Measuring landscape pattern

Landscape ecology and fragmentation analysis

- Applied Biogeography links to Landscape Ecology concepts through Island Biogeography
- Fragmented landscapes may be considered to share characteristics with islands
- Deforestation leads to the formation of patches of intact habitat within a more hostile matrix
- Reserves are also islands of protected habitat embedded within a more hostile matrix.

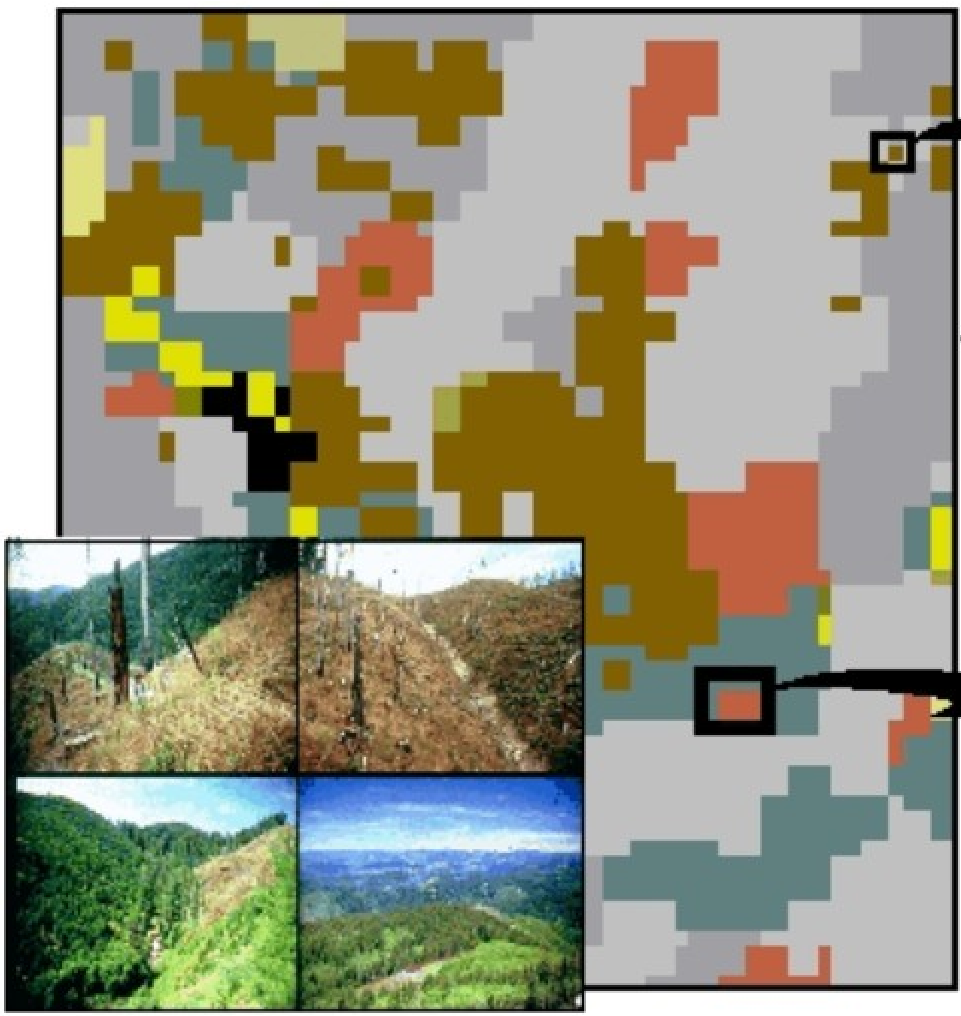
Landscape ecology reading

- **Turner, M., Gardner, R., & O'Neill, R. (2001). Landscape ecology in theory and practice: pattern and process.**
- Forman, R. T. T., and M. Godron. 1986. Landscape ecology. Wiley, New York.
- McGarigal Fragstats documentation (various)

Scale of landscapes

- Forman and Godron (1986) suggested a lower limit for landscapes at a "few kilometers in diameter".
- The principles of landscape ecology apply to ecological mosaics at any level of scale
- Each organism "scales" the environment differently.
- From an organism-centered perspective, a landscape could range in absolute scale from an area smaller than a single forest stand (even a single log) to an entire national park.
- So, we need to manage habitats across the full range of spatial scales.

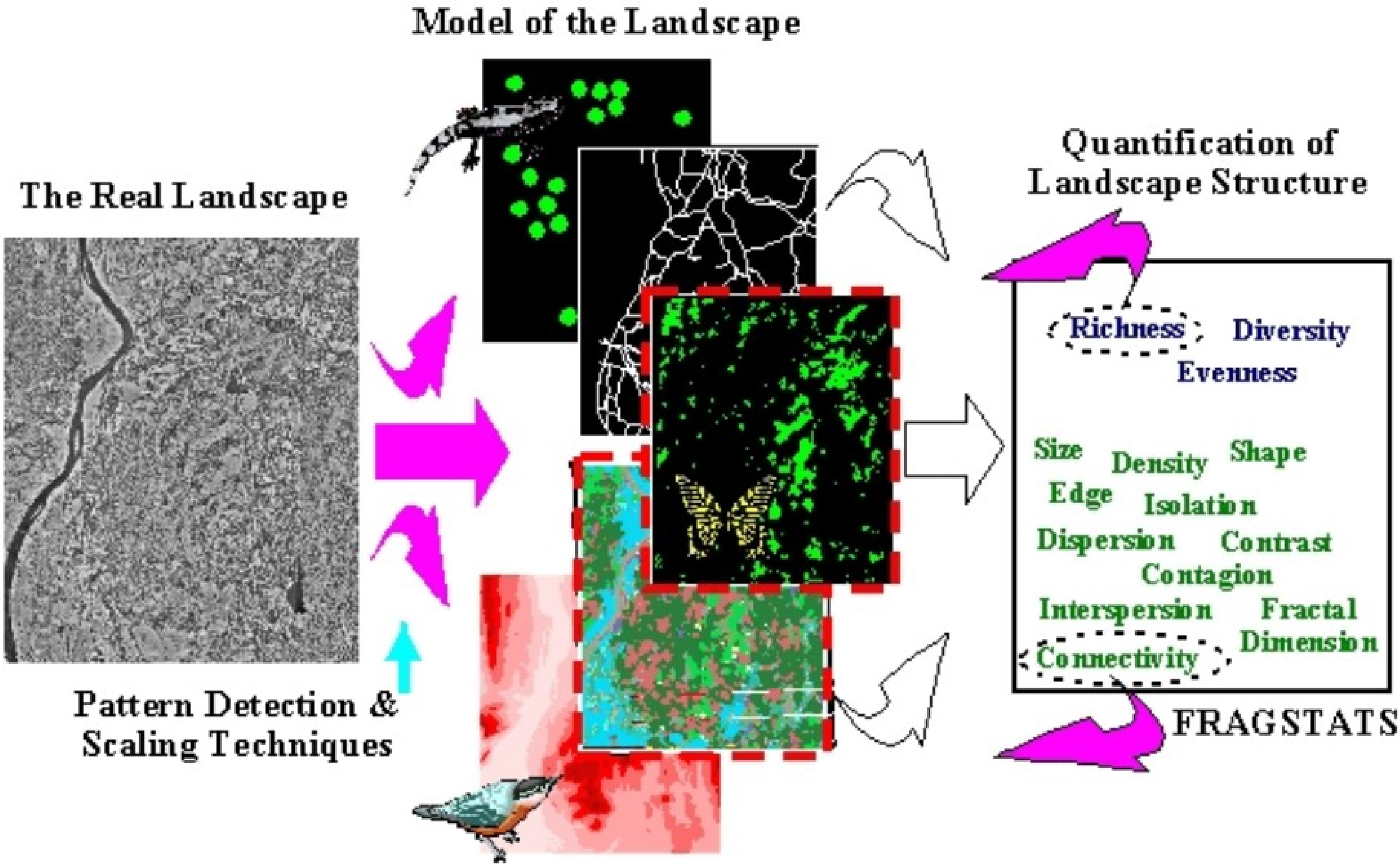
The Importance of Scale



- **GRAIN:** The minimum resolution of the data, defined by the cell size (raster data) or minimum polygon size (vector data).
- **EXTENT:** The scope or domain of the data, defined as the size of the landscape or study area under consideration
- ***Minimum Patch Size*:** The minimum patch size considered, equal to or above the resolution of the data.

From McGarigal Fragstats conceptual foundation

Quantifying landscape pattern



From McGarigal Fragstats conceptual foundation

Landscape metrics

- Designed to allow quantitative comparisons between landscapes
- Large number of metrics have been defined ranging from the trivially simple to the fiendishly complex and abstract.
  - Area/density/edge metrics
  - Shape metrics
  - Core area metrics
  - Contrast metrics
  - Contagion/interspersion metrics
  - Isolation/proximity metrics
  - Connectivity metrics
  - Diversity metrics

Calculating metrics

- Although it is possible to calculate metrics on a paper map, a GIS makes it much easier
- Landscape ecology took off as a result of GIS
- A GIS can calculate metrics on both vector or raster data
- Some metrics can be difficult to calculate directly using a standard GIS (e.g. certain types of connectivity index).
- Specialised programs such as Fragstats have been designed to enable many indices to be calculated at once

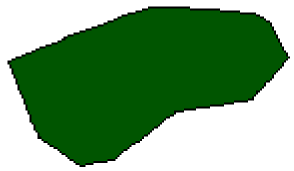
Questions

- How different are landscapes in terms of ...
  - Patch size?
  - Patch shape?
  - Core area?
  - Edge effects?
  - Connectivity between patches?
- How might these differences affect key processes taking place on the landscape?

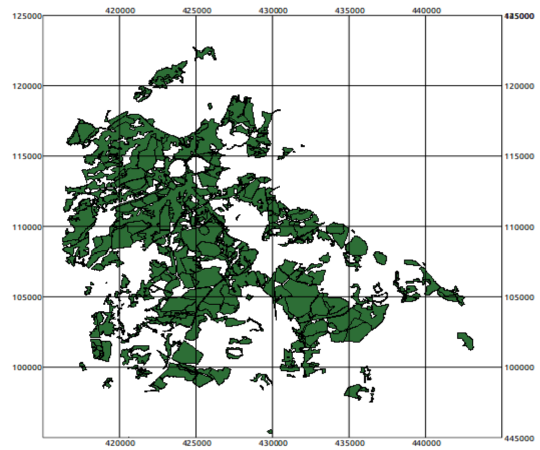
Levels of heterogeneity

- Patch
- Class
- Landscape

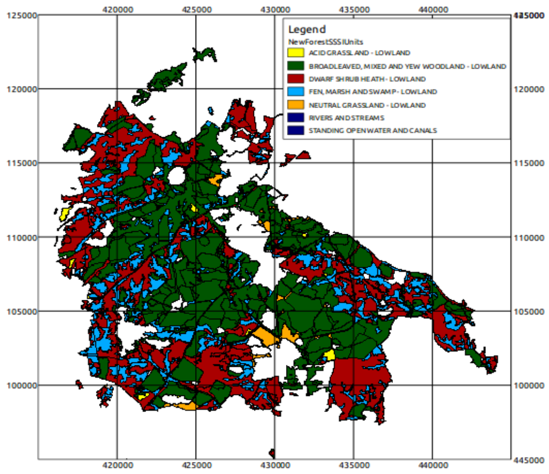
Patch



Class

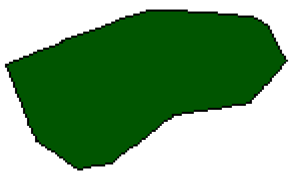


Landscape



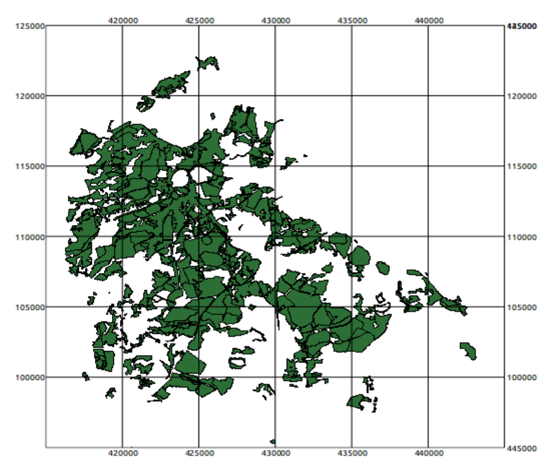
Patch level

- The single patch level does not take into account the landscape context.
  - Useful for discussing the properties of each one of the elements that make up the landscape.
  - Some patches are more important than others and their characteristics may be important in understanding the whole landscape
  - The size of the largest patch is often very important for conservation.



Class level

- The class level only takes into account only one habitat type.
  - Based on the “patch/matrix” model, i.e. assume all non habitat areas are hostile.
  - Useful for looking at change in a single focal habitat.
  - One habitat type is often particularly important for a focal organism.

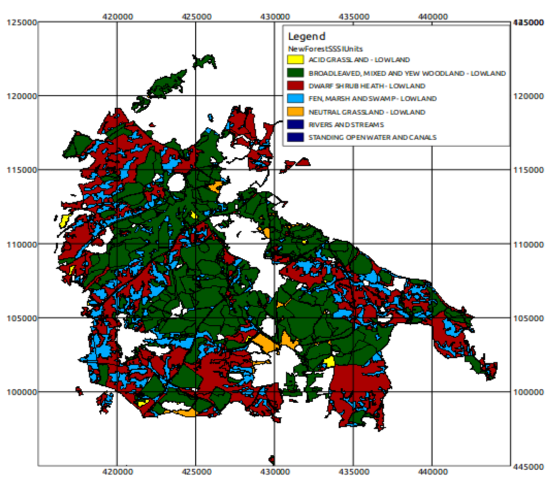


Landscape level

The true landscape level potentially takes into account interconnectivity between classes.

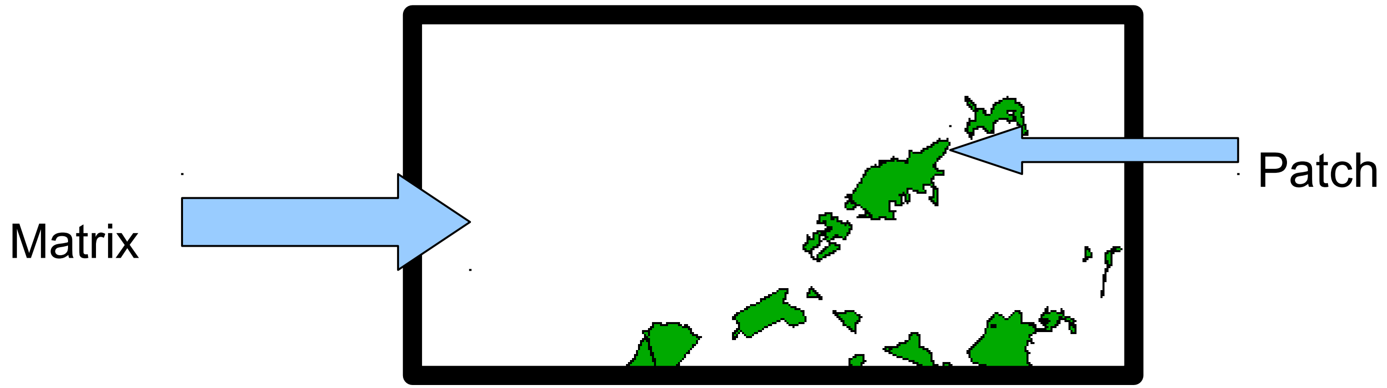
Useful for comparing landscape diversity

Can be very challenging to interpret the metrics when many classes are involved.



Patch (corridor) matrix model

- A class level simplification
- Each habitat patch is considered to be embedded within a “hostile” matrix.
- Later we will see how this relates to theory (Island Biogeography)
- Useful, but simplistic model

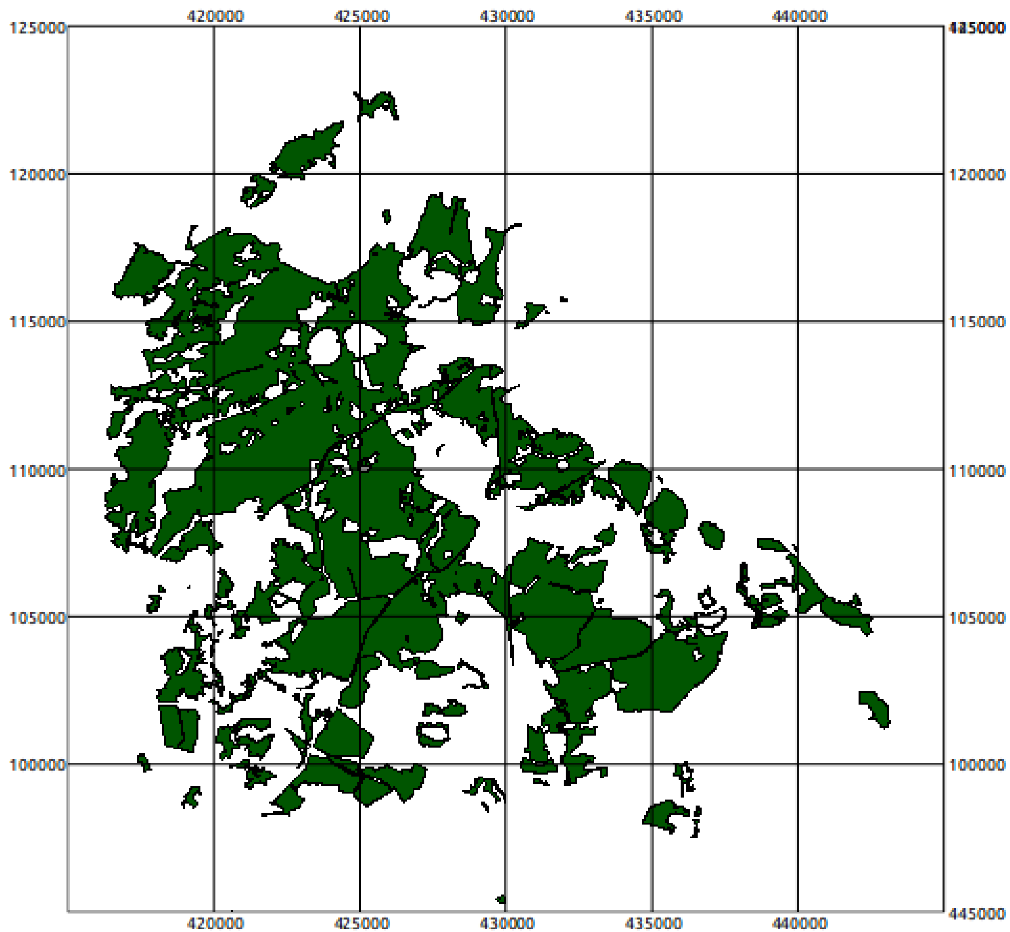


Patch corridor matrix model

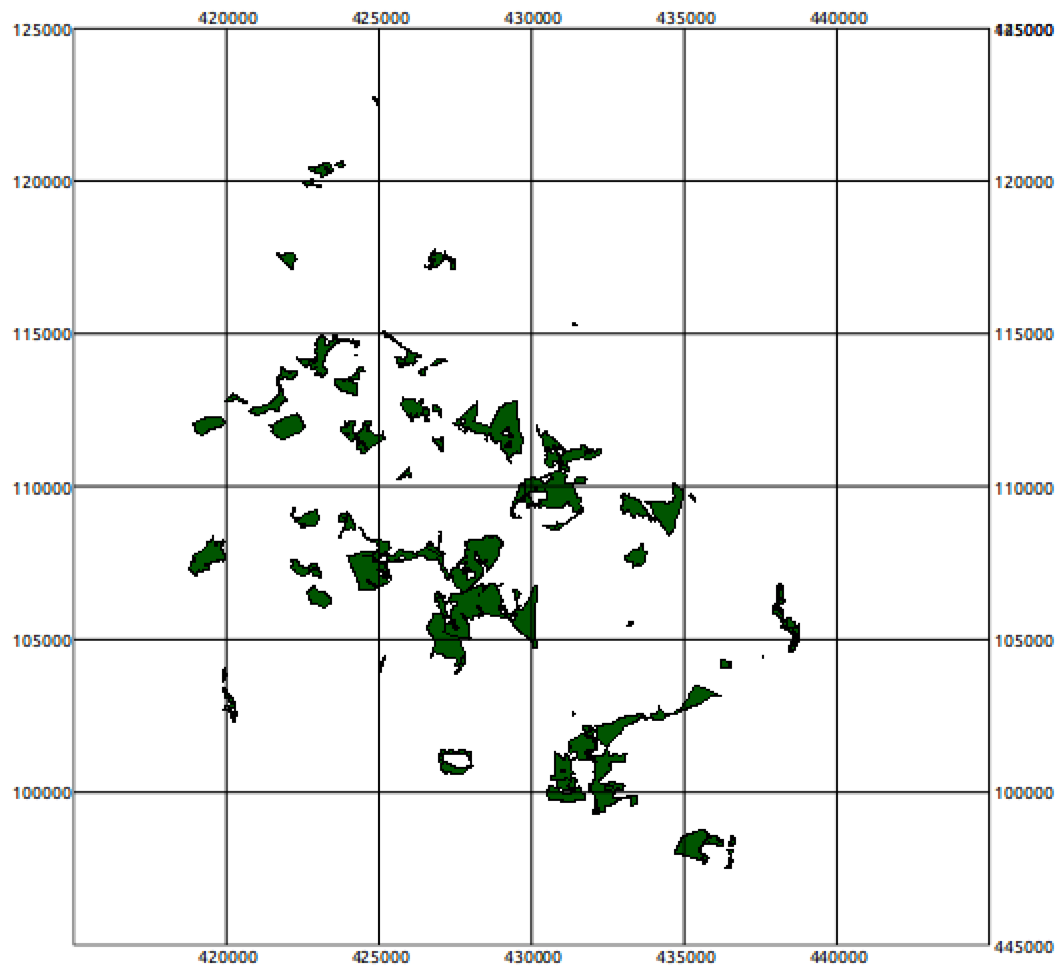
- **Patch...**relatively homogeneous ecological units (ecosystems) more alike in some attribute than the landscape as a whole.
- **Corridor...**linear landscape elements that differ from the matrix on either side; as a consequence of their form and context, they function as habitat, dispersal conduits, barriers, filters, or a source of abiotic and biotic effects on the surrounding matrix.
- **Matrix...**landscape element with the greatest relative area; most connected; plays a dominant role in the dynamics of the landscape.

From McGarigal Fragstats conceptual foundation

Forest patches prior to deforestation



Forest patches after deforestation



A simple metric

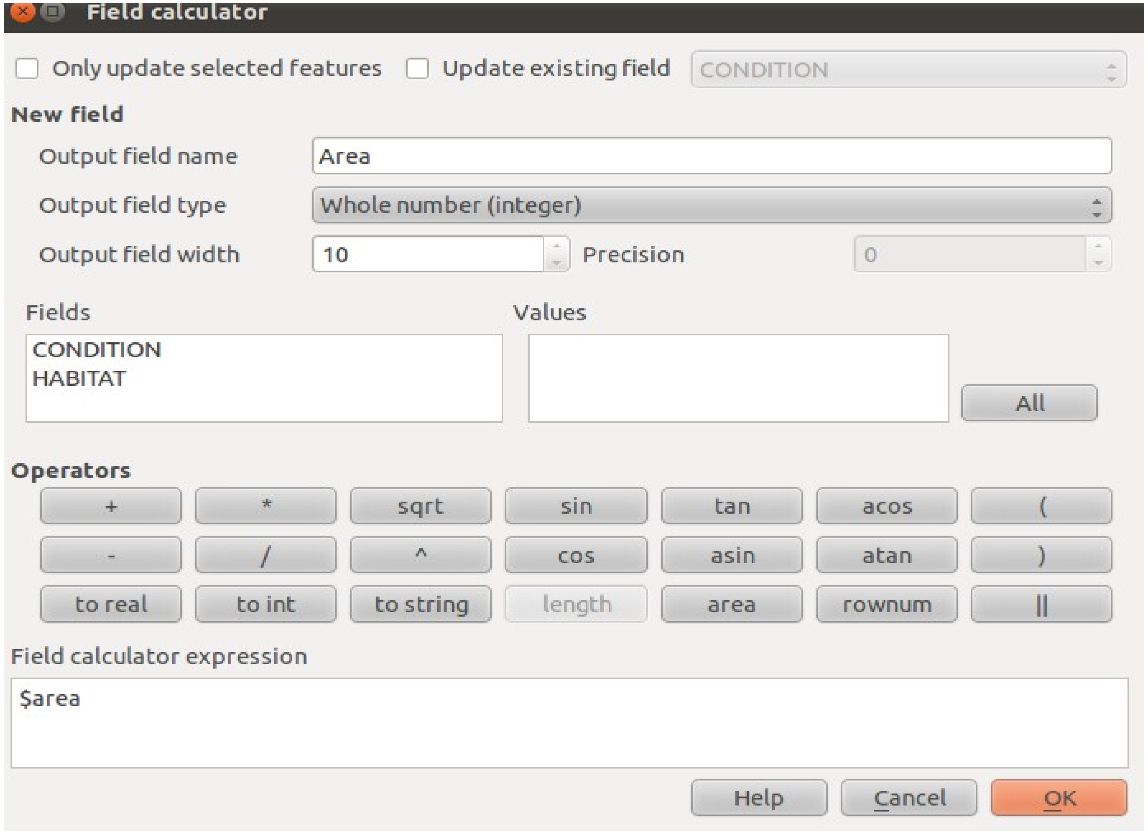
- Area of largest patch.
  - Simple to measure
  - Simple to communicate
  - Simple to interpret.
- For example we might be able to say “As a result of deforestation the area of the largest patch decreased from 6000 ha to 5000 ha”

Focal habitat analysis

- The patch matrix model
- The landscape is composed of many patches that each have different properties
- A whole landscape analysis of this class of habitat uses statistical summaries of the properties of all the patches within the landscape

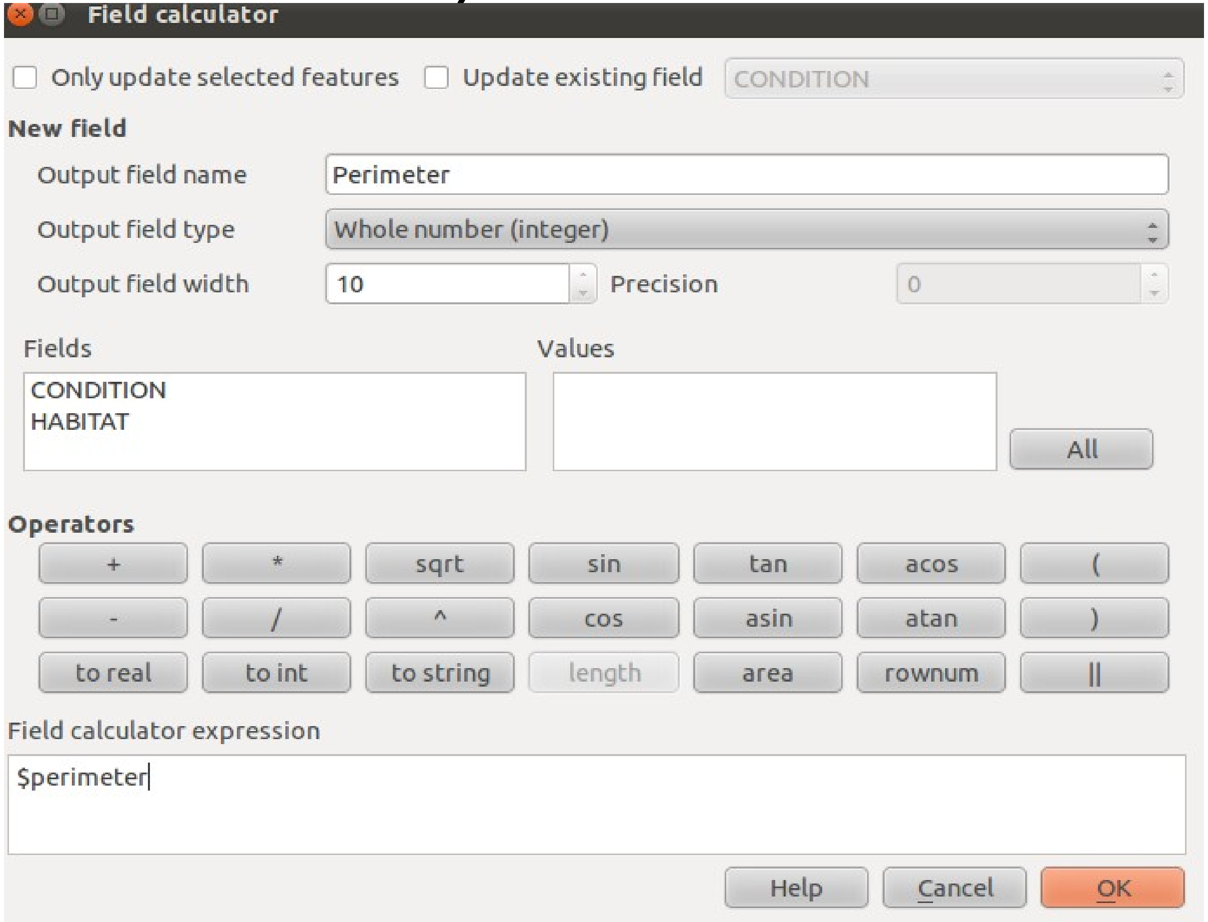
GIS tip

- You can add the area to the attribute table easily in any GIS. You need the layer to be projected or the area will be in square degrees.



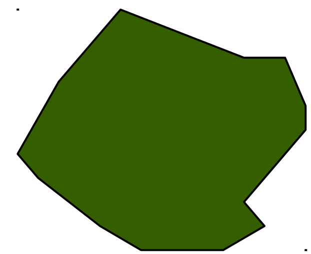
GIS tip

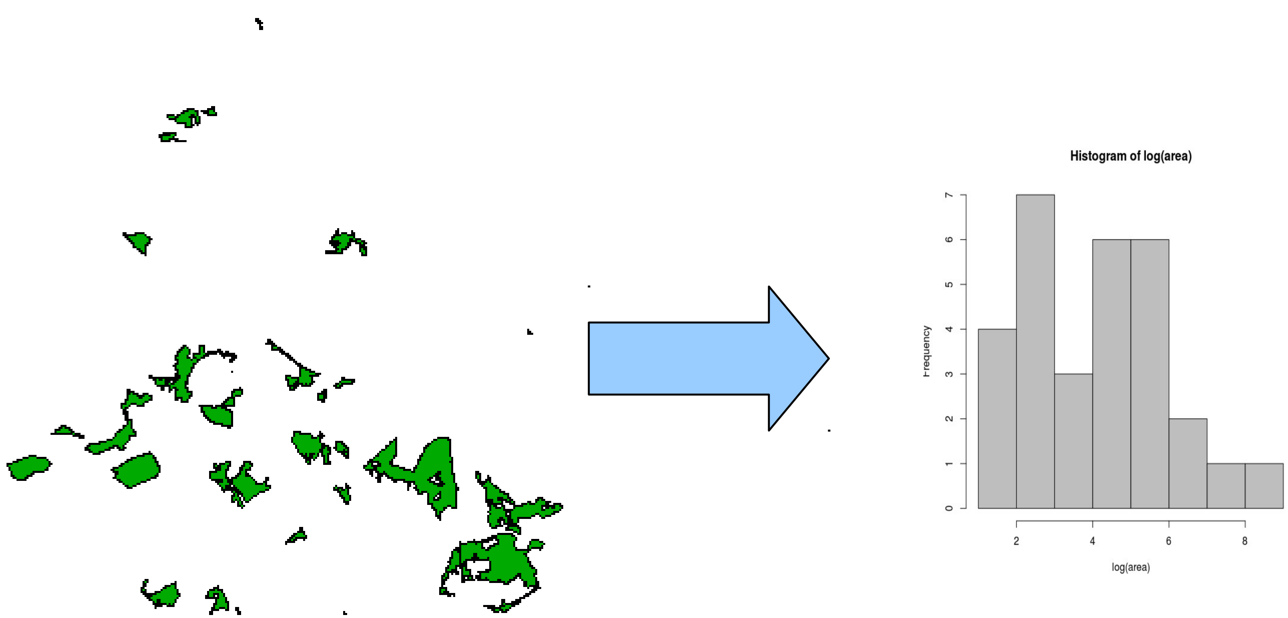
- QGIS can also calculate perimeter in the same manner (Note that the $perimeter operator is not shown on the list)



Simple patch level statistics

- Patch area
- Patch perimeter
- After measuring these on many patches we can get distribution statistics.



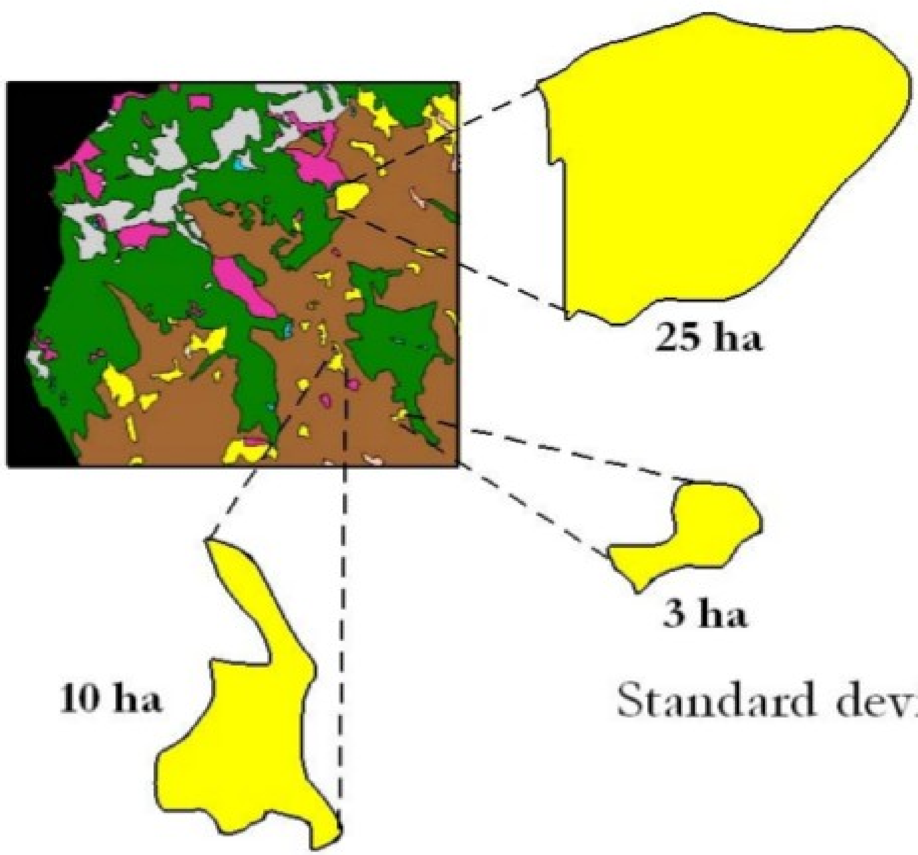


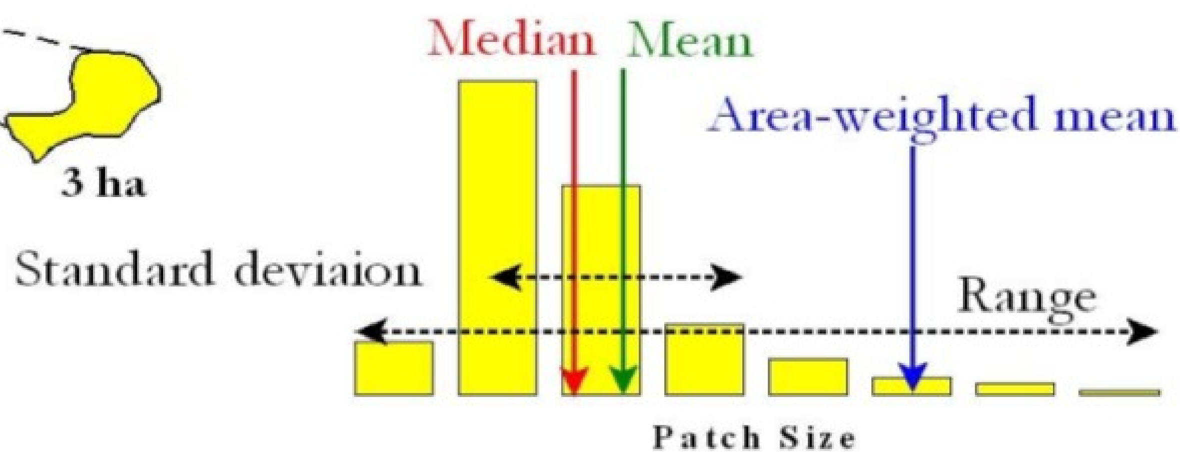
Distribution statistics

Insights on Metrics...*distribution statistics*

Patch metrics can be summarized for a single class or the entire landscape using a variety of *distribution* statistics

- Median
- Mean
- Area-weighted mean
- Range
- Standard deviaion
- Coefficient of variation





Summarising patch area and perimeter

- Once area has been calculated by the GIS you can open the *.dbf file in any spreadsheet or a statistical program such as SPSS
- Easy to calculate elements such as total area and total edge length (sum of perimeters)

	A	B	C	D
1	PID,N,11,0	Area,N,10,0	Perimeter,N,10,0	Shape,N,10,2
2	0	31303	811	1.15
3	1	50276	1675	1.87
4	2	165301	2565	1.58
5	3	8032	689	1.92
6	4	27793	1160	1.74
7	5	75476	1916	1.74
8	6	485940	4352	1.56
9	7	1024088	8150	2.01
10	8	1243076	11272	2.53
11	9	56928	1321	1.38
12	10	22683	1015	1.68
13	11	251173	2432	1.21
14	12	11910	626	1.43
15	13	22302	1312	2.20

Analysis tip

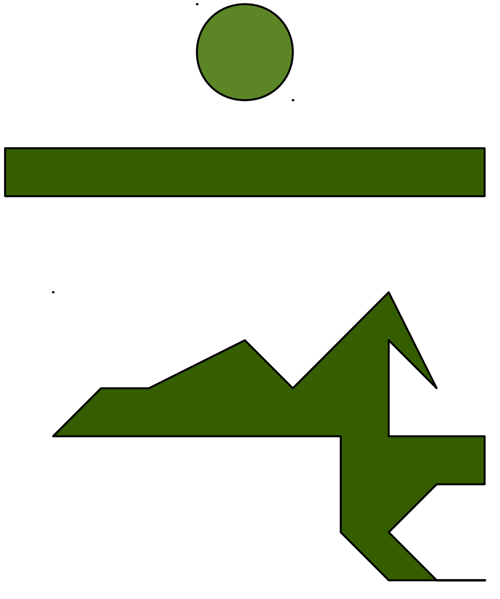
- Patch size histograms are almost always skewed
- You may wish to try log transforming the values.
- Use appropriate units to make numbers easier to understand
  - 1 ha =10000 m^2 (so divide values in m^2 by 10000)
  - 1 km^2=1000000 m^2

Summary of the common metrics

$MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$	MN (Mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values, divided by the number of patches of the same type. MN is given in the same units as the corresponding patch metric.
$AM = \sum_{j=1}^{n}\left[x_{ij}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$	AM (area-weighted mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric value multiplied by the proportional abundance of the patch [i.e., patch area (m^2) divided by the sum of patch areas].
$MD = x_{50\%}$	MD (median) equals the value of the corresponding patch metric for the patch representing the midpoint of the rank order distribution of patch metric values for patches of the corresponding patch type.
$RA = x_{max} - x_{min}$	RA (range) equals the value of the corresponding patch metric for the largest observed value minus the smallest observed value (i.e., the difference between the maximum and minimum observed values) for patches of the corresponding patch type.
$SD = \sqrt{\frac{\sum_{j=1}^{n}\left[x_{ij} - \left(\frac{\sum_{j=1}^{n} x_{ij}}{n_i}\right)\right]^2}{n_i}}$	SD (standard deviation) equals the square root of the sum of the squared deviations of each patch metric value from the mean metric value of the corresponding patch type, divided by the number of patches of the same type; that is, the root mean squared error (deviation from the mean) in the corresponding patch metric. Note, this is the population standard deviation, not the sample standard deviation.
$CV = \frac{SD}{MN}(100)$	CV (coefficient of variation) equals the standard deviation divided by the mean, multiplied by 100 to convert to a percentage, for the corresponding patch metric.

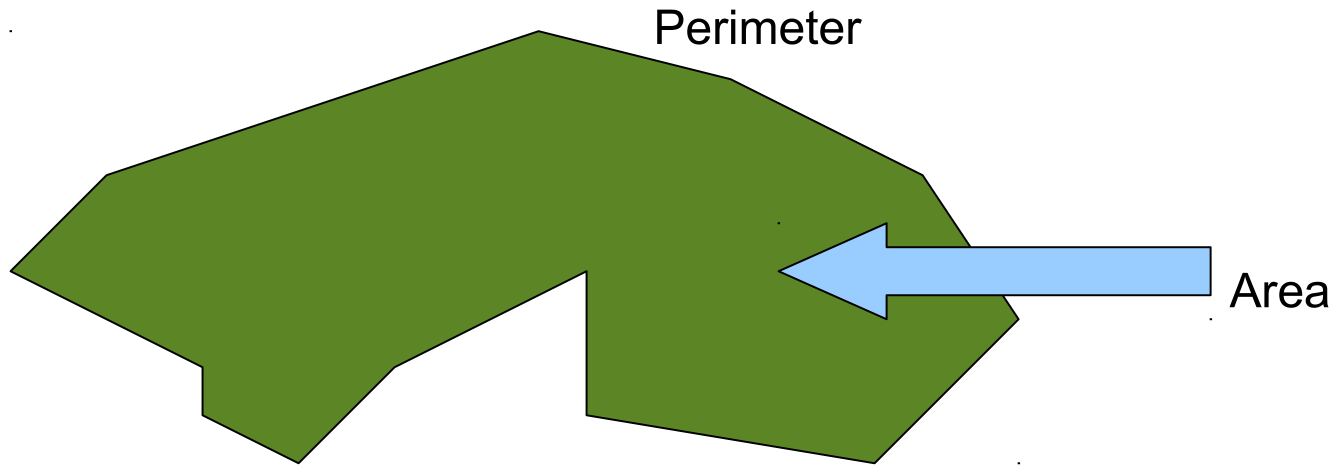
Measures of patch shape

- Area and perimeter are direct measurements
- Shape is rather more difficult.
  - Round?
  - Long?
  - Thin?
  - Compact?
  - Convoluted?



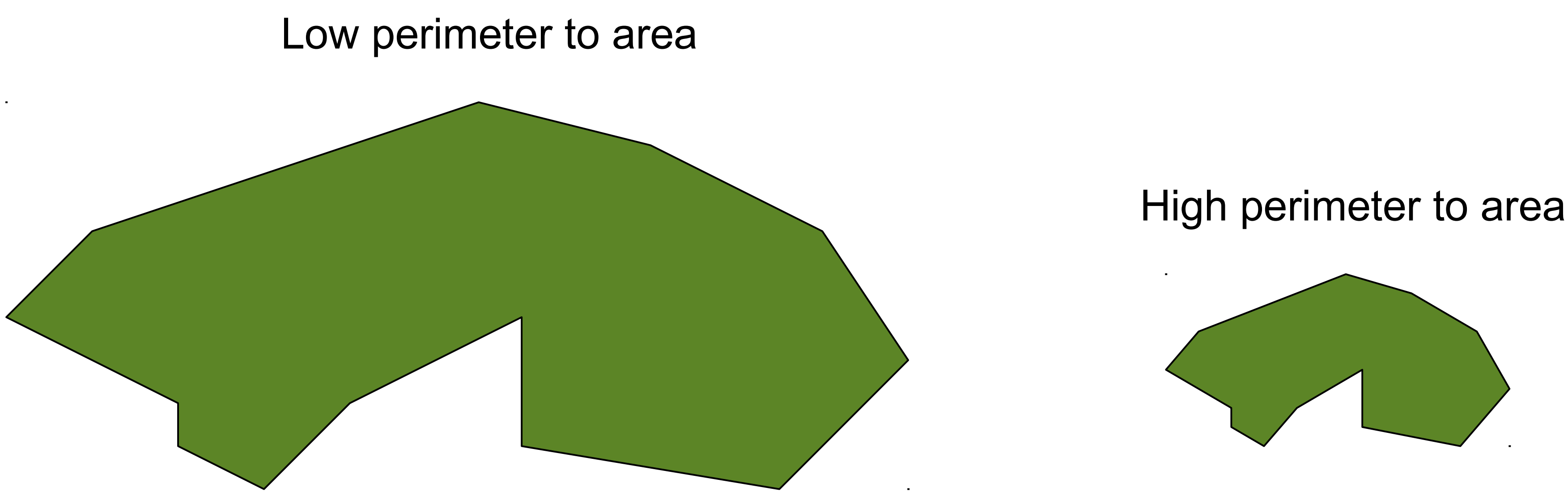
Measure of shape

- The more convoluted the shape, the greater the perimeter of the patch will be for the same area.
- A simple measure is the perimeter/area ratio.



Measure of shape

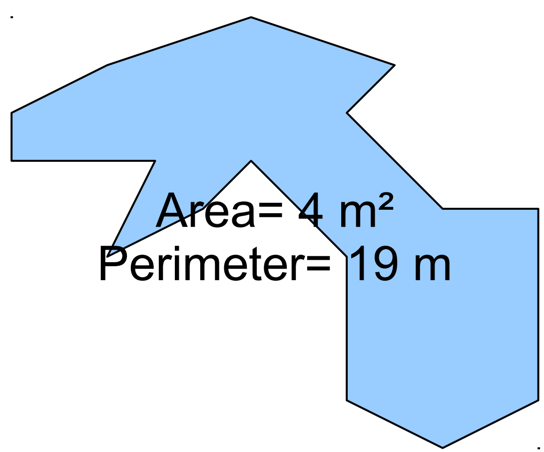
- However the perimeter area ratio is sensitive to the size of the patch.
- A small patch with same shape has a greater perimeter to area ratio

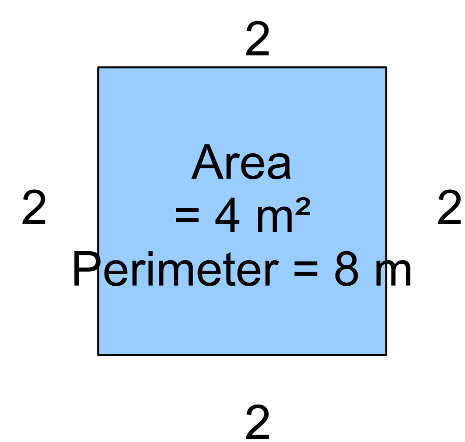


Shape index

- One shape index is found by dividing the perimeter by 4 times the square root of the area. $shape = \frac{perimeter}{4\sqrt{area}}$
- We compare the perimeter with that of a standard compact shape of the same area (say a square)

$$\sqrt{4} = 2$$



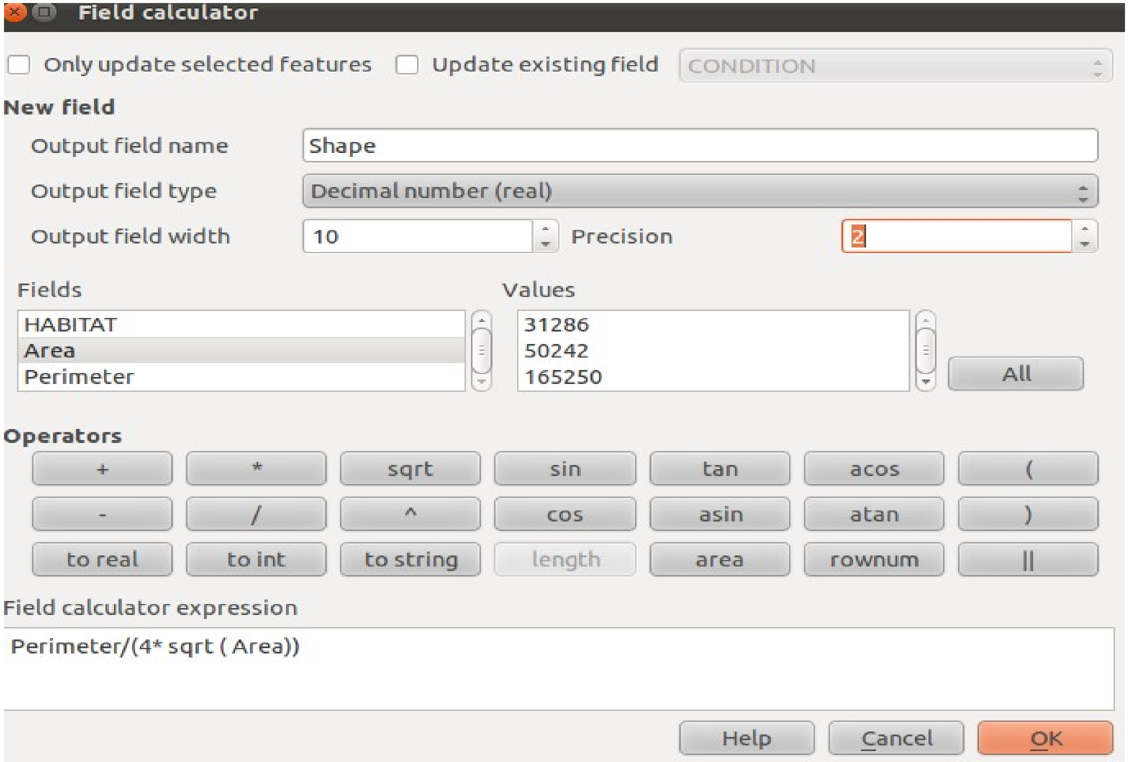


Interpretation

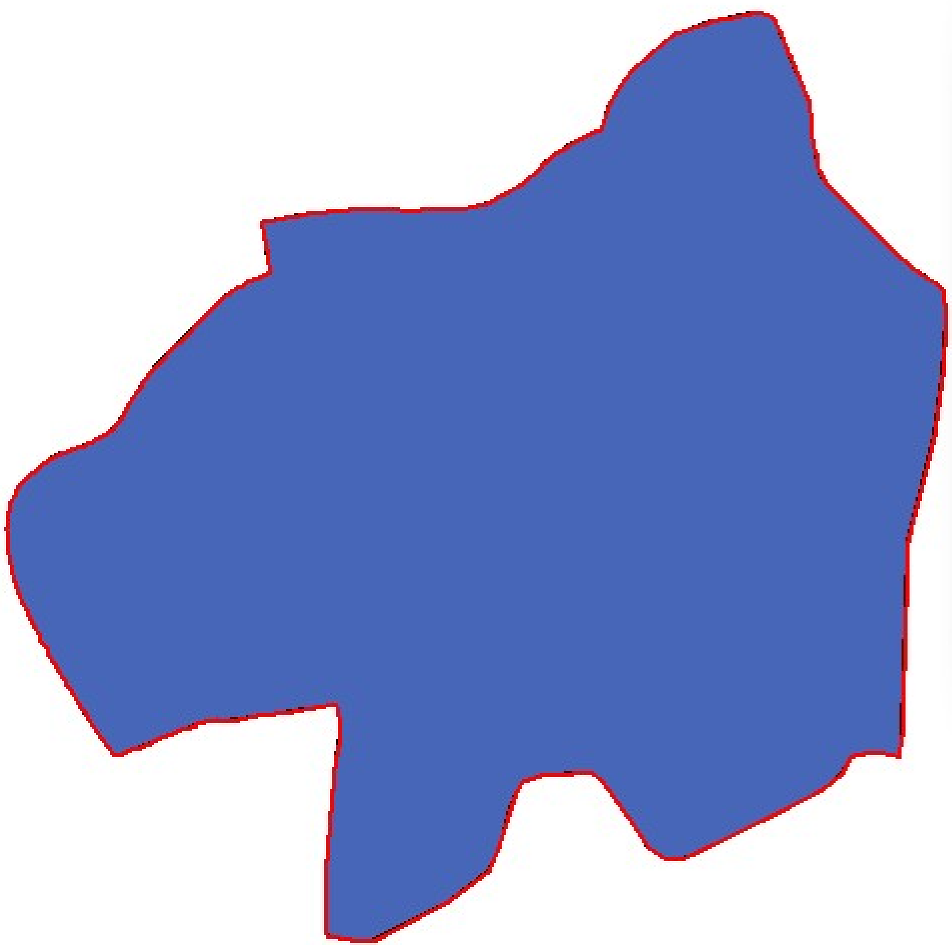
- The shape index can take values between 1 to infinity
- The more edge a patch has when compared to the minimum possible, the larger the index
- Thus if we wish to minimise exposure to edge effects we would aim to reduce the value of the shape parameter at the patch and landscape scale

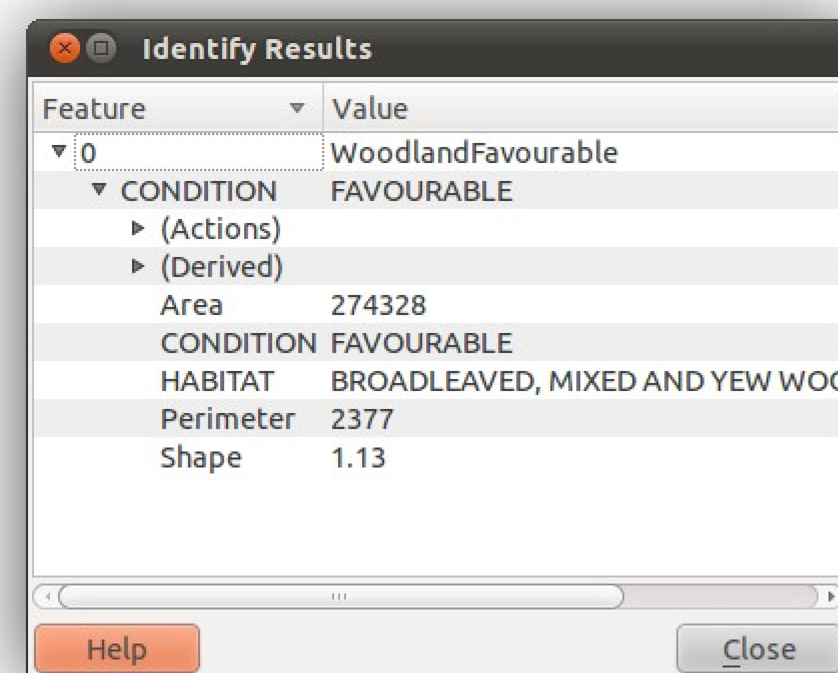
How to calculate the shape index

- Can be calculated in GIS from area and perimeter



Shape index




Identify Results
Feature
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WoodlandFavourable
CONDITION
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(Actions)
(Derived)
Area
274328
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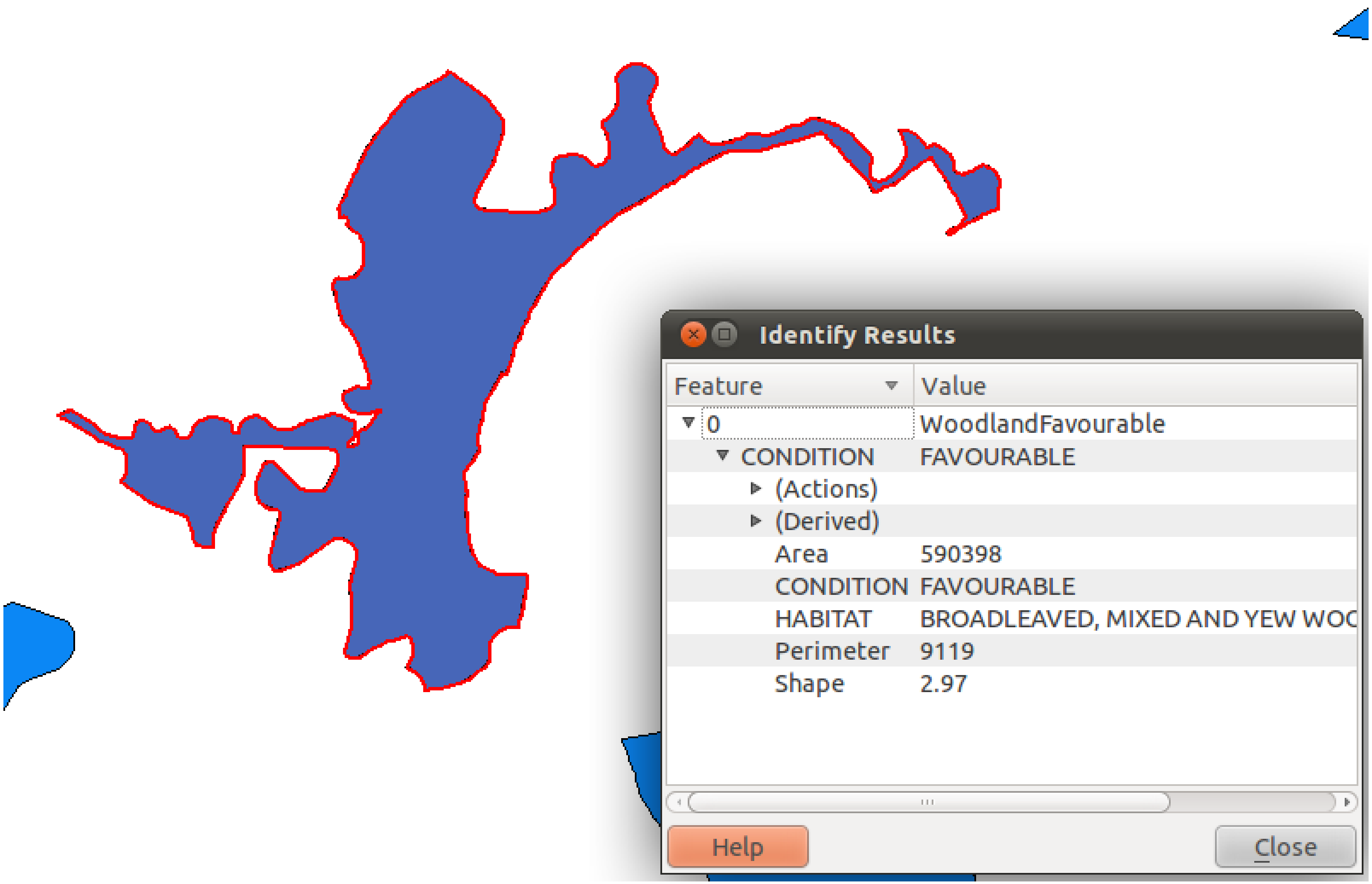
HABITAT
BROADLEAVED, MIXED AND YEW WOC
Perimeter
2377
Shape
1.13
Help
Close

Shape index



Identify Results
Feature
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Shape
2.97
Help
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Other shape metrics

- Calculated using specialised software (Fragstats)
  - Fractal dimension
  - Related circumscribing circle
  - Linearity index
  - Contiguity index
- Correlated with shape index, but may provide some additional information

Uses of shape indices

- Patches with low values of the shape index are more compact.
- If we wish to reduce edge effects through management we would aim to lower shape indices.
- However, in some cases more complex shapes are desirable. They increase landscape heterogeneity

Uses of shape indices

- The best use of shape indices is to in the context of a formal measure for contrasting two or more landscapes.
- For example, we might want to mention at the patch level like “Deforestation resulted in the largest patch of forest becoming less compact. This was demonstrated by a increase in the shape index from 3.4 to 5.9”
- You can aggregate shape indices at the class level and calculate mean, median etc. This may allow an overall change in pattern to be quantified.

Core area metrics

- The perimeter of each patch measures the amount of edge as a linear feature.
- However edge effects will take place in a strip of habitat around the perimeter.
- The core area is the area within a certain depth from the edge.
- Patch shape and size will affect this.

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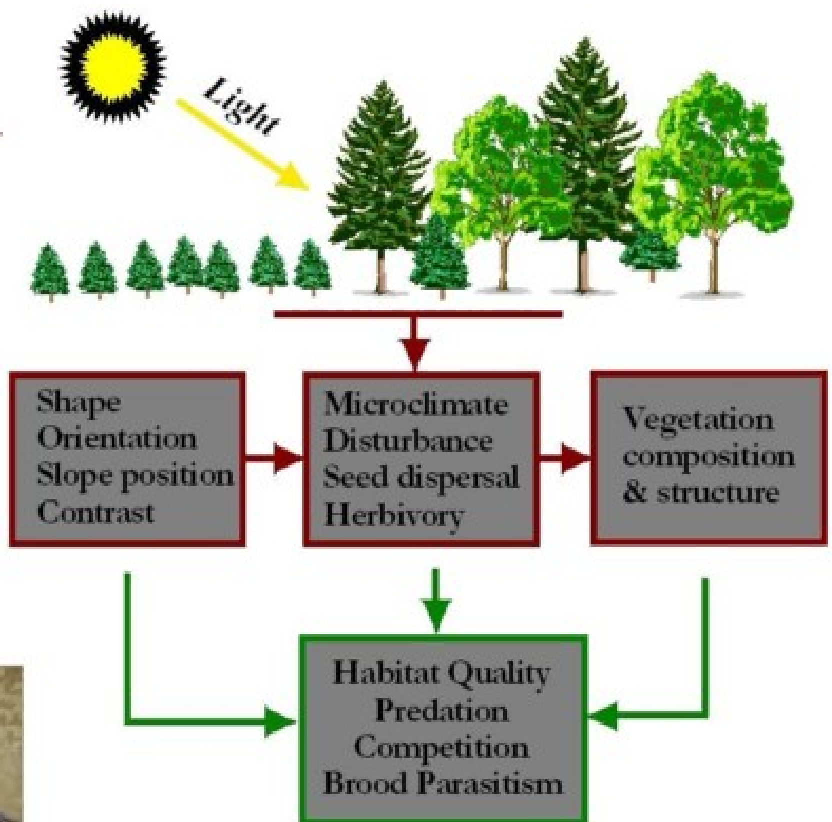
Insights on Metrics...*core area metrics*

Why does core area matter?

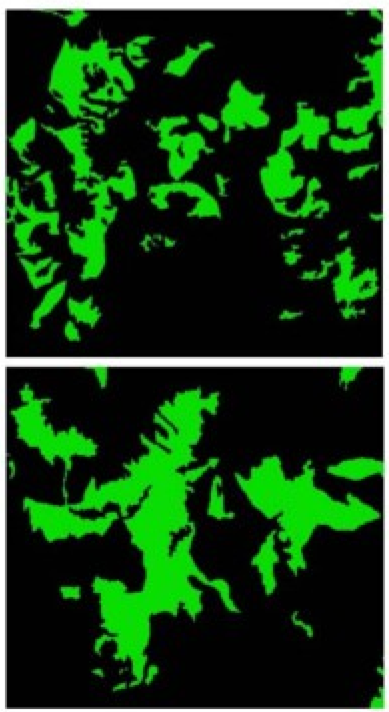
- Edge effects and implications for interior-sensitive species and ecosystem integrity



Core area metrics

Insights on Metrics...*core area metrics*

Collection of metrics describing the patch interior (core) area after accounting for depth-of-edge effects



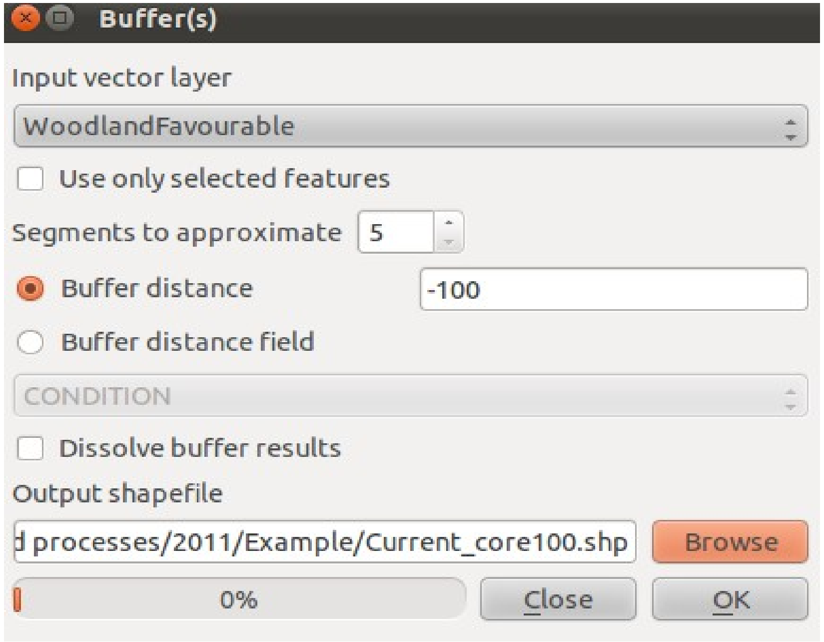
Less core area

More core area

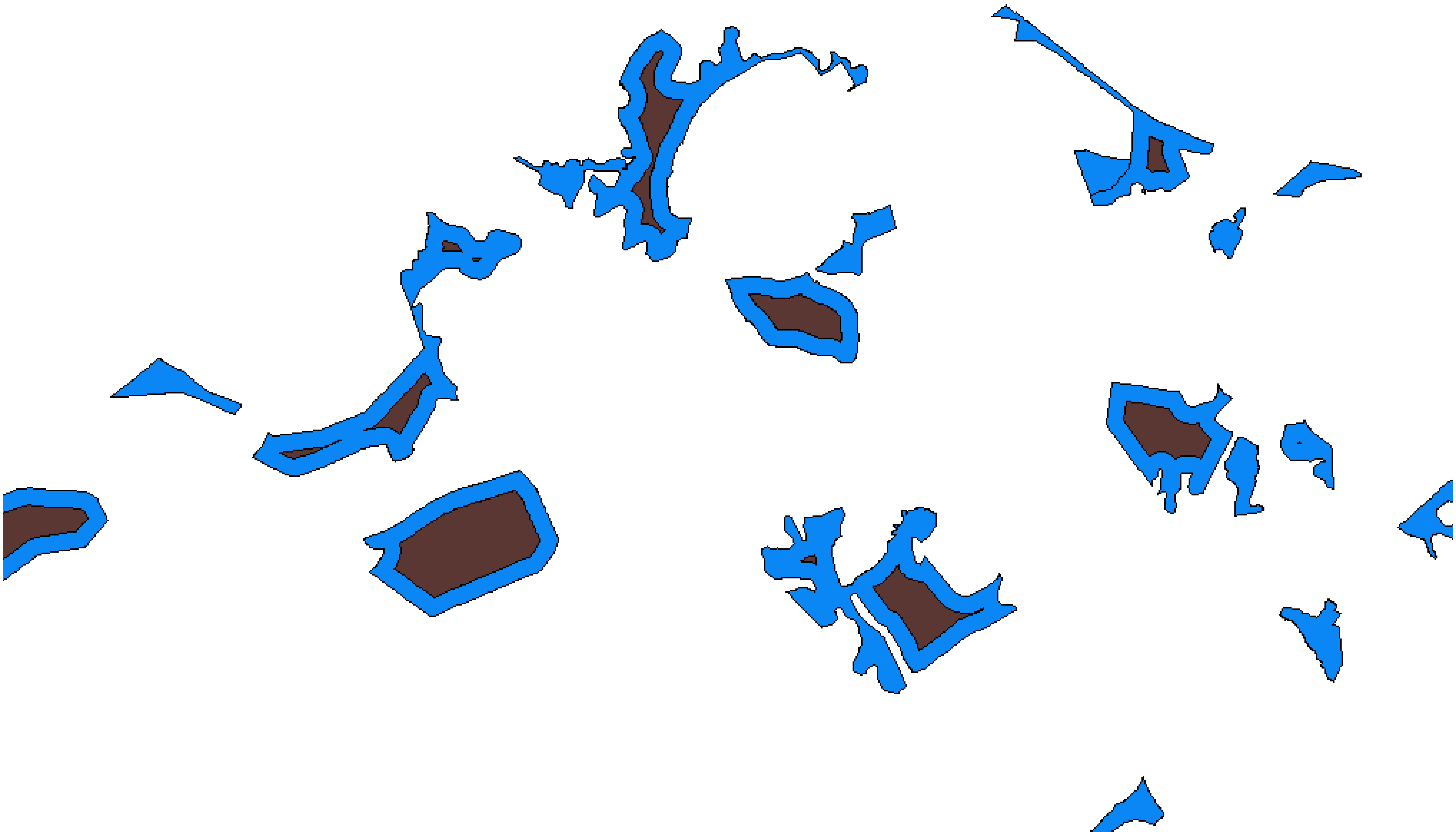
- Patch core area (ha)
- Core area index (%)
- Total core area (ha) *or* Core area percent of landscape (%)
- Number of disjunct core areas (#) *or* Disjunct core area density (#/ha)

GIS tip

- Core areas are easy to obtain by using a negative buffer
- Produce a new shapefile for the cores



Core areas



Core area analyses

- There is no single edge depth that accounts for all the processes of interest
- For example, light may penetrate up to 30m from the edge of a tropical forest.
- However risk of understory fire may extend to 100m or further
- Grazing animals may penetrate further. Hunting may take place up to several km from the edge

Core area metrics

- Extracting core areas is often very informative
- Clearly show edge effects
- Some patches have no core areas
- Others may have more than one
- Core areas in separate patches are disjunct
- Core areas often represent high quality, undisturbed habitat
- Changes in number and size of core areas can be very important to wildlife

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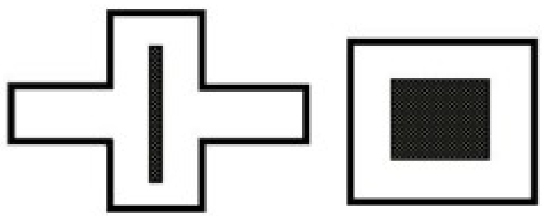
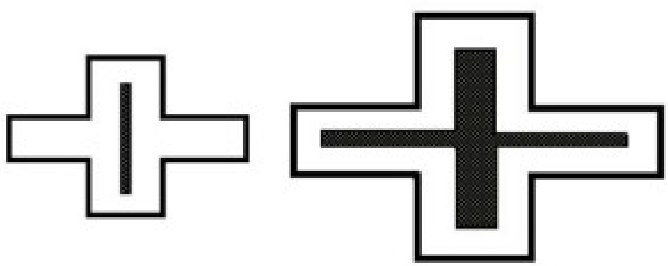
Insights on Metrics...*core area metrics*

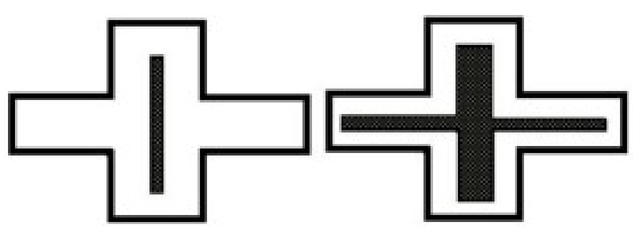
Core area is a compound measure of shape, area and edge depth; i.e., all three components effect core area



- *Shape effect*... increasing shape complexity decreases core area



- *Area effect*... increasing patch area increases core area



- *Edge depth effect*... increasing depth-of-edge effect decreases core area

Core area index

Insights on Metrics…*core area metrics*

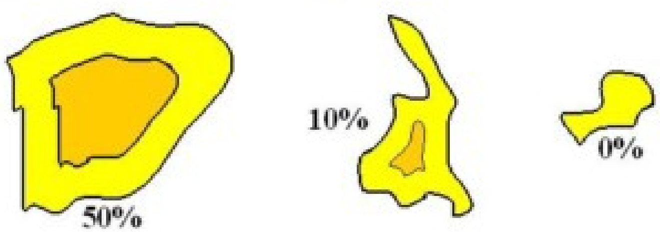
- **Core area index (%)**

Edge depth… based on user-specified distance

Core Area Index

$$\frac{a_{ij}^{c}}{a_{ij}}(100)$$

Patch level



Core area index (%) gives the percentage of the patch comprised of interior area (core) based on user-specified depth-of-edge effects, and can be summarized at the class or landscape levels

Issues to be aware of

- There are no fixed rules regarding the width of the buffer
- You may will usually run the analysis for several buffer widths and compare the results
- Choices should be made based on knowledge of the system and previous studies if possible

Issues to be aware of

- Core area is a compound measure of shape, area and edge depth.
- In other words, core area is effected by all three of these components simultaneously (i.e., they are confounded).
- This can be viewed as ...
  - an advantage, because it is an integrative measure of functional relevance,
  - A disadvantage, because it confounds multiple effects.