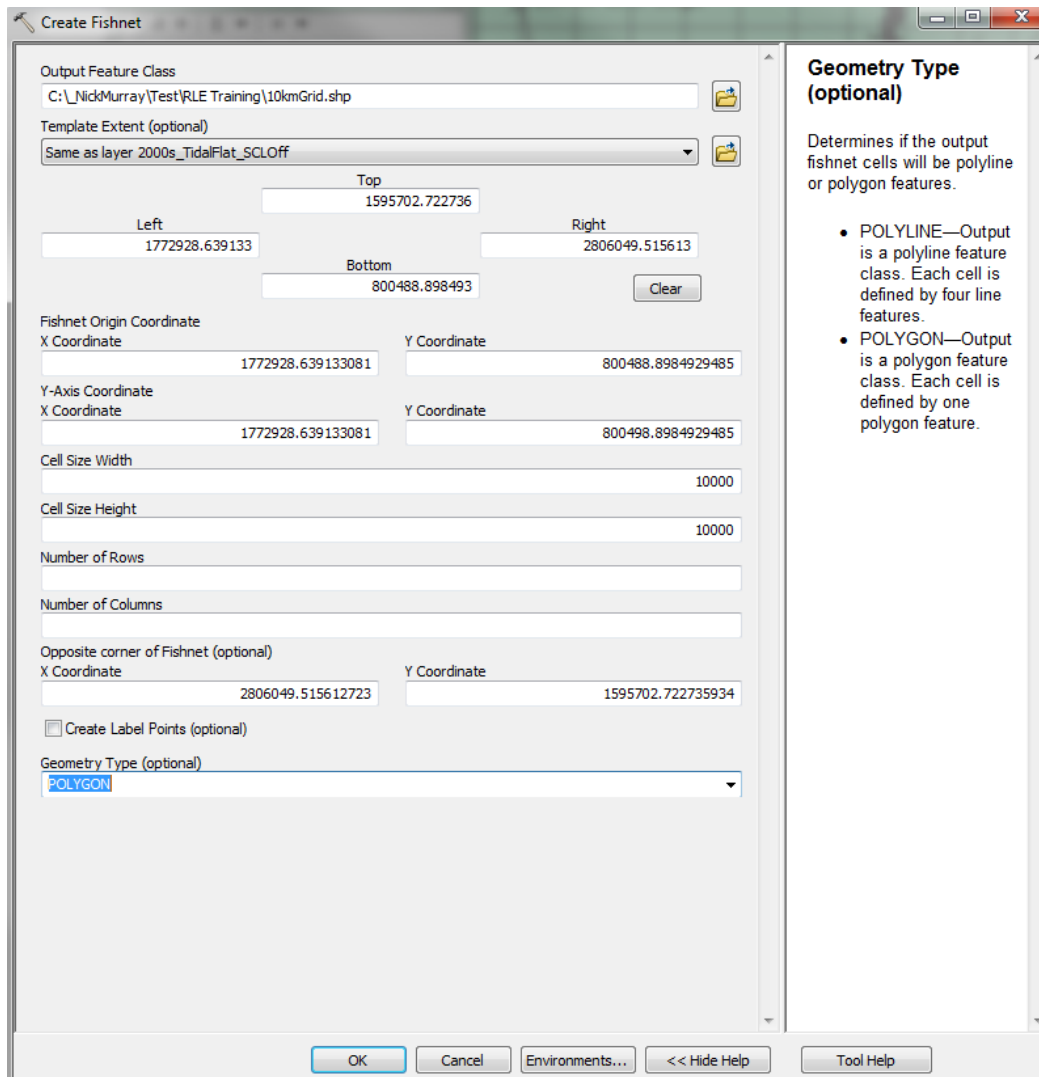
Area of occupancy (AOO). Measures of AOO are highly sensitive to the grain size (pixel resolution) at which the distribution is mapped (Nicholson *et al.*, 2009), so all measures of AOO of an ecosystem type must be standardized to a common spatial

grain. The AOO of an ecosystem defined in the RLE is determined by counting the number of 10 × 10 km grid cells that contain the ecosystem. This relatively large grain size is applied for three reasons: (i) ecosystem boundaries are inherently vague (Regan *et al.*, 2002), so it is easier to determine that an ecosystem occurrence falls within a larger grid cell than a smaller one; (ii) larger cells may be required to diagnose the presence of ecosystems characterized by processes that operate over large spatial scales, or possess diagnostic features that are sparse, cryptic, clustered or mobile (e.g. pelagic or artesian systems); (iii) larger cells allow AOO estimation even when high resolution distribution data are limited. Some ecosystem distributions comprise a highly skewed distribution of patch sizes. In these cases large numbers of small patches contribute a negligible risk-spreading effect to that of larger patches and a correction may be applied by excluding from the AOO those grid cells that contain patches of the ecosystem type that account for less than 1% of the grid cell area (i.e. < 1km<sup>2</sup> of the focal ecosystem type, Box 10). Research is in progress to support guidance on when to apply this correction (Bland *et al.*, 2016).

As with the EOO, it is essential that the methods used to determine the AOO of an ecosystem type is consistent and well documented.

To measure the AOO of an ecosystem, we must first develop a suitable 10 × 10 km grid for which to count the grid cells occupied by the ecosystem type. This is possible using standard tools from ArcGIS:

1. Load the 2000's tidal flat shapefile into ArcGIS using the procedure above, if not already completed.
2. From the Geoprocessing menu, select Search For Tools.
3. In the search box, search for *Create Fishnet*.
4. Open the *Create Fishnet (Data Management)* Tool.
5. Provide a file name (10kmGrid.shp) as the Output Feature Class.
6. Use the 2000s tidal flat shapefile as the Template Extent (by dragging it in), which limits the size of the fishnet grid.
7. Set the Cell Size Width to 10,000 m.
8. Set the Cell Size Height to 10,000 m.
9. Set the Number of Rows and Number of Columns to 0.
10. Uncheck the Create Label Point checkbox.
11. Change the Geometry Type to Polygon.
12. Click OK.

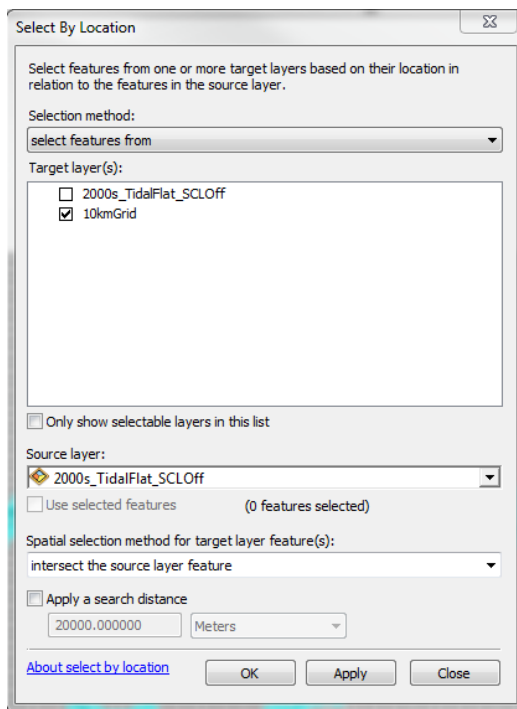


We now have a 10 × 10 km grid suitable for determining the AOO of the Yellow Sea tidal flat ecosystem:

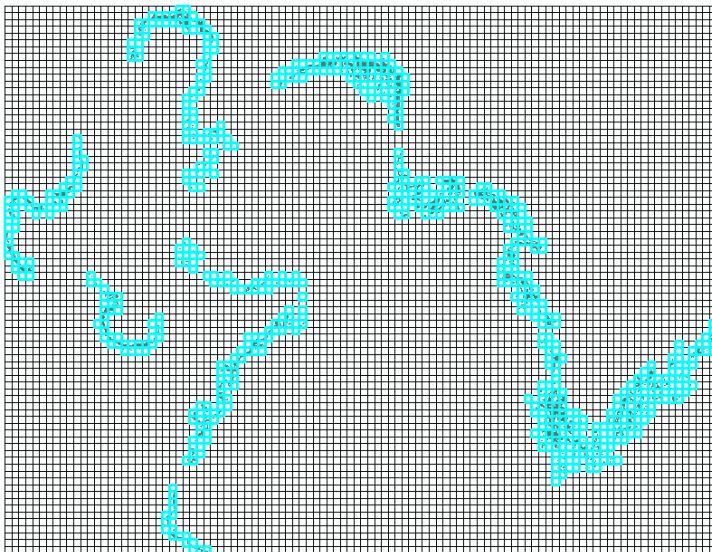


Now that we have the grid, it is a simple matter of counting the number of cells that intersect it. This can be achieved in several ways, but we will use a few handy tools including select by location:

1. First we select the grid cells that intersect our ecosystem dataset.
2. From the *Selection* menu, open *Select By Location*.
3. Set *Select features from* to the 10 x 10 km grid shapefile.
4. Set Source Layer to the ecosystem shapefile.
5. Set the *Spatial selection method for target layer features* to “*intersect the source layer feature*”.
6. If default checked, uncheck the *Apply a search distance* box.
7. Click OK.

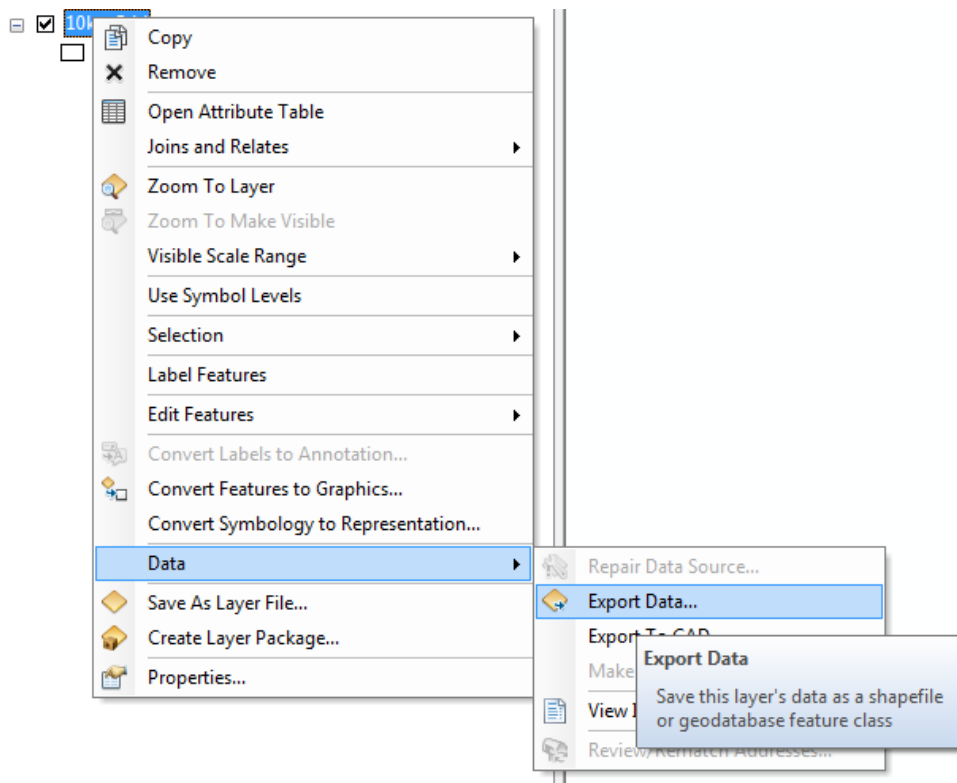


We now have the grid cells that intersect the ecosystem data selected:



Export this as a separate file by:

1. Right click the 10 x 10 km grid shapefile.
2. Select Data, then Export Data. This will export only the selected features of the dataset. Call it GridSelect.shp.



3. Now we have a shapefile with 10 x 10 km grid cells that intersect our ecosystem dataset. Since we are not using the 1% rule, we will simply count the number of grid cells in this shapefile and use that as our AOO estimate. (Hint: use the attribute table for this, each row is a grid cell).

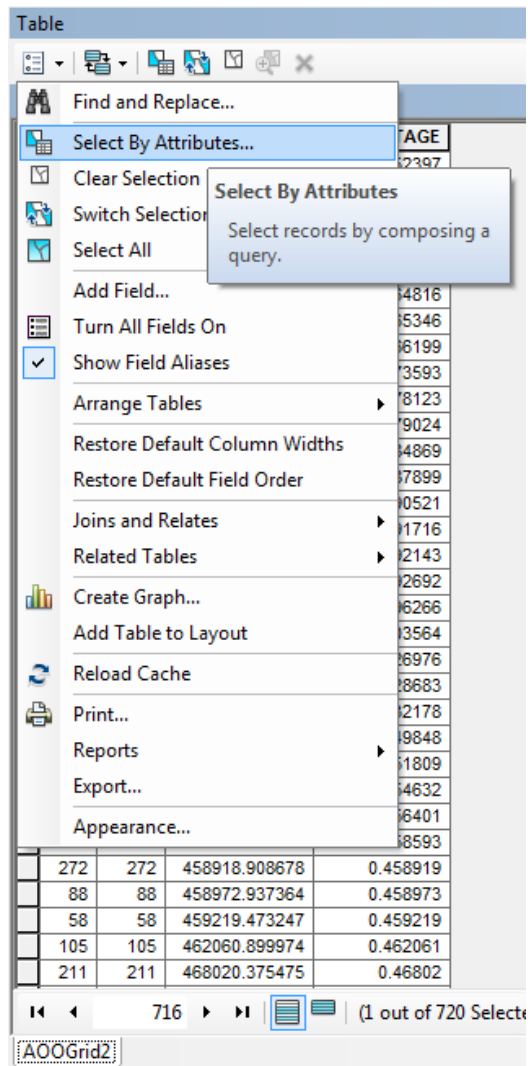
However, at this stage it is important to consider the so-called 1% rule. The 1% rule is used when a large number of small patches have negligible risk-spreading effect for the ecosystem type. In our case, we are using tidal flats where small patches are likely to exist in small estuaries and bays and we wish to include them in our AOO estimate.

However, in many cases small patches of habitat are more likely to have negligible impact on risk spreading or are perhaps an artifact of mapping limitations. In those cases we use the 1% rule. In our case, we are using tidal flats where small patches are likely to exist in small estuaries and bays and we wish to include them in our AOO estimate. Assuming you have ArcGIS 10.2 or greater, we must determine the amount of area of the ecosystem type within each grid cell 10 × 10 km grid cell. We also need to determine which of these cells contain >1 km<sup>2</sup> of our ecosystem type. We can use a neat little built in ArcGIS tool to determine this:

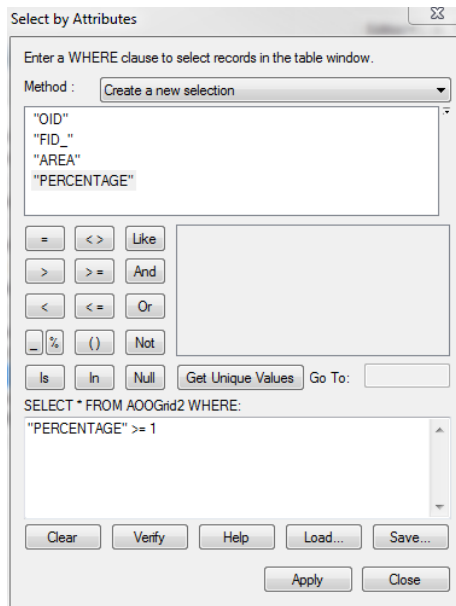
- a. From the *Geoprocessing* menu, select Search For Tools.
- b. In the search box, search for *Tabulate Intersection*. Note: this method only works on ArcGIS 10.2 or greater.
- c. As the *Input Zone Features*, use the GridSelect.shp.
- d. Set the *Zone Fields* to FID (which is an individual identifier for each grid cell).
- e. Use the ecosystem dataset as the *Input Class Features*.
- f. Call the table TabulateIntersection.dbf.



- g. Click OK.
- h. Now we have a .dbf table that gives the area and percentage coverage of the ecosystem in each individual grid cell.
- i. Open the table (you can use ArcGIS by right-clicking the table in the *Table of Contents*, or you can use Microsoft Excel).
- j. Now it is simply a matter of determining how many grid cells are occupied by  $\geq 1\%$ . This can be done by selecting grid cells with Percentage  $\geq 1\%$ .
- k. Use the *Table Options* menu in the top left (below Table) and choose *Select by Attribute*.



- l. Create a new selection by double clicking "PERCENTAGE".
- m. Add the  $\geq$  operator.
- n. Add the number 1, as shown below.



- o. Now, click *Apply* and note that 373 out of 720 rows are selected. Thus our AOO is 373 grid cells.

OID	FID	AREA	PERCENTAGE
103	103	740490.429264	0.74049
242	242	742149.879656	0.74215
128	128	751218.703934	0.751219
615	615	755975.281499	0.755975
126	126	765785.158394	0.765785
360	360	773449.420737	0.773449
278	278	779622.786994	0.779623
168	168	795805.958224	0.795806
54	54	808134.784191	0.808135
422	422	811241.426838	0.811241
43	43	813010.337275	0.81301
532	532	818450.890314	0.818451
608	608	826662.897394	0.826663
42	42	849557.903497	0.849558
174	174	852224.128895	0.852224
109	109	877849.735395	0.87785
184	184	889400.753338	0.889401
359	359	893103.806473	0.893104
305	305	927587.30837	0.927587
460	460	943531.701207	0.943532
507	507	957350.42963	0.95735
630	630	962545.363825	0.962545
634	634	963271.937698	0.963272
136	136	976777.236891	0.976777
280	280	984258.419895	0.984258
118	118	985004.5644	0.985005
482	482	992157.162219	0.992157
244	244	1015462.08487	1.015462
571	571	1016656.82777	1.016657
291	291	1019150.54022	1.019151
200	200	1022125.99465	1.022126
119	119	1022609.38532	1.022609

716 (373 out of 720 Selected)

4. We can map this by simply using a "Join" in ArcGIS to join the TabulateIntersection.dbf to the GridSelect.shp, using the ID columns as the common variable, and "Area" and "Percentage" as the *Join Fields*. The result is a new column

in GridSelect.shp with Percentage and Area in there, which can then be selected and exported.

5. The final result is the AOO grid cells that contain  $\geq 1\%$  of the ecosystem in black, below, and the grid cells that intersect in orange.

Record the number of AOO cells in the results table above.



#### 4.4 Continuing declines (Subcriteria B1a, B1b, B2a, B2b)

Now we have measured the AOO and EOO of the ecosystem, we must assess it under the subcriteria. In our case, both metrics indicate the Yellow Sea tidal flat does not meet the thresholds for listing under criterion B.

However, it is still necessary to consider the following information from the RLE guidelines:

To be eligible for listing under subcriteria B1 or B2, an ecosystem must meet the EOO or AOO thresholds that delineate threat categories, as well as at least one of three subcriteria that address various forms of decline. These subcriteria distinguish restricted ecosystems at appreciable risk of collapse from those that persist over long time scales within small stable ranges (Keith *et al.*, 2013). Only qualitative evidence of continuing decline is required to invoke the subcriteria, but relatively high standards of evidence should be applied.

Therefore, had we met any of the Criterion B thresholds, the ecosystem could only be listed if we had observed continuing declines, or if we expected future declines and have evidence to support that claim.

## 4.5 Locations (Subcriteria B1c, B2c, B3)

The original published paper for the RLE assessment of the Yellow Sea tidal flats did not report the number of locations for assessment under Criterion B (Murray *et al.*, 2015). This was principally due to not meeting any of the criteria and sub-criteria under B. However, below we provide a few theoretical examples to assist in interpreting the number of locations under Criterion B.

### 4.5.1 Locations example 1

An ecosystem/habitat type is distributed across 10 small islands in the Galapagos Islands. A potential threat comes from El Niño events, which impacts the entire ecosystem across its distribution by causing substantial declines in key characteristic species. So far these species appear to be able to recover well from these events, thus the ecosystem is able to rebound, but if the frequency of El Niño events increases (for example, through the effects of climate change), this may pose a serious problem to the survival of the species and therefore the condition and stability of the ecosystem. The relationship between El Niño and global climate change patterns is unknown, so considering El Niño as a major threat at present may be premature. Counting the entire distribution as one location may **not** be an appropriate application of the criteria.

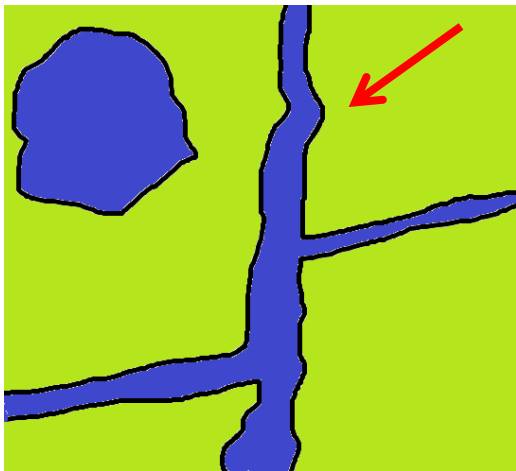
The ecosystem is exposed to other threats, including pollution events and shifting species composition as a result of predator introduction. Both of these threats are likely to affect individual islands rather than the entire area in one sweep. Each island could be seen as a location, so we conclude that the ecosystem is composed of **10 locations**.

A rare habitat type occurs at 5 sites. One site occurs near an expanding urban area, and is threatened by conversion to residential and other human uses. Two of the sites are in a rural area and are threatened by agricultural runoff of herbicides. Two sites are in a protected area and are not under any threat.

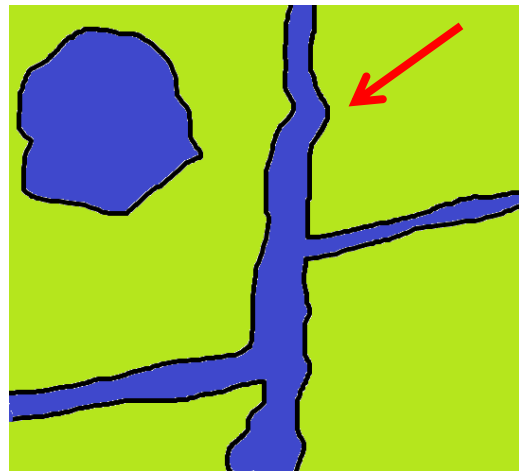
1. How many locations can be estimated for this ecosystem?

### 4.5.2 Locations exercise

Locations are areas within the distribution of the ecosystem type for which one threat may affect all localities at once. Their extent therefore depends on the nature and size of the threat. The following figure shows a freshwater ecosystem type with two distinct spatial occurrences: a river with a main channel that flows from top to bottom and two tributaries that empty into the main channel, and a lake. Two plausible threats exist: introduction of an exotic predatory fish and pollution. The red arrow indicates the point of entry of each threat.



Invasive species: \_\_\_ locations



Pollution: \_\_\_ locations

1. Please outline the locations in the figure above and indicate the number in the space provided.

#### 4.6 Extra exercises

##### *Oyster Beds of the species *Ostrea edulis**

This case study considers *Ostrea* beds distributed in several sites along coastlines in the North-East Atlantic Sea. Dense beds of *Ostrea* oysters occur on shallow (typically 0-10m), mostly sheltered sediments, where clean and hard substrates are available for settlement. They also occurred in deeper waters and offshore (down to 50 m), but these beds are now mostly depleted. Large quantities of dead oyster shell make up a substantial portion of the substratum, supporting large numbers of other small and large marine invertebrates. Several polychaete species are important in distinguishing this habitat type, whilst various seaweed species are also frequently present.

The principle species in these oyster beds, *Ostrea edulis*, grows very large (>20 cm) and can have a long lifespan (>20 years). *Ostrea edulis* is considered a keystone species given its role in the ecology of the ecosystem type.. These functions include providing a solid surface for settlement by other species; providing a cryptic, protective habitat that serves as a nursery ground for small fish and other species; stabilising sediments which may in turn provide some protection from shoreline erosion; and filtering large quantities of water.

*Ostrea* beds are under threat and/or decline throughout their range. *Ostrea* species have been a part of the human diet for centuries, however, during the 18th and 19th centuries fishing effort led to over-exploitation, failing recruitment, and destruction of European natural beds, which were also affected by extremely cold winters. More recently (during the 20th century), disease has impacted *Ostrea* beds, causing massive mortality and significant population declines in European waters; populations later recovered but were replaced by

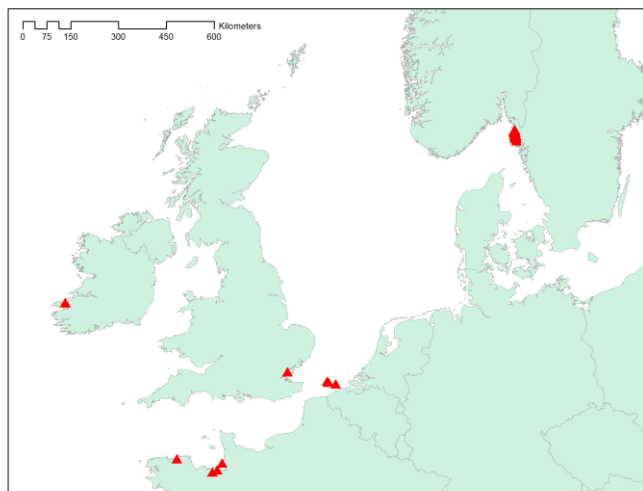
other species in several traditional areas. Despite new management practices and intensive repletion programs, the production of *O. edulis* has remained low.

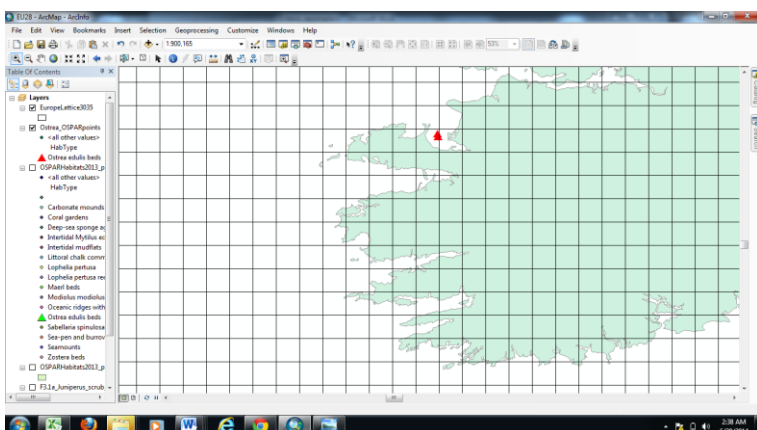
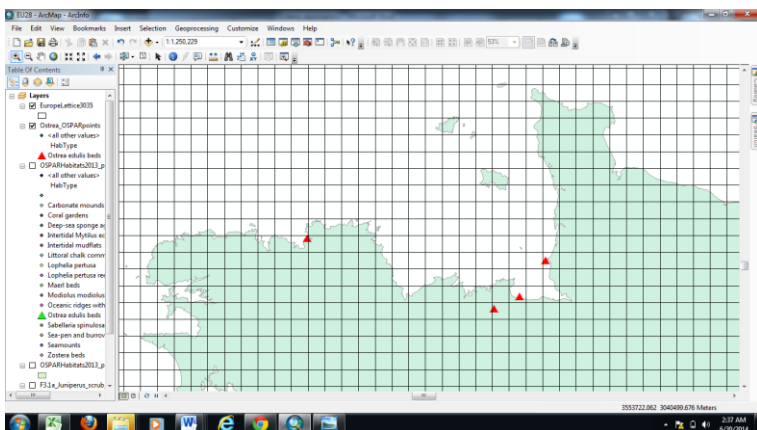
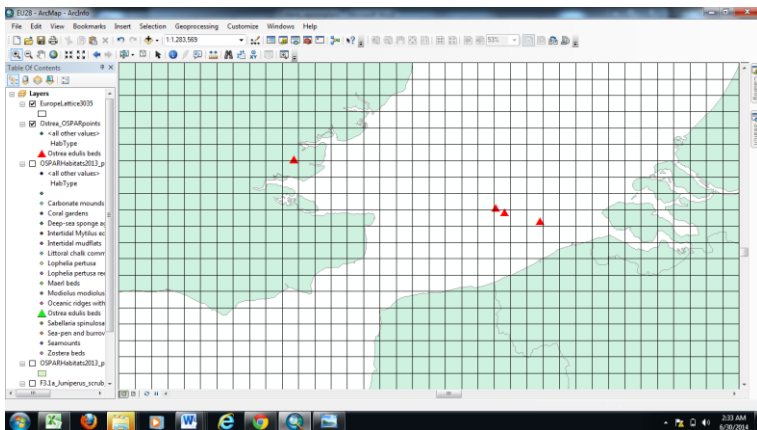
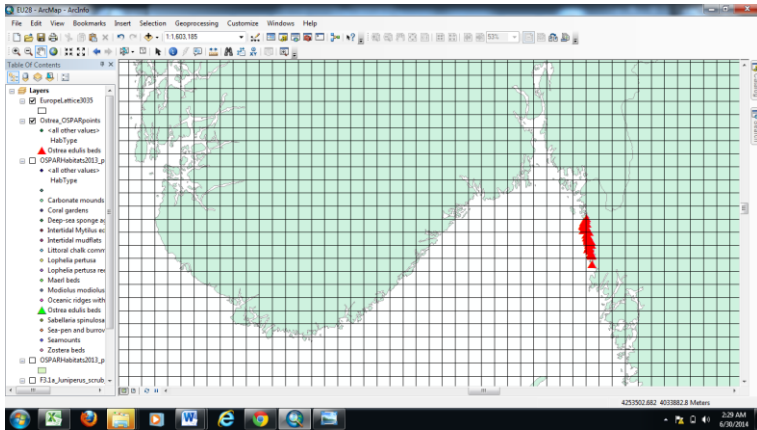
Using the maps provided:

1. Using a minimum convex polygon, draw the extent of occurrence (EOO) and estimate its value in km<sup>2</sup> (each cell is 10 x 10 km).
2. Calculate the area of occupancy (AOO) of this habitat type (in red):
  - a. Using all cells where habitat is present.
  - b. Excluding cells with <1% occupied.
3. Using the values of EOO and AOO calculated above, as well as the information given in the text, please proceed to assess this habitat type against Criterion B. Each subcriterion must be assigned a risk category. Briefly justify the assessment below, using the information provided.

Criterion B	B1				B2				B3
	EOO	a	b	c	AOO	a	b	c	
<i>Ostrea beds</i>									

Distribution of *Ostrea beds* considered for this exercise:







## Northern Sea Sponge Aggregations

The distribution of this habitat type of sponge aggregations is restricted to an area off the north coast of Norway. These aggregations provide habitat for 50 different species and are found at water depths of 250-1300m where temperatures do not exceed 10°C. Sponge communities are slow-growing and if damaged, their communities take a long time to recover.

In the area, there has been a marked increase in bottom trawling (demersal and benthic) and oil drilling and a documented increase in suspended sediments.

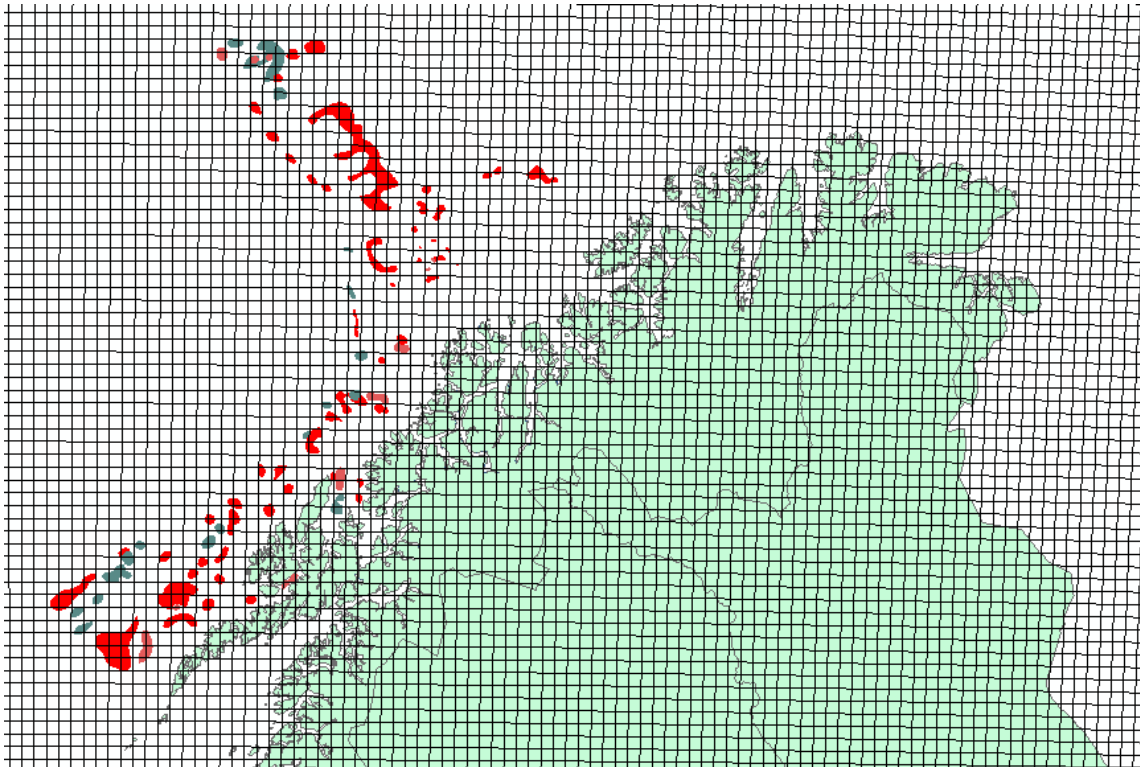
Using the map provided:

3. Using a minimum convex polygon, draw the extent of occurrence (EOO) and estimate its size (each cell is 10 x 10 km);
4. Calculate the area of occupancy (AOO) of this habitat type (in red):
  - a. Using all cells where habitat is present.
  - b. Excluding cells with <1% occupied.
5. Using the values of EOO and AOO calculated above, please proceed to assess this habitat type against Criterion B. Each subcriterion must be assigned a risk category. Briefly justify the assessment below, using the information provided.

Criterion B	B1				B2				B3
	EOO	a	b	c	AOO	a	b	c	
Northern sea sponge aggregations									

\*fictitious habitat type and descriptions, provided for training purposes only

Map: Northern sea sponge aggregations (10x10km<sup>2</sup>)



## 5. Exercises: Day 2

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We continue our training today on Criteria C and D. As discussed in the lectures and in detail in the guidelines (Bland *et al.*, 2016), Criteria C and D are defined for assessing decline in ecosystem function or processes. These criteria focus on aspects of abiotic (environmental, Criterion C) and biotic (Criterion D) change of an ecosystem type.

### 5.1 Understanding relative severity

Prior to beginning these exercises, take a moment to revisit the concepts presented in the Scientific Foundations (Section 3), the Assessment Process (Section 4) and the specific sections for each of these criteria in the RLE guidelines (Section 5.3 and 5.4). In particular, focus on your understanding of the selection of variables suitable for assessing the relative severity and extent of decline. Ask your instructors if you have any questions.

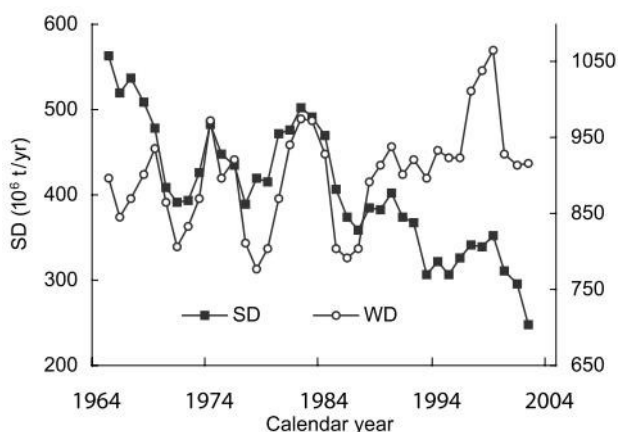
## 6. Criterion C. Environmental degradation

To assess an ecosystem type under Criterion C, suitable variables for estimating the extent of environmental degradation must be selected. The guidelines contain many examples for a suite of case studies to assist in this process. Refer to Section 5.3.3 for a list of requirements that should be met when selecting variables to assess abiotic degradation. For the Yellow Sea tidal flat ecosystem Murray *et al.* (2015) used data of sediment outflow from the region's major rivers. The input of sediment into the Yellow Sea is considered to balance the rate of seaward erosion, compaction and subsidence of tidal flats, thereby maintaining their areal extent.

In this exercise we will digitise sediment flux data from a peer-reviewed paper, determine a collapse threshold and estimate the relative severity of sediment decline.

### 6.1 Digitising data from published studies

We use sediment decline data from the Yangtze river to demonstrate how to calculate relative severity according to the methods described in Keith *et al.* (2013) and Rodriguez *et al.* (2015). The data originated as a plot in Yang *et al.* (2005).



1. From the data folder, review the paper by Yang *et al.* (2005). Figures 10 and 11 present data on sediment flows from the Yangtze.
2. We will use an online application to harvest the data from this plot. Navigate to <http://arohatgi.info/WebPlotDigitizer/>
3. Click on *Launch App* (top right)

## Purpose

A large quantity of published data is available only in the form of plots and it is often difficult to extract numerical data accurately out of these pictures. There are several softwares available to aid this process, but most are either paid, difficult to use or lack some essential features. Also, many of the existing programs work only on a few specific operating systems and require installation by the user. Most programs only support 2D X-Y plots and so it is not possible to work with polar diagrams, ternary diagrams, microscope images or maps. With these issues in mind, WebPlotDigitizer was developed to be an easy to use, free of charge and opensource program that can work with a variety of plot types and images. This program is developed using HTML5 which allows it to run within a web browser and requires no installation on to the user's hard drive.

## Features

- Now, either load the *Sediments\_Yangtze.jpg* of the plot from the data folder or drag it into the data section of the WebPlotDigitizer.
- Follow the instructions. It is necessary to state the type of plot and then to calibrate the axes. Note we are using SD data (the black squares on the Y1 axis, left side of plot) for sediment decline.

Launch App!

Chrome App Store

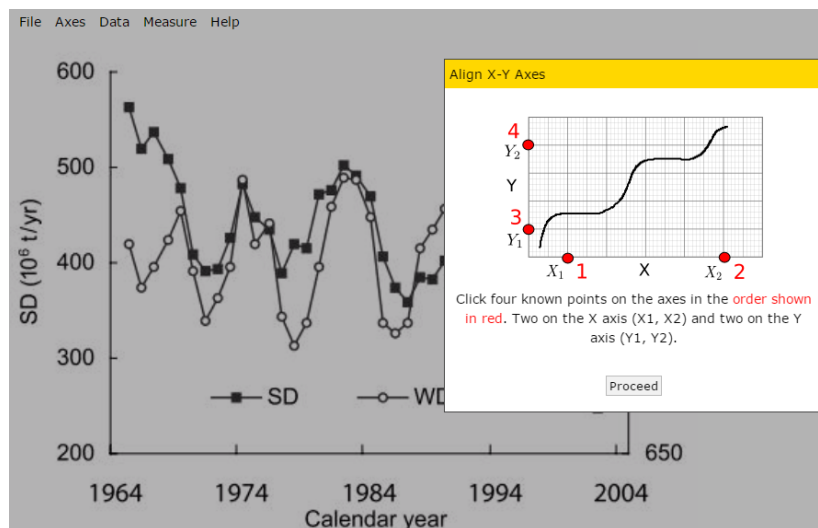
Download

(Windows 7/8/10)

R Package

GitHub

RSS Feed



- Now, for each point on the graph collect the data by clicking on it.
- When all points are acquired, click view data, then export the final dataset as a .csv

## 6.2 Calculating relative severity

Relative severity is defined as:

*The estimated magnitude of past or future environmental degradation or disruption to biotic processes, expressed as a percentage relative to a change large enough to cause ecosystem collapse.*

Relative severity describes the proportional change observed in an environmental variable scaled between two values: one describing the initial state of the system (0%), and one describing a collapsed state (100%). Thus, if an ecosystem type undergoes degradation with a relative severity of 50% over an assessment time frame, this implies that that it has transformed half way to a collapsed state.

The method for calculating the relative severity of the decline of an abiotic variable has been described clearly in the following three papers (Bland *et al.*, 2016, Keith *et al.*, 2013, Rodríguez *et al.*, 2015). Here, we will use the method as described in the RLE guidelines, recognizing that we do not have 50 years of data – it is useful for demonstration purposes. However, note that this is different from the analysis published in Murray *et al.* (2015), which used a least-squares regression model to estimate the severity of the decline beyond the range of the time-series dataset.

We use a collapse threshold of zero sediment outflow, as per Murray *et al.* (2015). However, for the rest of the exercise feel free to explore different thresholds to assess the sensitivity of the method to changing the threshold of collapse.

To determine the relative severity of the observed declines of sediment outflow from the Yangtze River:

1. Determine the sediment flow for the first and last points in our sediment dataset (SD.t1 and SD.t2)
2. Use the following equations to rescale this variable to a proportional change:

$$\text{Relative severity (\%)} = (\text{Observed or predicted decline} / \text{Maximum decline}) \times 100$$

where

$$\text{Observed or predicted decline} = \text{Initial value} - \text{Present or future value}$$

and

$$\text{Maximum decline} = \text{Initial value} - \text{Collapse value}$$

$$3. \text{ Relative severity (\%)} = (SD_{t1} - SD_{t2}) / (SD_{t1} - \text{Collapse threshold}) \times 100$$

$$= (SD_{t1} - SD_{t2}) / (SD_{t1} - 0) \times 100$$

$$= \underline{\quad} \%$$

Record the result.

Note that if a collapse threshold similar to the final sediment outflow would dramatically increase how close the ecosystem is to collapsing:

$$4. \text{ Relative Severity} = (SD_{t1} - SD_{t2}) / (SD_{t1} - 240) \times 100$$

$$= \underline{\quad} \%$$

Next, assessors determine the extent of the degradation as a proportion of the total distribution of the ecosystem. With these two quantities assessors assign a risk category using the described thresholds. The extent of degradation was assumed to affect the entire Yellow Sea tidal flat ecosystem (100%). Record the outcome of this assessment.

## 6.3 Extra exercises (Criterion C)

### *Karst rising-spring wetland community of south east South Australia*

The distinguishing feature of this ecological community is the presence of surface expression of groundwater with sufficient head pressure to push water above the seal of the pool resulting in flows at any given time of the year. A number of wetland plant associations occur within the Karst Rising Spring (KRS) Wetland Community in the south east region of South Australia. These include vegetation associations of the spring pools and those of the peripheral peat fens. They consist of reedbeds, sedgeland, *Melaleuca squarrosa* shrublands and Silky Tea-tree wet shrublands.

The principal mechanism of environmental degradation is through decline in hydrological processes related to unsustainable extraction of groundwater, draining and global climate change. Suitable hydrological variables for assessing criterion C include ground water discharge volumes from spring pools and flow volume measurement from natural drainage channels. Ground water discharge and stream flow data are available, but only for a few sites. Drying of the springs is the most salient threat to the ecosystems because they are a water-dependent ecosystem. Environmental degradation under criterion C may be quantified using the daily spring discharge rate, with the collapse threshold assumed to be 30-38 megalitres per day.

#### Current decline:

The average flow in 2010 was estimated to be 40 ML/yr, declining from an average flow of 85.7 ML/yr in 1970. It is certain that decline in discharge commenced prior to 1970. No information is available regarding future or historic changes in this ecosystem.

Criterion	C		
	C1	C2	C3
Wetland community			



## 7. Criterion D. Biotic processes

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We will not continue with an assessment of the Yellow Sea tidal flat ecosystem, as criterion D was not assessed quantitatively due to a lack of region-wide data. It is expected that further data synthesis, collaboration and targeted studies would allow this criterion to be assessed adequately in the medium-term future. However, please read the paper and obtain a good understanding of the data sources used, which included:

- Observed population declines of key species, including migratory shorebirds
- Increasing rate of harmful algal blooms,
- Increasing rate of jellyfish blooms,
- The extent and severity of plant invasions.

### 7.1 Extra exercises (Criteria C + D)

We provide several exercises to further your understanding of applying criteria C and D.

#### *Montane mossy temperate forest*

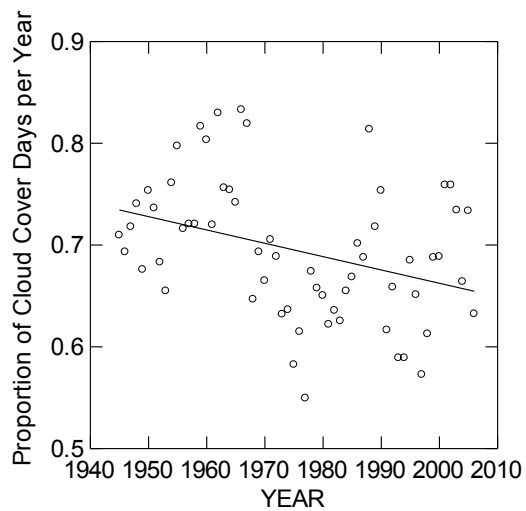
A mossy temperate forest occurs only on mountains higher than 700 m above sea level on Mediterranean islands. The forest is characterised by several endemic trees, shrubs and herbs that do not occur at lower elevations. Its stature is considerably shorter than lowland forests on the islands, and it has a distinctive abundance and diversity of arboreal bryophytes. The trees also support a unique arthropod assemblage.

The forest is strongly associated with a mesic microclimate. The moisture is contributed by orographic processes, which produce significant mists and rain on the mountain tops and upper slopes. Lower on the mountain slopes, the mossy temperate forest is replaced by pine forests that lack the endemic trees and arboreal bryophytes. The transition takes place at 700 - 800m above sea level, and the highest mountain in the region is 900m.

1. What process is likely to pose a threat to the persistence of the mossy temperate forests?
2. Which of the following would be the most suitable variable(s) for assessing the status of the mossy temperate forest under criterion C?
  - a) Mean annual temperature
  - b) Mean annual rainfall
  - c) Cloud cover
  - d) Mean rainfall of the summer months

Time series data are available for weather stations on three mountains located throughout the spatial and elevational range of the forest. These record precipitation and presence/absence of cloud on the mountains during each day. Meteorologists from the region advise that clouds have never been observed below 400 m elevation, and only extend

below 700 m on about 90 days per year. The cloud incidence data were pooled and, after inspection, were fitted to a linear regression shown below.



The fitted regression is:

$$\text{Proportion of cloudy days} = 0.736 - 0.0010 \cdot \text{year}.$$

The 95% confidence intervals on the intercept and slope parameters are 0.735 – 0.737 and 0.0009 – 0.0011, respectively.

3. What is the status of the habitat type under criterion C?
4. How would you incorporate uncertainty into the assessment?

### *Snowmelt herbfields (Criterion C and D)*

The highest elevated areas below permanent snow in the Alps support a unique herbfield community. The herbfield is locally restricted to small seepage zones on flat sites and moderate slopes, as snowmelt moisture is not retained on steeper slopes. Its occurrence is determined by the shortest growing season tolerated by vascular plants. Sites at warmer lower elevations and southern aspects support different assemblages dominated by mixtures of grasses and herbs. These larger plants are able to competitively exclude the smaller herbs at warmer temperatures, but cooler temperatures close to the permanent snowline are beyond their physiological tolerance because the growing season is too short to allow them to grow to maturity.

1. What processes are likely to pose a threat to the persistence of the snowmelt herbfields?
2. Which of the following would be the most suitable variable(s) for assessing the status of the snowmelt herbfields under criteria C and D?
  - a) Mean annual temperature
  - b) Duration of growing season
  - c) Depth of snow above the permanent snowline
  - d) Abundance of snowmelt specialist herbs at the snowline
  - e) Abundance of grasses in current snowmelt herbfield sites

Snowdepth time series data are available for a set of locations above the permanent snowline throughout the range of the snowpatch herbfields. The mean winter snow depth across the monitoring sites is currently  $2.0 \pm 0.1$  metres. There is no suitable habitat for snow patch herbfields at higher elevations than the snow depth monitoring sites. A linear regression is a good fit to these data and shows that snow depth has been declining at a rate of 0.50 to 1.0 cm per year (95% confidence interval) over the past 30 years.

3. What is a suitable threshold of snow depth that might indicate collapse of the snowmelt herbfields? Justify your answer(s).
4. What is the estimated depth of snow 50 years from now? Can you quantify the uncertainty in the estimate?
5. Use your answers to 3 & 4 calculate the relative severity of projected declines in snow depth over the next 50 years. How can you quantify the uncertainty in relative severity?
6. What is the extent of projected declines in snow depth over the next 50 years?
7. Use your answers to 5 and 6 to determine the status of snowmelt herbfield under criterion C2.
8. Outline some limitations of this assessment, e.g. what assumptions are necessary and how robust do you think they are?

## 8. References

---

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## 9. Appendices

### 9.1 Answers to the exercises

#### Criterion A

Year	Area (km <sup>2</sup> )	Notes
1958	11416.8	
1988	5448.5	Area change 1958 – 1988 = 5968.3
2008	3893.03	Provided in Murray et al (2014)

$$\begin{aligned}\text{ARD} &= - (\text{Area.t2} - \text{Area.t1})/(\text{year.t2} - \text{year.t1}) \\ &= - (5448.5 - 11416.8)/(1988-1958) \\ &= 198.94 \text{ km}^2/\text{year}\end{aligned}$$

$$\begin{aligned}\text{PRD} &= 100 \times (1 - (\text{Area.t2}/\text{Area.t1})^{1/(\text{year.t2} - \text{year.t1})}) \\ &= 100 \times (1 - (5448.506 / 11416.76)^{1/(1988-1958)}) \\ &= 2.44 \text{ \%/yr}\end{aligned}$$

$$\begin{aligned}\% \text{ lost} &= ((\text{Area.t1} - \text{Area.t2})/\text{Area.t1}) \times 100 \\ &= ((11416.76 - 5448.506) / 11416.76) \times 100 \\ &= 52.27\%\end{aligned}$$

$$\begin{aligned}\text{Area.2008.PRD} &= \text{Area.t1} \times (1 - (\text{PRD}/100))^{n\text{Years}} \\ &= 11416.8 \times (1 - (2.44/100))^{50} \\ &= 3320\end{aligned}$$

$$\begin{aligned}\text{Area.2008.ARD} &= \text{Area.t1} - (\text{ARD} \times n\text{Years}) \\ &= 11416.8 - (198.94 \times 50) \\ &= 1469.8 \text{ km}^2\end{aligned}$$

$$\begin{aligned} \text{\% lost} &= ((\text{Area.t1} - \text{Area.2008.PRD})/\text{Area.t1}) \times 100 \\ &= ((11416.8 - 3320)/11416.8) \times 100 \\ &= 70.9 \text{ \%} \end{aligned}$$

Year	1986 (km <sup>2</sup> )	2001 (km <sup>2</sup> )	ARD	PRD	2051 Area Estimate	% Change	Assessment outcome
Evergreen forest	397	385	0.8	0.2	347.56	9.7	PRD
Semi-deciduous forest	1190	1037	10.2	0.9	655.47	36.9	PRD
Deciduous forest	2227	1563	44.3	2.33	480.2	69.3	PRD
Grasslands	1249	2001	-50.1	-3.2	4507.7	-125.3	ARD assumption: don't expect an exponential increase of grasslands

### Criterion B

Measure of Distribution	Area (km <sup>2</sup> )	Notes
AOO	720	.
AOO (excluding 1 per cent)	373	
EOO	524823.6	

### Criterion C

SD.t1 = 562

SD.t2 = 244

Collapse Threshold = 0

$$\begin{aligned} \text{Relative severity (\%)} &= (\text{SD.t1} - \text{SD.t2}) / (\text{SD.t1} - \text{Collapse threshold}) \times 100 \\ &= (562 - 244) / (562 - 0) \times 100 \\ &= 56.6 \text{ \%} \end{aligned}$$

## 9.2 R Code for RLE Assessments



# Introduction to the IUCN Red List of Ecosystems Categories and Criteria

*N. Murray*

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Welcome to the training course for the introduction of the Red List of Ecosystems categories and criteria. We will work through a range of exercises supported by lectures over the next few days, with the aim of providing an in-depth introduction to all aspects of the RLE required to complete an assessment of one or more ecosystems. This training course is intended to be accompanied by the Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria, which is the definitive source for all information required to ensure consistent application of the criteria (IUCN, 2015).

## Structure of this course

The training course and course manual is intended as a largely self-learning exercise which is supported by experts in ecosystem risk assessment. Our course will largely follow the general process for assessing ecosystems, as depicted in Figure 1. We will begin with a series of introductory lectures that provides the history, background and purpose of the IUCN Red List of Ecosystems. Following this, we will develop the theoretical basis for assessing ecosystems under the Red List categories and criteria, allowing us to (i) define an ecosystem type under assessment, (ii) identify and describe the key features and processes of the ecosystem, (iii) map the distribution of the ecosystem type and (iv) collect the data necessary for submitting to the IUCN for adoption.

The remainder of the course will follow a series of lectures and practical exercises to ensure a thorough understanding of the application of the categories and criteria. Using a case study provided by the course instructors, we will then work through each of the criteria, enabling us to assess the ecosystem type using a range of tools and resources that are available for the purpose. You may wish to use a dataset of your own to complete these exercises.

Lastly, we will determine the final outcome of the ecosystem risk assessment, enabling a final classification of the status of the focal ecosystem. At all times we will allow time for questions, discussion and you can feel free to contact us by email.

## Tools and resources

We provide a range of tools and resources for completing a Red List of Ecosystems assessment. The main tools we will use include:

1. ArcGIS. Optional to use QGIS, Grass or some other open source software. We are working towards extending our documentation to include open-source software.
2. Microsoft Excel or Google Spreadsheets.
3. We can also use program R and Python for many of the analyses. For analytical tools and functions written in these programming languages please go to: <https://github.com/nick-murray> (<https://github.com/nick-murray>)

# Exercises: Day 1

## Mapping an ecosystem

We will begin the exercises with a preliminary analysis of a dataset depicting the spatial distribution of an ecosystem type. This assumes that we have fully defined our focal ecosystem type, its characteristic native biota and abiotic environment, and have a good understanding of the key drivers that influence the ecosystem type. As we have discussed in the first lectures of the course, much of this information will be based on your own expertise of the ecosystem type, a very detailed literature review of published and grey literature, discussion with key experts, and clarification with experts on ecosystem risk assessment.

In this course we will not undertake any remote sensing, vegetation classifications, map digitization or any other work required for mapping an ecosystem type. Instead, we will use a simulated ecosystem that has been slowly degrading due to a threat that operates uniformly across the edges of the ecosystem (such as land-clearing).

## Some caution required

As with all mapping exercises, it is essential to fully understand the data:

1. Where did the data come from?
2. How was the data mapped?
3. What was the resolution of the map?
4. How accurate were the maps? If the maps are inaccurate then this must be accounted for to ensure our estimates of change are comparable over time, rather than an artefact of mapping inaccuracies (see Fuller et al 2003).
5. Are the datasets suitable for our purposes?

After checking for these important factors, we are satisfied that the dataset is directly comparable for our purposes, avoiding some common mistakes with time-series mapping (see Section 5, guidelines). For further consideration of these common mistakes and how to combat them, refer to these papers:

- Fuller, R. M., Smith, G. M. & Devereux, B. J. 2003. The characterisation and measurement of land cover change through remote sensing: problems in operational applications? *International Journal of Applied Earth Observation and Geoinformation*, 4, 243-253.
- Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E. & Wulder, M. A. 2014. Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, 42-57.
- Olofsson, P., Foody, G. M., Stehman, S. V. & Woodcock, C. E. 2013. Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment*, 129, 122-131.

## Importing the data

First we need to download and load some libraries that we will use in our analysis.

```
# install.packages(c("raster", "sp", "rgeos"))  
library(raster)
```

```
## Loading required package: sp
```

```
library(sp)
library(rgeos)
```

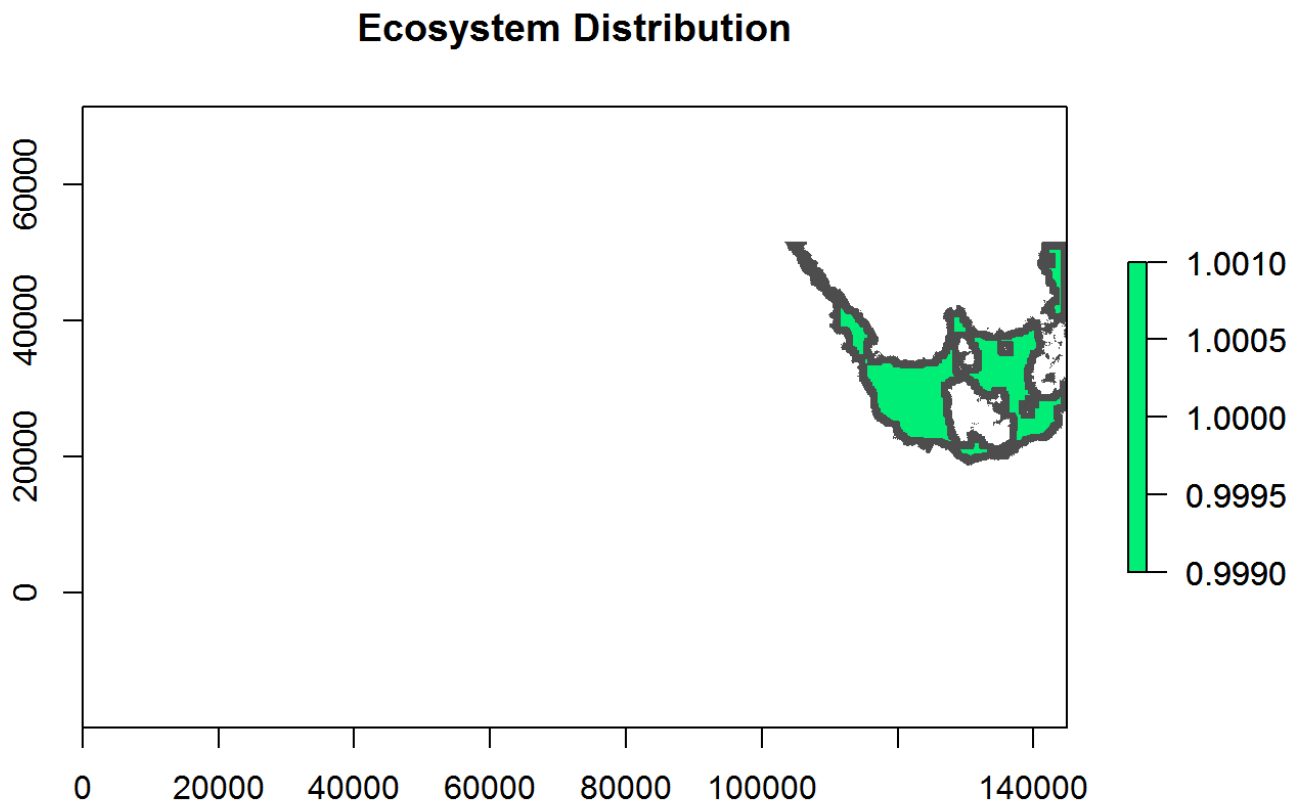
```
## rgeos version: 0.3-13, (SVN revision 508)
## GEOS runtime version: 3.4.2-CAPI-1.8.2 r3921
## Linking to sp version: 1.2-1
## Polygon checking: TRUE
```

Now we set the workspace, and load the two raster datasets that we will use in this exercise. Note that the two rasters are distributions of the ecosystem at time1 = 1990 and time2 = 2012

## Plot the data

Let's look at the distributions. Note that at time2 the ecosystem (in green) is smaller than at time1 (in grey) due to uniform land clearing around the ecosystem boundaries.

```
plot (r1, col = "grey30", main = "Ecosystem Distribution")
plot (r2, add = T, col = "springgreen2")
```



At this stage it is also good to compare the ecosystem distribution maps against satellite images and other information that assists in understanding the quality of the maps and ensuring they are fit for purpose. This can be achieved using packages such as ggmap, plotgooglemaps, googleVis etc.

# Criterion A: reduction in geographic distribution

## Determining ecosystem areas

The RLE allows assessment of ecosystems over a range of timeframes. However, to achieve an estimate of change we must first determine the area of an ecosystem at each point in time. We can use a custom function (which we call `getArea`) to do this with our raster distribution datasets. This function first determines the width of each cell of the raster, then counts the number of cells in the raster. Last, we convert the area to km<sup>2</sup>.

```
getArea <- function (ecosystem.data){
  cell.res <- res(ecosystem.data)
  cell.width <- cell.res[1]
  n.cell <- ncell(ecosystem.data[values(ecosystem.data)!="NA"]) # count non NA cells
  aream2 <- (cell.width * cell.width) * n.cell
  areakm2 <- aream2/1000000
  return (areakm2)
}
```

We can now run the function:

```
a.r1 = getArea(r1)
a.r1
```

```
## [1] 498.46
```

```
a.r2 = getArea(r2)
a.r2
```

```
## [1] 196.83
```

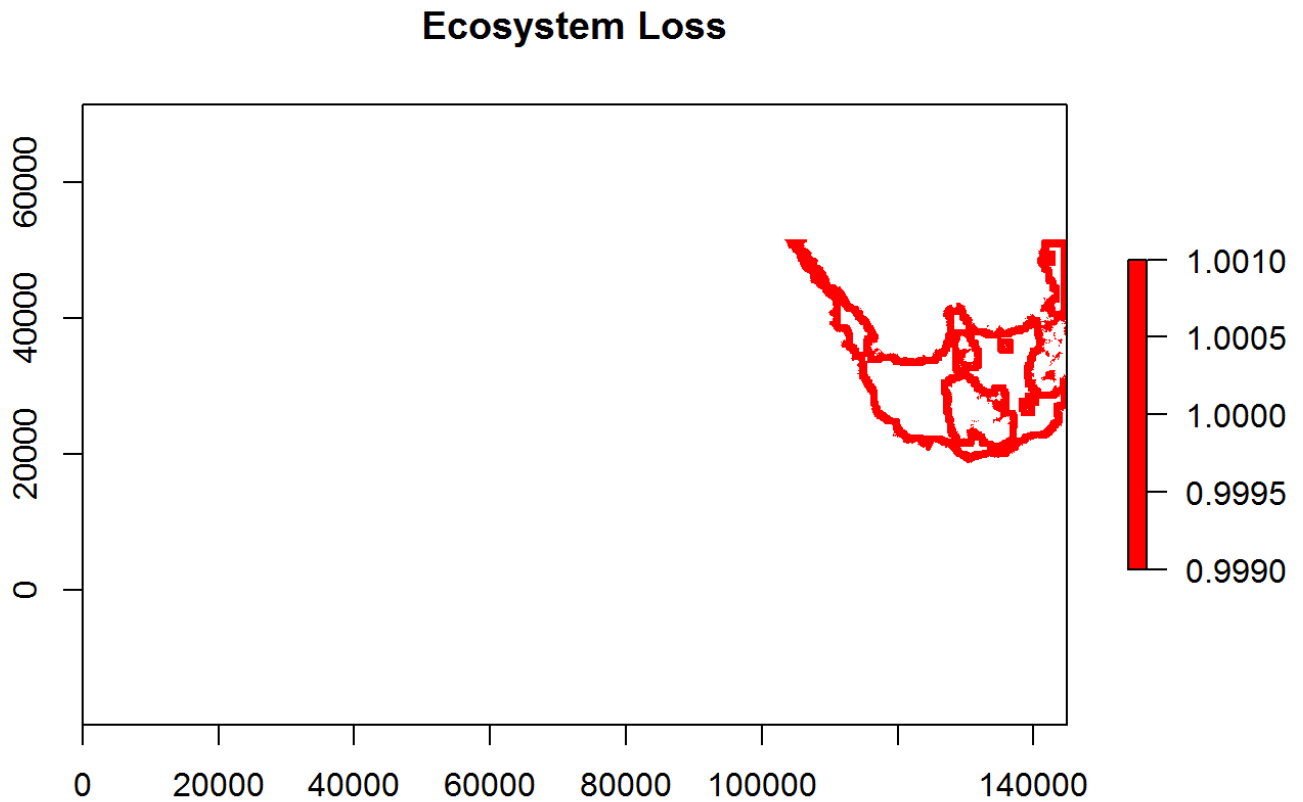
The result: at time 1 (1990) the ecosystem was 498.46 km<sup>2</sup> and at time 2 (2012) the ecosystem was 196.83 km<sup>2</sup>.

We can also use image differencing to identify the locations where the ecosystem has changed over time. Note this procedure can be slow for large datasets.

```
difRast <- function (r1, r2){
  p1 <- rasterToPolygons(r1, dissolve = T)
  p2 <- rasterToPolygons(r2, dissolve = T)
  dif.p <- gDifference(p1, p2)
  dif.r <- rasterize(dif.p, r1)
  return (dif.r)
}
dif <- difRast(r1, r2)
```

```
## Warning in RGEOSBinTopoFunc(spgeom1, spgeom2, byid, id, drop_lower_td,
## unaryUnion_if_byid_false, : spgeom1 and spgeom2 have different proj4
## strings
```

```
plot (dif, col = "red", main = "Ecosystem Loss")
```



## Calculating rates of decline

In the Red List of Ecosystems, we suggest two methods to determine the rate of decline of an ecosystem, each of which assumes a different functional form of the decline (IUCN, 2015). In a PRD, the decline is a fraction of the previous year's remaining area ( $0.02 \times$  last year's area), while in an ARD the area subtracted each year is a constant fraction of the area of the ecosystem at the beginning of the decline ( $0.02 \times 1000 = 20 \text{ km}^2/\text{year}$ ) (IUCN, 2015). These rates of decline allow extrapolation to the full timeframe of an assessment based on the assumption of proportion (50 years in past, present or future). The annual rate of change (ARC) uses a compound interest law to determine the instantaneous rate of change (Puryvaud 2004)

Again, we set the functions up according to the equations in Keith et al (2009) and Puryvaud (2004).

```

# Criterion A stuff
getARD <- function (A.t1, A.t2, year.t1, year.t2){
  # Absolute Rate of Change (also known as Annual Change(R))
  ARD <- (A.t2-A.t1)/(year.t2-year.t1)
  ARD <- -ARD # make it a positive number to be consistend with Keith et al 2009
  return (ARD)
}

getPRD <- function (A.t1, A.t2, year.t1, year.t2){
  # Proportional rate of change (also known as trajectory (r))
  PRD <- 100 * (1-(A.t2/A.t1)^(1/(year.t2-year.t1)))
  return (PRD)
}

getARC <- function (A.t1, A.t2, year.t1, year.t2){
  # Annual rate of change from Puyravaud 2004. Also known as instantaneous rate of change.
  ARC <- (1/(year.t2-year.t1))*log(A.t2/A.t1)
  return (ARC)
}

```

We run the functions to determine the ARD, PRD and ARC.

```

ARC = getARC(a.r1, a.r2, year.t1 = 1990, year.t2 = 2012)
ARC

```

```
## [1] -0.04223559
```

```

ARD = getARD(a.r1, a.r2, year.t1 = 1990, year.t2 = 2012)
ARD

```

```
## [1] 13.71045
```

```

PRD = getPRD(a.r1, a.r2, year.t1 = 1990, year.t2 = 2012)
PRD

```

```
## [1] 4.135609
```

## Estimating future decline

Now we can use the rates of change (PRD = 4.1356091 and ARD = 13.7104545) to determine the percentage lost over one of the Red List of Ecosystems timeframes. Here we forecast into the future from 1990, which is allows an assessment under Criterion A2b.

Again we use a custom function that returns a data frame of our estimates

```

futureAreaEstimate <- function(A.t1, year.t1, PRD, ARD, ARC, nYears = 50){
  A.PRD.t3 <- A.t1 * (1 - (PRD/100))^nYears
  A.ARC.t3 <- A.t1 * (1 + ARC)^nYears
  A.ARD.t3 <- A.t1 - (ARD*nYears)
  if (A.PRD.t3 < 0) A.PRD.t3 = 0
  if (A.ARC.t3 < 0) A.ARC.t3 = 0
  if (A.ARD.t3 < 0) A.ARD.t3 = 0
  y.t3 <- year.t1+nYears
  out <- data.frame(area.t1 = A.t1,
                    year.t1 = year.t1,
                    prop.rate.decl = PRD,
                    abs.rate.decl = ARD,
                    annual.rate.change = ARC,
                    forecast.year = y.t3,
                    forecast.area.prd = A.PRD.t3,
                    forecast.area.arc = A.ARC.t3,
                    forecast.area.ard = A.ARD.t3)

  return(out)
}

fut.est = futureAreaEstimate(a.r1, year.t1 = 1990, PRD = PRD, ARD = ARD, ARC = ARC, nYears = 50)
fut.est

```

```

## area.t1 year.t1 prop.rate.decl abs.rate.decl annual.rate.change
## 1 498.46 1990 4.135609 13.71045 -0.04223559
## forecast.year forecast.area.prd forecast.area.arc forecast.area.ard
## 1 2040 60.32484 57.61892 0

```

We now have an assessment of how much area will remain in the year 2040 under various decline scenarios. The most extreme scenario, which assumes a linear decline where 13.7104545 of the ecosystem is lost per year, results in 0 km<sup>2</sup> of the ecosystem remaining. The least pessimistic, the proportional rate of decline, estimates that 60.3248395 will remain in the year 2040.

## Criterion B: restricted geographic distribution

Criterion B utilizes measures of the geographic distribution of an ecosystem type to identify ecosystems that are at risk from catastrophic disturbances. The geographic distribution of an ecosystem type is assessed under criterion B with two standardized metrics: the extent of occurrence (EOO) and the area of occupancy (AOO) (Gaston and Fuller, 2009, Keith et al., 2013). It must be emphasised that EOO and AOO are not used to estimate the mapped area of an ecosystem like the methods we used in Criterion A; they are simply spatial metrics that allow us to standardise an estimate of risk spreading. Thus, it is critical that these measures are used consistently across all assessments, and the use of non-standard measures invalidates comparison against the thresholds. Refer to the guidelines for more information on AOO and EOO.

### Measuring the Extent of Occurrence

The RLE guidelines defines the EOO as:

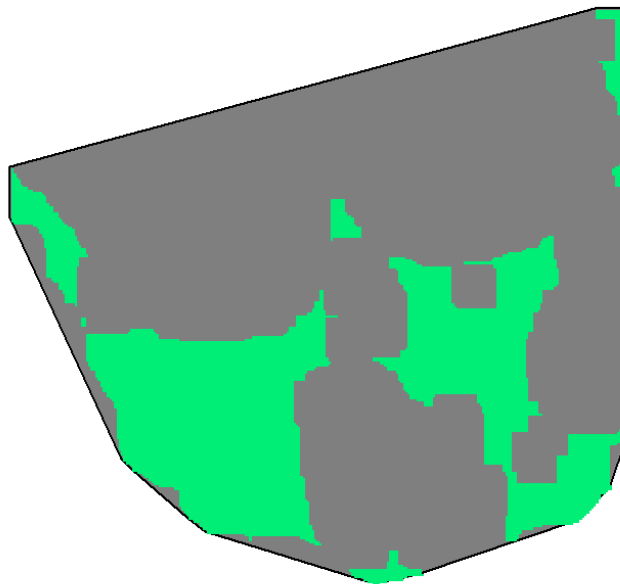


*The EOO of an ecosystem is measured by determining the area (km<sup>2</sup>) of a minimum convex polygon-the smallest polygon that encompasses all known occurrences of a focal ecosystem in which no internal angle exceeds 180 degrees- fitted to an ecosystem distribution. The minimum convex polygon (also known as a convex hull) must not exclude any areas, discontinuities or disjunctions, regardless of whether the ecosystem can occur in those areas or not. Regions such as oceans (for terrestrial ecosystems), land (for coastal or marine ecosystems), or areas outside the study area (such as in a different country) must remain included within the minimum convex polygon to ensure that this standardized method is comparable across ecosystem types. In addition, these features contribute to spreading risks across the distribution of the ecosystem by making different parts of its distribution more spatially independent.*

Thus, to accurately measure the EOO of an ecosystem we must apply a minimum convex polygon to our most recent ecosystem data (2012), which we can achieve in several ways using R. Here we use the convex hull tool from the package rGeos.

```
E00.function <- function( r ) {  
  # uses rgeos package  
  ps <- rasterToPoints(r, spatial = TRUE)  
  n = gConvexHull(ps)  
  return (n)  
}  
eoo <- E00.function (r2)  
plot (eoo, col = "grey 50", main = "Extent of Occurrence")  
plot (r2, add = T, col = "springgreen2", legend = FALSE)
```

## Extent of Occurrence



To measure the area of the EOO, which is required for assessing against thresholds, we can use another function.

```
getAreaEOO <- function(EOO.polygon){
  # Returns the area of the makeEOO output (spatialpolygons object)
  EOO.arem2 <- sapply(slot(EOO.polygon, "polygons"), slot, "area") # get the area from
  m the slots in the polygon dataset
  EOO.areakm2 <- EOO.arem2/1000000
  return(EOO.areakm2)
}
eooArea <- getAreaEOO(eoo)
eooArea
```

```
## [1] 714.45
```

We estimate the area of the EOO is 714.45. This places it within the CR category of Criterion B1. Note that to achieve a final status of CR, the ecosystem must also meet three subcriteria. Without meeting these, the ecosystem remains least concern.

## Measuring the Area of Occupancy

As the primary source of all information on the RLE, the RLE guidelines has a detailed section on the theory, background and methods for measuring the AOO of an ecosystem type:

*Area of occupancy (AOO). Measures of AOO are highly sensitive to the grain size (pixel resolution) at which the distribution is mapped (Nicholson et al., 2009), so all measures of AOO of an ecosystem type must be standardized to a common spatial grain. The AOO of an ecosystem defined in the RLE is determined by counting the number of 10 × 10 km grid cells that contain the ecosystem. This relatively large grain size is applied for three reasons: (i) ecosystem boundaries are inherently vague (Regan et al., 2002), so it is easier to determine that an ecosystem occurrence falls within a larger grid cell than a smaller one; (ii) larger cells may be required to diagnose the presence of ecosystems characterized by processes that operate over large spatial scales, or possess diagnostic features that are sparse, cryptic, clustered or mobile (e.g. pelagic or artesian systems); (iii) larger cells allow AOO estimation even when high resolution distribution data are limited. A global 10 × 10 km gridded dataset suitable for this purpose is available on the IUCN Red List of Ecosystems website in both raster and vector formats. Some ecosystem distributions comprise a highly skewed distribution of patch sizes. In these cases large numbers of small patches contribute a negligible risk-spreading effect to that of larger patches and a correction may be applied by excluding from the AOO those grid cells that contain patches of the ecosystem type that account for less than 1% of the grid cell area (i.e. < 1km<sup>2</sup> of the focal ecosystem type, Box 10). Research is in progress to support guidance on when to apply this correction.*

As with the EOO, it is essential that the methods used to determine the AOO of an ecosystem type is consistent and well documented.

First, we load a global 10 x 10-km raster grid, which can be downloaded at <https://github.com/nick-murray> (<https://github.com/nick-murray>), and clip it to the extent of our ecosystem map.

```

fishnet <- raster("C:\\Dropbox\\GIS_Data\\GIS_Projects\\Red_List_Ecosystems\\Data\\A0
O_Grids\\Multiprocessing\\Fishnet_10x10km.img")

resampleFishnet<- function (ecosystem.data, Fishnet) {
  # Crops and resamples the global fishnet to ecosystem extent
  ecosystem.extent <- extent(ecosystem.data)
  fishnet.crop <- crop(Fishnet, ecosystem.extent)
  fishnet.resample <- resample(fishnet.crop, ecosystem.data, method = "ngb")
  alignExtent(ecosystem.extent, fishnet.resample, snap='near') # snap cell boundaries
  return(fishnet.resample)
}

grid.crop <- resampleFishnet(r2, fishnet)
rm(fishnet) # remove the global one from the environment

```

The next step is to define a function that can determine the amount of ecosystem that occurs within each 10 x 10 km grid cell. We need to provide the ecosystem dataset (r2), the cropped 10 x 10 km grid (grid.crop) and state whether we want the *one percent rule* to apply. Here, we are satisfied that the 1 per cent rule is not needed due to our confidence in the mapping routine and the

```

getA00 <- function (ecosystem.data, fishnet.resample, one.percent.rule = TRUE) {
  # Computes the number of 10x10km grid cells that are >1% covered by an ecosystem
  agg.extent <- extent(ecosystem.data)
  agg.resample <- resample(ecosystem.data, fishnet.resample, method ="ngb")
  zonalstat <- zonal(agg.resample,fishnet.resample, 'sum') # provides stats of number o
f grid cells in each A00 cell
  zonal.data <- as.data.frame(zonalstat)
  cell.res <- res(ecosystem.data)
  zonal.data$area <-((cell.res[1]*cell.res[2])*zonal.data$sum)/1000000
  if (one.percent.rule == TRUE){
    zonal.data$A00 <- zonal.data$area>1 # >1km2 for 1pc A00
    A00.number <- sum(zonal.data$A00)
  }
  if (one.percent.rule == FALSE){
    zonal.data$A00 <- zonal.data$area>0 # >0km2 for 1pc A00
    A00.number <- sum(zonal.data$A00)
  }
  return(A00.number)
}

A00 <- getA00(r2, grid.crop, one.percent.rule = FALSE)
A00

```

```
## [1] 11
```

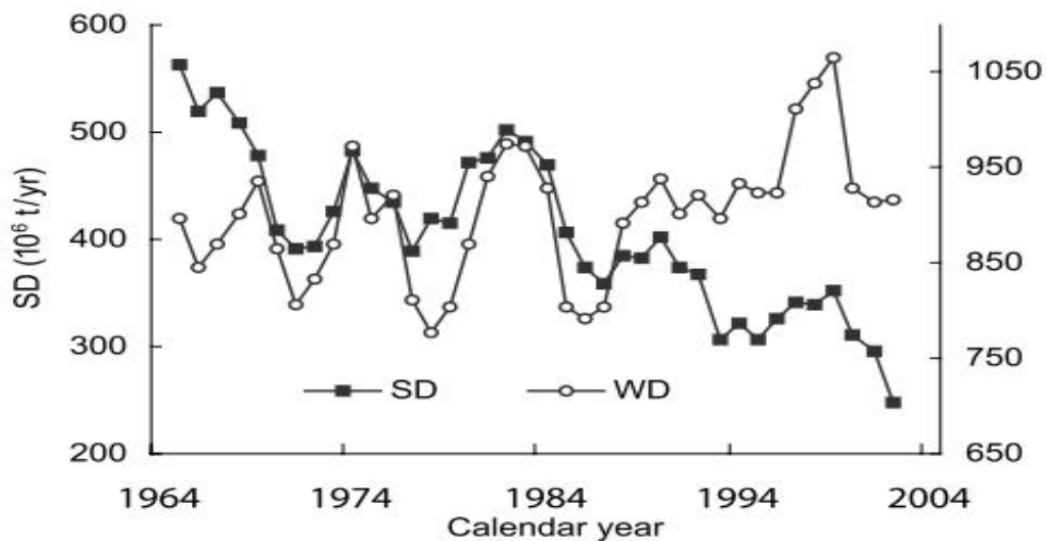
We estimate the area of the AOO of the ecosystem is 11 10 x 10 km cells (without the 1 per cent rule). This places it within the EN category of Criterion B2. As with Criterion B1, to meet the thresholds under Criterion B the ecosystem must also meet three additional subcriteria. Without meeting these, the ecosystem remains least concern.

# Exercises: Day 2

## Calculating relative severity

We use sediment decline data from the Yangtze river to demonstrate how to calculate relative severity according to the methods described in Keith et al (2013) and Rodriguez et al (2015). The data originated as a plot in Yang et al (2005).

```
#install.packages("jpeg")
library(jpeg)
YangtzeSediment <- readJPEG("C:\\_NickMurray\\Murray_Git\\RLE-Tools\\Data\\Yangtze Yang
et al 2005.jpg", native = T)
plot(0:1, 0:1, type = "n", ann = FALSE, axes = FALSE)
rasterImage(YangtzeSediment, 0,0,1,1)
```



We digitised the plot using WebPlotDigitizer, which enabled the collection of data within the plot. We import the csv file, and look at the data. The dataset has 38 sediment measurements between 1965 and 2004.

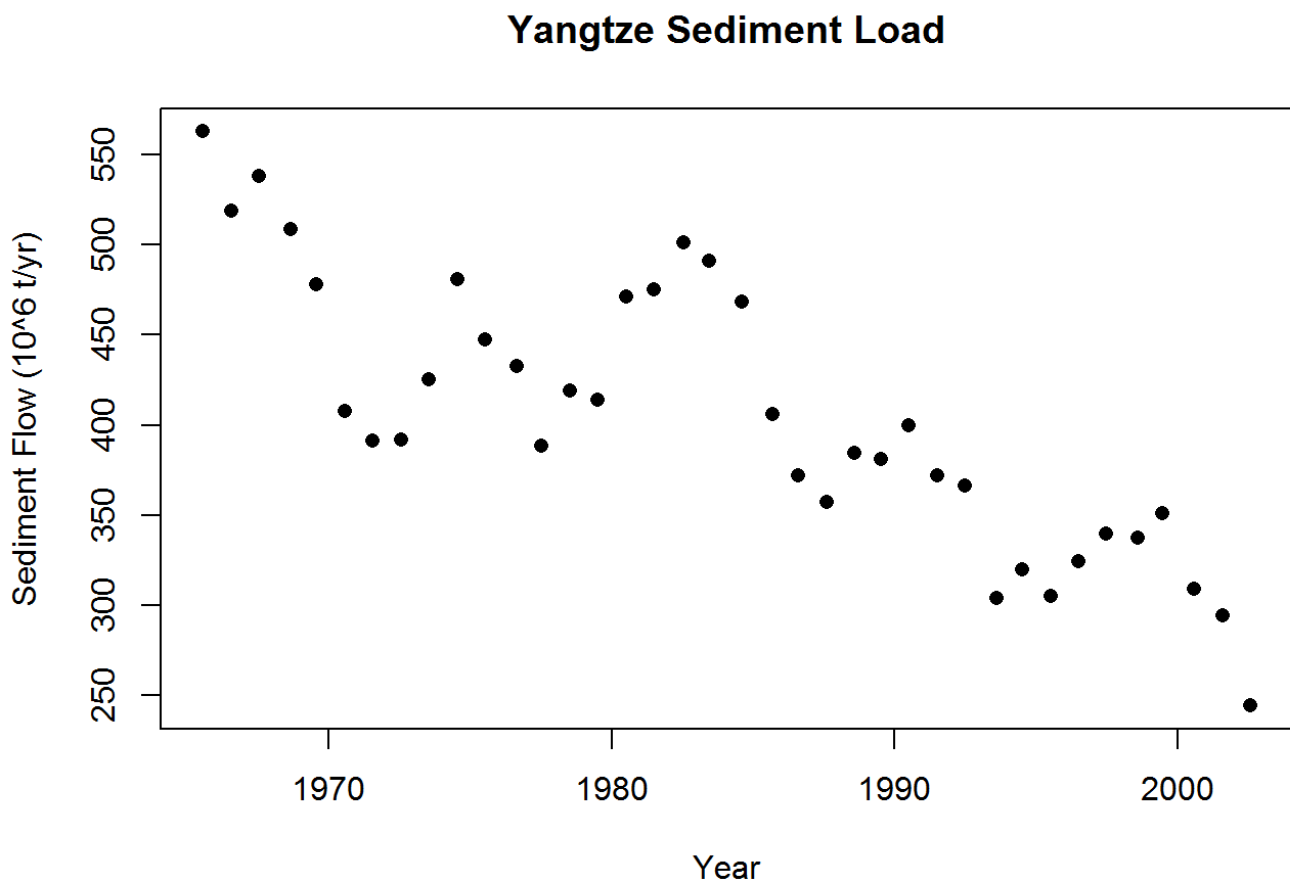
```
sed <- read.csv("C:\\_NickMurray\\Murray_Git\\RLE-Tools\\Data\\YangtzeSediments.csv")
head(sed)
```

```
##      Year Sediment
## 1 1965.532 562.9434
## 2 1966.553 519.0953
## 3 1967.518 537.9688
## 4 1968.652 508.4763
## 5 1969.560 478.2325
## 6 1970.582 407.9361
```

```
nrow(sed)
```

```
## [1] 38
```

```
plot (Sediment ~ Year, data = sed, pch = 16, main = "Yangtze Sediment Load", ylab = "Sediment Flow (10^6 t/yr)")
```



As a quick method to calculate relative severity of the sediment decline we use a least-squares linear regression to estimate the change in sediment over a 50 year period

```
lm.fit <- lm(Sediment ~ Year, data = sed)
summary(lm.fit)
```

```
##
## Call:
## lm(formula = Sediment ~ Year, data = sed)
##
## Residuals:
##   Min     1Q  Median     3Q      Max
## -84.28 -23.64   1.69  21.11  88.25
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 11654.0525  1245.1522   9.360 3.53e-11 ***
## Year         -5.6699     0.6276  -9.035 8.70e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 42.42 on 36 degrees of freedom
## Multiple R-squared:  0.6939, Adjusted R-squared:  0.6854
## F-statistic: 81.63 on 1 and 36 DF,  p-value: 8.702e-11
```

```
t.end= max(sed$Year)
t.start = max(sed$Year) -50 # work out the assessment period
low.sed = min (sed$Sediment) - 20
end.sed = lm.fit$coefficients[[2]]*t.end+lm.fit$coefficients[[1]] # find the
start.sed = lm.fit$coefficients[[2]]*t.start+lm.fit$coefficients[[1]] #
high.sed = start.sed + 20

pc.change = 100*((start.sed - end.sed)/ start.sed ) # the "percent change in 50 years v
alue"
pc.change
```

```
## [1] 48.61882
```

Therefore, assuming the linear regression is a fair model, we estimate that there has been a 48.6188212 decline in sediment outflow between 1952.58156 and 2002.58156

We can now use the relative severity equation from Keith et al (2013) to estimate the relative severity of the decline. We set the collapse threshold before calculating relative severity

```
collapse.threshold = 0
rel.sev = 100*((end.sed-start.sed)/(collapse.threshold-start.sed))
rel.sev
```

```
## [1] 48.61882
```

We should plot the above to ensure our estimates of relative severity appear correct.

```
plot(sed$Year, sed$Sediment, type="o", pch = 20, col = "black",  
     ylab = "Sediment Flow (10^6 t/yr)", xlab = "Year", yaxs="i", xaxs = 'i',  
     xlim = c(1948, 2010), ylim = c(0,high.sed+20), main = "Yangtze Sediment Decline")  
abline (lm.fit, col = "slateblue", lwd = 2)  
abline(v = t.end, col = "darkgrey", lty = 1, lwd = 2)  
abline (v = t.start, col = "darkgrey", lty = 1, lwd = 2)  
abline(h = collapse.threshold, col = "darkblue", lty = 1, lwd = 2)  
abline (h = end.sed, col = "red", lty = 2, lwd = 4)  
abline (h = start.sed, col = "red", lty = 2, lwd = 4)
```

## Yangtze Sediment Decline

