UN-REDD
PROGRAMME

Identifying and mapping the biodiversity and ecosystem-based multiple benefits of REDD+

A manual for the ExploringMultipleBenefits tool

UN-REDD PROGRAMME

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Multiple Benefits Series **8**

The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries. The Programme was launched in September 2008 to assist developing countries prepare and implement national REDD+ strategies, and builds on the convening power and expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP).

The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is the biodiversity assessment and policy implementation arm of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organization. The centre has been in operation since 1989, combining scientific research with practical policy advice.

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UNEP WCMC

Summary

This document provides guidance and a detailed technical manual on identifying, mapping and understanding the spatial relationship between ecosystem carbon stocks, other ecosystem services, biodiversity, land-use and pressures on natural resources. The outputs of such work can support REDD+ decision-making, in that they:

- can be adapted to specific national priorities and needs for information;
- provide a relatively quick-to-produce snapshot (rapid assessment) of the distribution of carbon stocks based on best available data;
- illustrate where REDD+ could secure biodiversity and other ecosystem services (ecosystem-based multiple benefits) in addition to maintaining carbon stocks;
- present the distribution of carbon stocks in relation to land-use plans and management units (such as protected areas) that countries may wish to consider when planning for REDD+;
- highlight where areas of importance for ecosystem-based multiple benefits may be under pressure, e.g. from deforestation or oil, gas and mining activities;
- identify areas of importance for biodiversity or ecosystem services that are unlikely to directly benefit from REDD+. As land-use change is reduced in REDD+ forests, some of these areas may come under additional risk of change;
- assist countries in identifying what spatial distribution of REDD+ activities will help to promote and support the Cancun safeguards[1] on natural forest and biodiversity.

Overall, these outputs can contribute to decision-making on the location of REDD+ activities, bringing multiple benefits into the picture. The detailed requirements for Measuring, Reporting and Verification (MRV) of carbon under REDD+ are not considered in this document. The outputs are intended to support the planning process for REDD+, but not as a basis for MRV.

This document has been written to accompany the ExploringMultipleBenefits tool, created to assist such mapping efforts in ArcGIS. GIS[2]-competent users can use this manual to generate maps and statistical results, assuming that the necessary software and data are available.

An overview is also offered of how this work can be useful and how to organise it. Ways to think about the meaning of resulting maps and statistics are described in order to facilitate the interpretation of results. The document finishes with some advice on the finalisation of outputs.

By its nature, this is a working document that will be updated in line with changes to the mapping toolbox. Your comments are very welcome – please send to ccb@unep-wcmc.org.

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[1] Paragraphs 69, 71d, 72, 76 and Appendix I in the UNFCCC Decision 1/CP.16 : The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (Decisions adopted by the UNFCCC on its sixteenth session, held in Cancun, Mexico from 29 November to 10 December 2010). **Referred to in this document as the 'Cancun safeguards'.**

2 Geographic Information System

Table of contents

1. Introduction

1.1 Why map the multiple benefits of REDD+?

This document provides guidance and a detailed technical manual on identifying, mapping and understanding the spatial relationship between ecosystem carbon stocks, other ecosystem services, biodiversity, land-use and pressures on natural resources. The outputs of such work can support REDD+ decision-making, in that they:

- can be adapted to specific national priorities and needs for information;
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- assist countries in identifying what spatial distribution of REDD+ activities will help to promote and support the Cancun safeguards[3] on natural forest and biodiversity.

Overall, these outputs can contribute to decision making on the location of REDD+ activities, bringing multiple benefits into the picture. It is necessary, however, to recognise the potential limitations of the available datasets. Data quality may vary, and there may not be appropriate data to reflect all the different values of land. In addition, it should be noted that the detailed requirements for Measuring, Reporting and Verification (MRV) of carbon under REDD+ are not considered in this document. The outputs are intended to support the planning process for REDD+, but not as a basis for MRV.

This type of mapping work often represents a starting point for discussion of more detailed analyses, or complementary work on multiple benefits. Subsequent proposals have included the development of a monitoring system for ecosystem-based multiple benefits from REDD+; the improvement of existing data, generation of new data, and incorporation of more data in the analyses; mapping of future scenarios for REDD+ and the implications for multiple benefits; and using the outputs to review current conservation incentive programmes.

[3] Paragraphs 69, 71d, 72, 76 and Appendix I in the UNFCCC Decision 1/CP.16 : The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (Decisions adopted by the UNFCCC on its sixteenth session, held in Cancun, Mexico from 29 November to 10 December 2010). **Referred to in this document as the 'Cancun safeguards'.**

To determine whether the products that this manual describes are exactly what you need, we recommend considering the following questions before continuing:

- What do you want to use the maps and analyses for? Is this intended use compatible with the advantages and limitations of the analyses, as summarised above?
- Does your available funding permit more detailed work, which would be more useful for your purposes? If so, could these analyses still form a useful first step?

1.2 Objectives of this manual

This document offers step-by-step guidance, in the form of a manual, for mapping and spatially analysing carbon, biodiversity and other aspects of interest when planning for multiple benefits from REDD+. The manual covers all aspects of this work, from planning through to mapping, analysis of data and interpretation of results. As a consequence, some sections are more relevant for REDD+ policy-makers and coordinators of this work (sections on Tasks 1, 3 and 4) whereas others are more relevant for technical experts executing the work (section on Task 2).

With the help of this document, an overview can be gained of how this work can be useful and how to organise it. GIS[4]-competent users can use it as a manual for generating maps and statistical results, assuming that the necessary software and data are available. Ways to think about the meaning of resulting maps and statistics are described in order to facilitate the interpretation of results. The document finishes with some advice on the finalisation of outputs.

Several sections contain a box with some helpful considerations to facilitate the work, based on UNEP-WCMC's experience of working with collaborators from several countries. To illustrate the different steps taken in the mapping and analyses sections, examples from a case study are included.

1.3 Timing and planning

The time needed for the mapping work and analyses described here can vary considerably depending in particular on the following factors:

- Detail of analyses;
- Effort required to compile data;
- Extent to which raw data needs processing prior to use (i.e. generation of new datasets);
- Level of participants' knowledge of the software used: ArcGIS and Microsoft Office Excel;
- Plans for review of draft outputs and revision before finalisation;
- Plans for publication and distribution of results.

Budgetary constraints can obviously limit the detail that can be achieved, the ability to process raw data and also plans for review, revision, publication and distribution.

[4] Geographic Information System

Table 1 outlines the tasks that should be considered in the planning, provides an estimate of the time required per task and proposes a timeframe for conducting the work. Estimates are based on the experience of producing the national and sub-national reports available at http://www.carbon-biodiversity.net/OtherScales. The work is split into four tasks: (1) preparation of the work, (2) the mapping and analysis exercise, (3) review and interpretation of results and (4) production of final outputs. Our working model involves undertaking most of the mapping and analytical work during a collaborative working session of 1-2 weeks length, with the time required depending on the degree of preparation beforehand.

Table 1: Tasks to include in the planning of the work, estimate for number of work days required per task (involving 3-4 members of staff) and proposed time frame

Tasks	Days required	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
1. Preparation of the work	15-20						
2. Mapping and analyses	30-40			1-2 weeks			
3. Review of maps and interpretation of results	20-30						
4. Finalisation of report	20-30						

Box 1: Recommendations on planning an international collaborative working session

- Inform/involve stakeholders and data providers early on
- Organise any necessary visas well ahead of time
- Early exchange of data, especially carbon data as this is an essential base layer, can significantly speed up the work during the working session

This manual covers tasks 1 to 3. On the fourth task: the outputs can be distributed in a variety of forms and shapes as required by the purpose of the exercise, including summary reports, posters, presentations, through websites and even interactive online tools. Annex I provides some suggestions on effective map presentation, relevant to each of these communication methods.

2. Preparation of the work (task 1)

2.1 Identification of participants

The precise experience of the participants of the working session will determine the knowledge brought to the session and the questions asked of the data. Depending on the agreed working language for the working session, language skills may be another important criterion. In addition, some knowledge of and experience with ArcGIS of at least one participant is very beneficial, as this will save a considerable amount of time for a general introduction into GIS. Good knowledge of the political, socio-economic and ecological context of the country in general, and current and planned REDD+ policies and activities in particular, can represent a very useful complement to GIS skills.

Depending on the target audience for the results, involving an expert who is aware of the needs and priorities of this target audience can help increase the acceptance and impact of the work.

There are advantages of both smaller groups (i.e. 3-4 people) and larger groups (> 4 people), and decisions on the number of participants will depend on available resources, interest and training needs, among other criteria. Availability and interest in the work are two important criteria for identifying participants. For certain parts of the working session, such as the definition of priorities, questions and scope, as well as the presentation of preliminary results, organising bigger meetings to involve more stakeholders can be very useful.

2.2 Definition of priorities, questions and scope

As a first step, it is useful to determine the country/context-specific priorities for this work, agree on a set of questions that the results should be able to answer (or help to answer), and identify the scope of the work. Drawing up this list helps to define the questions that the work is expected to answer, and thus target the maps and analyses produced. The following list presents examples, all of which allow for case-specific adaptation and extension:

REDD+ opportunities

- Can the national forest definition be mapped?
- Where are the areas of highest carbon density?
- Where are forest concessions?
- Are there established reforestation plans?
- What is the historical extent of forest, and are there opportunities for restoration?

Ecosystem-based multiple benefits and safeguards

- Can natural forest be distinguished in maps from planted forest?
- Where do areas of high carbon density coincide with areas of importance for biodiversity?
- How much carbon is stored in mangrove, tropical dry forests or other ecosystems of conservation concern? How much of this is protected?

Potential for poverty alleviation

- How is human population and poverty distributed in relation to carbon?

Pressures

- Where are existing roads and settlements in relation to areas that are high in carbon and important for biodiversity?
- Where are areas of recent forest cover loss (or degradation pressures such as fire) in relation to high carbon – high biodiversity areas?
- How might carbon stocks be affected by oil palm plantations, road-building plans, and other development projects in the future?

The list of questions of interest can grow very long. This is useful, even if not all of the questions can be addressed in the current work plan. Keeping a record of all questions can help identify follow-up work and research needs at a later stage. However, for the planned mapping work to become more concretely defined, the questions should be considered and prioritised with the available time and budget in mind.

An initial planning meeting or teleconference, can help to determine the priorities, questions and scope of the work. It may be of interest to convene a larger group of stakeholders, so that different views can be taken into consideration. For example, the work may be initiated by the forestry division of a country's government in the context of planning for REDD+, but may be of interest to and depend on information from other sectors, such as agriculture and conservation. The involvement of other sectors may be limited by the available budget, but can range from simply informing to inviting to participate. Box 2 suggests some points for discussion.

Box 2: Considerations for defining priorities, questions and scope

- What is the main purpose of the mapping exercise?
- How much time and funding are available? (By when are outputs needed?)
- For what area are maps needed: A country? A region within a country or across several countries? A certain ecosystem type?
- Who are the key stakeholders in this geographical area? How can they be informed or involved? Might they hold or know of data relevant to the planned analyses?

While the definition of priorities, questions and scope is very helpful, it is recommended to allow the work plan to further evolve as work progresses: some questions may turn out to be impossible to address (e.g. due to lack of data), or another idea for a question or new data may arise later.

2.3 Software and data needs

2.3.1 Software requirements

These guidelines employ ArcGIS and Excel software, and the use of a customised ArcGIS[5] toolbox developed at UNEP-WCMC for REDD+ multiple benefits analyses. The toolbox can be downloaded from the UNEP-WCMC website at http://www.carbon-biodiversity.net/Interactive or the UN-REDD Programme website at http://www.un-redd.org/Multiple_Benefits/tabid/1016/Default.aspx. To use the customised toolbox it is necessary to have ArcGIS software installed, including the Spatial Analyst extension. The ArcGIS toolbox has been built in ArcGIS Version 9.3.1.

Recognising that not every GIS user has access to ArcGIS, this document aims to provide enough information on the principles, concepts and technical details so that similar procedures can be undertaken in other GIS platforms.

There are now a number of Open Source (freely available) GIS options, which are usually supported through online help, tutorials and/or forums. Without recommending specific software, here are some useful open source resources:

- **The Open Source Geospatial Foundation:** http://www.osgeo.org/
- **Quantum GIS or QGIS:** http://qgis.org
- **Grass GIS:** http://grass.itc.it/
- **The gvSIG project:** http://www.gvsig.org/web/
- **An alphabetical index of Open Source related software:** http://www.freegis.org/ -

[5] ArcGIS is a proprietary software product from ESRI. ESRI offers various grants to help those who lack funds to pay full costs for software (see http://www.esri.com/grants/)

- **Open Jump:** www.openjump.org
- **SAGA GIS:** http://www.saga-gis.org/en/index.html
- **GeoKettle:** http://www.geokettle.org/ (useful for translating data from one format to another)
- **GeoNetwork:** http://geonetwork-opensource.org/ (A catalog application to manage spatially referenced resources)
- **PostgreSQL:** http://www.postgresql.org/ (An object-relational database system)
- **PostGIS:** http://www.postgis.org/ (software that "spatially enables" the PostgreSQL)

2.3.2 Data needs

Depending on the priorities, questions and scope of the work, different datasets will be required. Experience has shown that it is very useful to start reviewing existing datasets well before the working session. This will not only save much time during the working session, but will also help define the scope of the analysis. Datasets that are very likely to be of interest include:

- Land cover, i.e. forest cover, extent of other ecosystems
- Land use, e.g. timber plantations, pasture
- Biomass estimates, ideally from field plots
- Soil, i.e. distribution of soil types and properties, ideally soil carbon data
- Biodiversity, e.g. distributions of threatened and endemic species, priority areas
- Management units, e.g. protected areas, forest concessions
- Resource use, e.g. timber extraction, use of non-timber-forest-products
- Watersheds / river catchments
- Socio-economic data, e.g. population density, poverty measures
- Infrastructure, e.g. roads and navigable rivers, dams
- Pressures, e.g. fire, forest cover change, agricultural conversion/deforestation, oil, gas and mining activities, logging concessions

Data at the scale of the area of interest, e.g. national level, can be more suitable than regional or global datasets as they may comply with national standards (e.g. on forest definition), reflect national or sub-national priorities and are less likely to have undergone large scale extrapolations. However, data at the scale of the area of interest may be scarce. Where this is the case, it is helpful to review existing regional and global databases for information of potential relevance to this work (see Table 2 for a selection).

All data that is considered for use in the analyses should first be checked for suitability. This depends on their age/up-to-dateness, their completeness and accuracy as well as the scale of the work (see Box 3). For instance, a coarse scale regional map on forest cover change may not be suitable for a sub-national analysis that requires higher resolved spatial information. In any case, it is important to understand the potential limitations of each dataset and interpret results with care (see 4. Review of maps and interpretation of results).

Box 3: Assessing the suitability of data

- How old is the data? How well does it reflect the current situation in the country?
- How does the resolution compare to that of other datasets used?
- Is the data politically sensitive? Has its use been approved by the government?
- Has the data owner or provider granted permission for its use for this purpose?

Compiling all the datasets that are considered relevant can be time-intensive, especially as they are likely to be hosted in different institutions (for example government agencies, NGOs, research institutions) and data license agreements may be required to ensure the data can be used for this purpose. Box 4 summarises some useful considerations for the data compilation phase.

Box 4: Data sourcing:

- Review datasets as they become available, and in good time before the working session: Is the content as expected? Do they have the right format? Do they need processing before they can be used in the analyses?
- Good documentation of data sources and terms of use is essential and will save much time during the production of the final outputs

Good data documentation, despite being time-consuming, is an essential part of this task as it will help to understand data limitations and use restrictions and facilitate the production of outputs, for which the full citation for each dataset will be necessary.

Table 2: Selection of available datasets on different themes of interest to carbon and ecosystem-based multiple benefits mapping

Theme	Dataset	Scope	Institution	Source
Land cover	Africover (1997-2002)	Kenya, DRC, Tanzania	FAO	http://www.africover.org/system/africover_data.php
	Mangroves (data produced for the World Atlas of Mangroves)	World	ITTO / ISME / FAO / UNEP-WCMC / UNESCO-MAB AND UNU-INWEH	Not yet available for download
	Global Land Cover 2000 (GLC2000)	World	JRC	http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php
	GlobCover (vector and raster, 2005)	World	ESA	http://ionia1.esrin.esa.int/
Landsat imagery	Multidate sample imagery and composites from USGS Global Land Survey (1990-2000-2005)*	e.g. For Tanzania – 51 scenes 1990; 59 scenes 2000; 57 scenes 2005	USGS	http://glovis.usgs.gov/
Topo-graphy	SRTM DEM (Shuttle Radar Topography Mission – Digital Elevation Model)	World	NASA	http://srtm.csi.cgiar.org/
Protected areas	World Database on Protected Areas (regularly updated, last version 2010)	World	UNEP-WCMC / IUCN	www.protectedplanet.net/
Popu-lation	Population (Mapping global urban and rural population distributions)	World	FAO / CIESIN	http://www.ciesin.columbia.edu/documents/estimatesof.pdf http://sedac.ciesin.columbia.edu/gpw/
Biomass	Forest carbon stocks in tropical regions across three continents	Tropical Latin America, Africa, Asia		Saatchi *et al.* (2011)
	Woody above-ground biomass	Tropical Africa	WHRC	Baccini *et al.* (2008)
	Pan-tropical Forest Carbon Mapped with Satellite and Field Observations	Pan-tropical	WHRC	http://www.whrc.org/mapping/pantropical/modis.html

	LBA-ECO LC-15 Amazon Basin Aboveground Live Biomass Distribution Map: 1990-2000	Amazon basin	INPE/NASA	Saatchi *et al.* (2007) http://webmap.ornl.gov/wcsdown/dataset.jsp?ds_id=908
Carbon	Global carbon in biomass, year 2000 [2005 version forthcoming]	World	Stanford University	Ruesch and Gibbs (2008)
	Global carbon in soils to 1m depth based on the Harmonized World Soil Database (HWSD)	World	JRC / UNEP-WCMC	(Scharlemann *et al.* in prep.) Not yet available for download. Contact UNEP-WCMC
	Combined biomass and soil carbon dataset	World	Stanford / JRC / UNEP-WCMC	Not yet available for download. Contact UNEP-WCMC
	Global peat land distribution based on Digital Soil Map of the World	World	FAO-UNESCO	http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/en/
	Carbon sequestration - calculated dry matter productivity based on 10-daily SPOT VGT NDVI data from 1998-2008	World	Kings College London (Dr. Mark Mulligan, Department of Geography)	Not yet available
Biodiversity	Important Bird Areas	World	Birdlife International	BirdLife International (2010), not available for download. Contact BirdLife
	Key Biodiversity Areas	World	CI / IUCN / Birdlife / Plantlife / AZE	BirdLife International and Conservation International (2010), not available for download. Contact BirdLife/CI
	Global priority schemes – WWF Ecoregions, Conservation International Biodiversity Hotspots, etc.	World	Various	http://www.worldwildlife.org/science/ecoregions/item1267.html http://www.biodiversityhotspots.org
	Species layers from IUCN Red List assessments	World	IUCN / collaborators	IUCN (2010), http://www.iucnredlist.org/technical-documents/spatial-data
Water (regulation)	HydroSHEDS tiles: river networks, watershed boundaries, drainage directions, and flow accumulations.	World	USGS	Lehner *et al.* (2006) http://gisdata.usgs.gov/website/HydroSHEDS/
	Global Reservoir and Dam (GRanD) database	World	Global Water System Project	Lehner *et al.* (2011) http://www.gwsp.org/fileadmin/downloads/GRanD_Techn

			(GWSP)	ical_Documentation_v1_1.pdf http://atlas.gwsp.org/
	Populations served by water from protected areas [potentially also other forest] – environmental service rather than ecosystem service – based on HydroSHEDS	World	Kings College London (Dr. Mark Mulligan, Department of Geography)	Not yet available
	Watershed drainage into dams – based on HydroSHEDS and world dams database [not yet acquired]	World	Kings College London (Dr. Mark Mulligan, Department of Geography)	http://hydrosheds.cr.usgs.gov/
Pressures	Humid tropical deforestation	Tropics	South Dakota State University (Dr. Matthew Hansen)	http://globalmonitoring.sdstate.edu/projects/gfm/humidtropics/htindex.html
	Agricultural Suitability	World	FAO/IIASA	http://www.iiasa.ac.at/Research/LUC/SAEZ/index.html
	Global Burnt Areas 2006-7	World	JRC	Tansey *et al.* (2008) http://bioval.jrc.ec.europa.eu/products/burnt_areas_L3JRC/GlobalBurntAreas2000-2007.php
	Active fires (MODIS) 2001-2009a	World	UMD/FAO	http://modis-fire.umd.edu/index.html
Misc	Ancillary data from ESRI	World	ESRI	http://www.arcgis.com/home/

* Landsat scenes distributed:

Country/Year	1990	2000	2005	Total
Bolivia	73	68	65	206
DRC	121	150	131	402
Indonesia	223	237	352	812
Panama	11	9	22	42
Paraguay	32	30	31	93
PNG	67	74	120	261
Tanzania	51	59	57	167
Vietnam	40	42	41	123
Zambia	46	49	47	142
Ecuador	22	19	25	66
Total	**686**	**737**	**891**	**2314**

3. Mapping and analysis (task 2)

3.1 Mapping carbon

This section explains how to generate maps of carbon stored in above- and below-ground biomass as well as in soil down to 1m depth. These maps give a first overview of carbon stocks, useful in producing overlays to estimate the potential to secure ecosystem-based multiple benefits from REDD+, and to meet the relevant Cancun safeguards. The maps and underlying data can be used separately, but they can also be combined, if the illustration of both stocks jointly is considered useful. For example, biomass-only maps will be most relevant if considering the likely carbon impacts of selective logging; but biomass and soil carbon maps give a total estimate of carbon stocks that could be vulnerable to forest conversion and ploughing.

Two different approaches are outlined below for the generation of carbon maps. While both mapping approaches can deliver carbon maps fairly rapidly, more sophisticated methods may deliver more accurate and precise maps, needed for detailed REDD+ planning. Where possible, we refer below to existing guidelines for their generation.

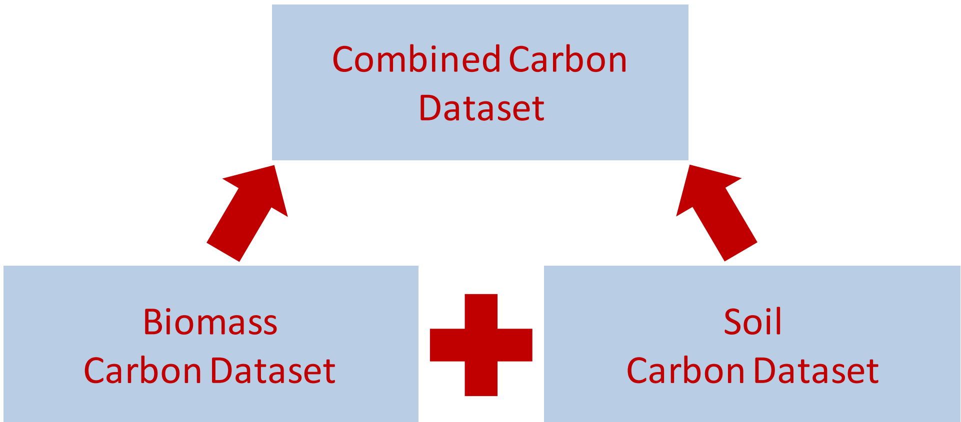


Figure 1: Simplified process for generating a dataset combining carbon in biomass and soil

3.1.1 Generating a biomass carbon map

Two different methodologies for generating a biomass carbon map will be explained. In approach 1, an existing GIS dataset on above-ground biomass derived from remote sensing data forms the baseline for the generation of the above- and below-ground biomass carbon map. In approach 2, a national GIS land cover dataset is used as a starting point (see Figure 2). This latter approach is less likely to capture the effects on carbon stocks of natural variation and disturbance. Neither approach is comprehensive in its treatment of ecosystem carbon pools: we typically include only carbon in above-ground woody biomass, below-ground biomass and soil organic carbon to 1 metre depth.

The GOFC-GOLD *sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation* offers guidance on the carbon mapping and monitoring systems likely to be required for REDD+ MRV (http://www.gofc-gold.uni-jena.de/redd/), recognising that negotiations on this topic under UNFCCC are still ongoing. The current document does not address carbon mapping for MRV; rather, these approaches will deliver a rapid, initial assessment of carbon stocks in ecosystems.

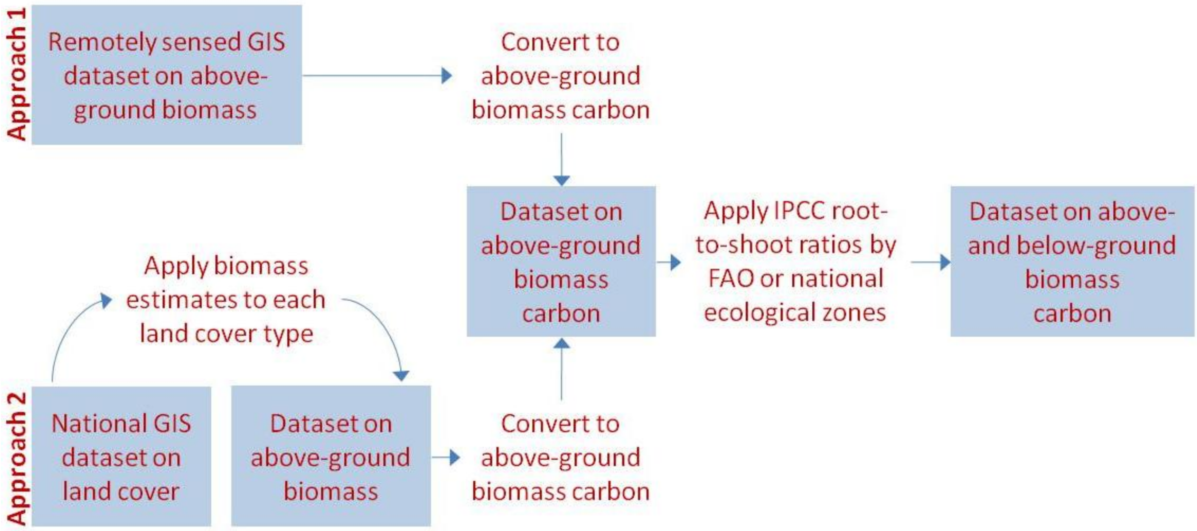


Figure 2: Data needed for and steps involved in two different approaches for generating a biomass carbon map

3.1.1.1. Using remotely-sensed GIS data on biomass

Pre-processed remotely-sensed GIS data on biomass can provide a useful basis for generating a map of carbon in above- and below-ground biomass. For example, Baccini *et al.* (2008) have produced a 1km resolution dataset of above-ground biomass for tropical Africa. This was derived from a model which used remotely-sensed MODIS NBAR data from 2000-2003. Such data can be used directly without the need for experience in analysis of remote-sensing imagery.

In this case, approach 1 from Figure 2 would be applied to generate a dataset of above and below ground carbon. Ecosystem-specific conversion factors (IPCC 2006) can be used to add below-ground biomass to this dataset, with the factors allocated to FAO ecological zones (FAO 2001). Equivalent national datasets can be used where available. The carbon mass of the resulting total is estimated as half the biomass (Gibbs and Brown 2007), unless ecosystem-specific carbon fractions are available.

In the African (Baccini) example, however, there are no model data for zones with <9 tons of biomass per hectare. Although not ideal, these 0 values could be substituted from another available source such as the global biomass carbon map (Ruesch and Gibbs 2008) to give a more complete map of biomass carbon. If taking this approach, it is essential to check that values >9 tons/ha have not been introduced via overlay with the alternative map.

3.1.1.2. Using land cover maps and field plot data

If no appropriate remote-sensing data is available, it is possible to generate a biomass carbon map from a recent land cover map and biomass estimates from field plots.

3.1.2 Generating a soil carbon map

While it is estimated that the world's soils store about twice the amount of carbon as that in the atmosphere (Houghton *et al*. 2001), well resolved data on carbon stored in soils are still scarce. The degree and detail with which soil types have been mapped and field data recorded varies greatly between countries. Although it is well known that some soil types store very large amounts of carbon (e.g. peat soils), their spatial extent and location are often unknown. In addition, soils vary greatly in depth, from less than 50cm deep to 3m depth or more. Existing datasets rarely provide information on soil properties below 1m depth.

Where data exist, they are often provided separately for topsoil (0-30cm layer of soil) and subsoil (30-100cm layer of soil). While organic matter is usually highest in the top soil, the amount of carbon in the subsoil is still significant. It is estimated that globally there is about 1500 Gt of organic carbon (C) to a depth of 1 m and a further 900 Gt from 1-2 m (Kirschbaum 2000).

3.1.2.1. Using data from the Harmonized World Soil Database

The Harmonized World Soil Database (HWSD) was the product of an initiative of the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) to combine the soil information contained within the 1:5 000 000 scale FAO-UNESCO Digital Soil Map of the World with the vast volumes of subsequent regional and national updates (FAO *et al.* 2009). The HWSD consists of a spatial database of soil mapping units (SMUs) and a linked table of soil attributes. Due to the different format and resolution of the contributing datasets, data were harmonised and scaled to a notional resolution of 1km, or 30 arc seconds by 30 arc seconds (i.e. downscaled as necessary). Reliability of the data varies according to the sources, with ISRIC's Soil and Terrain (SOTER) databases being considered as the most reliable information source (FAO *et al.* 2009). The resulting GIS raster database includes information for 16 107 unique soil mapping units (SMUs). Linked to each SMU are up to 10 soil typological units (STUs) with associated harmonized soil attribute data derived from 9 607 soil profiles in the World Inventory of Soil Emission Potential (WISE) database version 2.0 (Batjes 2002).

The soil properties presented in the HWSD originate from soil profile information from numerous countries and sources. However, the global distribution of soil profile information is uneven and there are still considerable gaps in soil data (FAO *et al.* 2009). Moreover, the data do not capture natural variation or disturbance in carbon stocks. However, the HWSD often represents the only available source of soil data.

As every soil mapping unit can include up to 10 different soil types (or STUs) in varying proportions, soil organic carbon (SOC) needs to be calculated for each STU. Weighting these values by each STU's share in each mapping unit and adding up the results gives an estimate of total SOC in the soil mapping unit.

The following data included in the HWSD are required to convert the information into a spatial dataset of carbon stored in soils to 1m depth:

- Share, i.e. proportion of soil profile unit within the mapping unit (HWSD field name SHARE, given in %)
- Soil depth (HWSD field name REF_DEPTH)
- Gravel content in topsoil and subsoil (HWSD field names T_GRAVEL and S_GRAVEL, given as % per volume), so that the volume of gravel can be excluded as it does not contain carbon
- Organic carbon (OC) content in topsoil and subsoil (HWSD field name T_OC and S_OC, given in % of dry weight)
- Bulk density of topsoil and subsoil (HWSD field name T_REF_BULK_DENSITY and S_REF_BULK_DENSITY, given as kg/dm^3, i.e. dry weight per volume)

With this information, SOC (in in $g\ C\ m^{-2}$) for each STU within a mapping unit can be calculated according to the following equations:

The average SOC for each soil mapping unit (SMU_i) is

$$\overline{SOC}_i = \sum_{j=1}^{n} \frac{S_{ij}}{100} \left(SOC_{tj} + SOC_{sj}\right), \tag{1}$$

where n (≤ 10) is the number of STUs within SMU_i, S_{ij} the share of STU_j within SMU_i (in %), and SOC_{tj} and SOC_{sj} are the SOC of STU_j in the topsoil (0-30cm) and subsoil (30-70cm) respectively.

The SOC for each of j STUs for top- and subsoil are calculated separately as

$$SOC_{lj} = SOC_{lj} \times BD_{lj} \times \left(1 - \frac{GC_{lj}}{100}\right) \times D_{lj} \times 10^2, \tag{2}$$

where l indicates the two soil layers topsoil (t) or subsoil (s), SOC_l is the soil organic content (in %) for the soil layer l, BD_l is the dry bulk density (in $kg\ dm^{-3}$), GC_l is the gravel content (in %) and D_l is the depth of the soil layer. Soil depth information in the HWSD for most parts of the world is 100cm. The topsoil depth (D_t) equals 30cm (depth 0-30cm) and subsoil depth (D_s) 70cm for subsoil (depth of 30-100cm). Where the total soil depth is 10cm or 30cm, the subsoil layer is absent and therefore D_s is set to 0, and D_t is set to 10cm or 30cm respectively.

In order to arrive at the SOC for one mapping unit, the results for the different soil types according to their shares are summed (see equation 1).

In doing this calculation, special care needs to be taken to correctly take the different units into account and arrive at a unit that reflects carbon content by volume.

A global dataset of terrestrial soil organic carbon has been generated from the HWSD using this method and will be available from UNEP-WCMC, pending publication. (Scharlemann *et al*. In preparation).

3.1.2.2. Using other soil data sources

As reliability of the data in the HWSD is limited, it is always worth checking whether higher resolved and more recent soil information can be obtained. The minimum information needed consists of (i) spatial information on the distribution of different soil types and (ii) information on the soil properties that are essential for the calculation of soil carbon content (SOC) for each soil type, as listed in the previous section.

3.1.2.3. Combining the biomass and soil carbon maps

Summing the biomass and soil carbon datasets to form a combined carbon dataset will affect the distribution of carbon stocks among landcover types. Including soil carbon will greatly increase the overall amount of carbon stocks and may show a very different distribution than considering biomass carbon on its own. Whether it is appropriate to use the combined or separate soil and biomass carbon datasets in an analysis will depend upon the questions being asked. It is not always appropriate to make decisions based on the combined carbon stock, as it is more difficult to predict the impacts of land-use change on soil carbon than on biomass carbon. For example, the impact of deforestation on soil carbon depends on the land clearance practices and subsequent land use.

3.1.2.4. Selecting carbon density classes for visualisation and analysis

To visualise the carbon data, it is useful to classify the map into different carbon density classes. We have usually adopted one of two approaches:

1. An area-based scheme: each class represents one fifth of the total land area; that is, the highest class highlights the fifth of the total land area that has the highest carbon density.
2. A content-based scheme: each class represents one fifth of the total carbon stock of the land, the cells in the highest carbon density class jointly store one fifth of the total carbon stock.

Either of the schemes can be adopted according to the situation of the focal area and the policy question being asked of the map. In both cases, the classes will be specific to the map in question, because the class boundaries are dependent upon the distribution of carbon in that particular geographic region and point in time. If comparing maps from multiple regions, then a single legend based on a range of values over the combined datasets would be preferable.

3.2 Incorporating information on other features

Depending on the multiple benefits, pressures or other themes of interest, spatial data may be more or less readily available. Mapped ecosystem service information is scarcer than land cover maps, for example, but national agencies or others may already have maps or subnational statistics that could be mapped for biodiversity priorities, timber production potential, woodfuel harvest, non-timber forest product harvest, poverty and so on. Where no national data are available, various relevant global layers are referred to in Table 2. In using these, care should be taken to examine how accurate the maps are for the area of interest.

Several groups have developed software packages enabling the mapping of ecosystem services, but each is sufficiently specialised that the user is referred to the software's own guidance. Points of entry include:

InVEST: Integrated Valuation of Ecosystem Services and Tradeoffs (http://www.naturalcapitalproject.org/InVEST.html)

RUSLE: Online soil erosion assessment tool (http://www.iwr.msu.edu/rusle)

SolVES: Social Values for Ecosystem Services (http://solves.cr.usgs.gov)

3.3 Running analyses in ArcGIS using the ExploringMultipleBenefits toolbox

This section provides technical instructions for the ExploringMultipleBenefits toolbox. It gives detailed descriptions of the individual tools contained within the toolbox and a set of workflow instructions, with a worked example. This toolbox allows both novice and experienced GIS users to undertake analysis using a consistent and efficient methodology and decreases the time required to undertake such analyses. Raster analysis is used, as many biomass and landcover datasets are derived from remotely sensed data and it is more preferable to convert from vector to raster formats than vice versa. The toolbox is flexible in that tools can be used interchangeably and the resolution of the analysis is defined by the user. The tools aid both preparation of data for map production and analysis for the production of statistical outputs. This manual and toolbox covers some elements of map production, and there is also some advice contained within the Annex on effective map presentation.

The following types of analysis can be undertaken within the toolbox:

- Creation of a carbon dataset based on remotely sensed biomass data.
- Creation of a carbon dataset starting with a landcover dataset
- Applying IPCC root to shoot ratios to estimate below ground carbon
- Converting datasets between vector and raster, ensuring a consistent approach and raster format for analysis
- Joining, adding, deleting and calculating fields
- Clipping and sub-setting data
- Creating buffers around data (vector or raster)
- Automatically filling gaps in data and fixing errors (e.g. matching coastlines/boundaries)
- Formatting data for map production and statistical analysis
    - Grouping data into classes by carbon stock rather than by area
    - Displaying thematic data by carbon content
    - Using a matrix style legends to display 2 graduated themes
- Combining numerous datasets to output a large statistics table that can be further analysed in another package such as Excel.

Please note: Although these instructions should help a basic GIS user to undertake some more complex analysis, they do assumes some knowledge of GIS and the ArcMap software. ESRI provide some free introductory training modules for ArcGIS and live training seminars at http://training.esri.com/gateway/index.cfm.

To discuss further guidance and/or training options please contact UNEP-WCMC.

3.3.1 Installation

The following steps need to be taken in order to make use of the ExploringMultipleBenefits toolbox:

1. Unzip the ExploringMultipleBenefits toolbox and save the file to chosen location

Note: the default area to which ArcGIS saves toolboxes is c:\Documents and Settings\<username>\Application Data\ESRI\ArcToolbox\My Toolboxes.

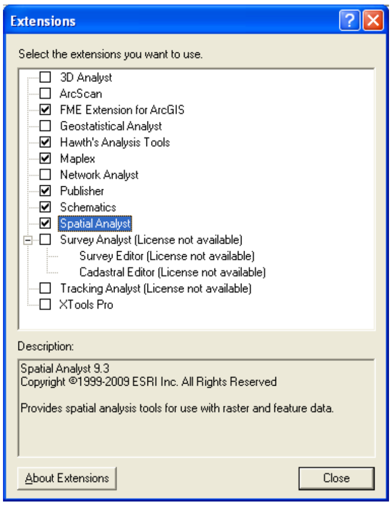
It may be preferable to save the toolbox within a current project folder. Make sure you keep the toolbox in a sub-folder called ExploringMultipleBenefitsTools otherwise the tools may show broken links.

2. Open the ArcMap software and activate the spatial analysis extension

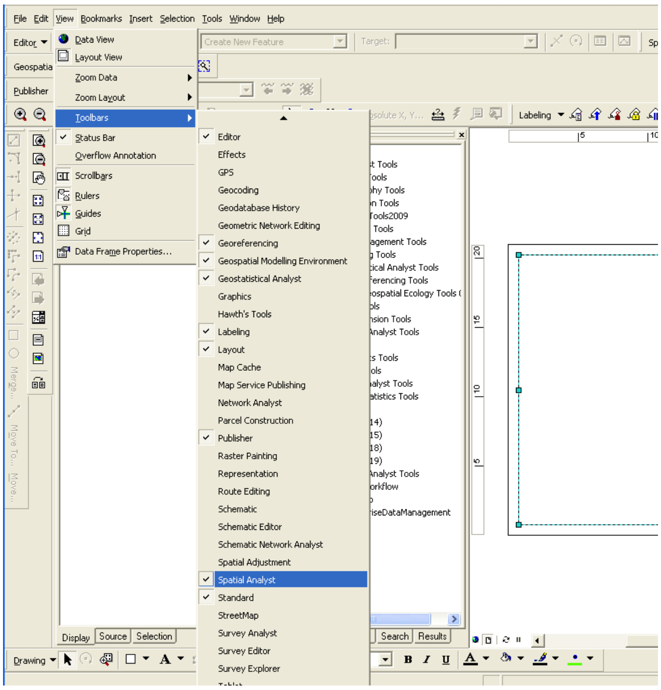
a) In ArcMap click on Tools - Extensions and ensure that the 'Spatial Analysis' extension is ticked (A).

Note: This extension is required to run the ExploringMultipleBenefits tools, therefore if this extension is not available the software vendor will need to be contacted to obtain a licence.

b) Next, if the toolbar is not already present, from the main menu bar click on View - Toolbars – Spatial Analyst (B). Dock the toolbar in the grey horizontal menu area.



(A)

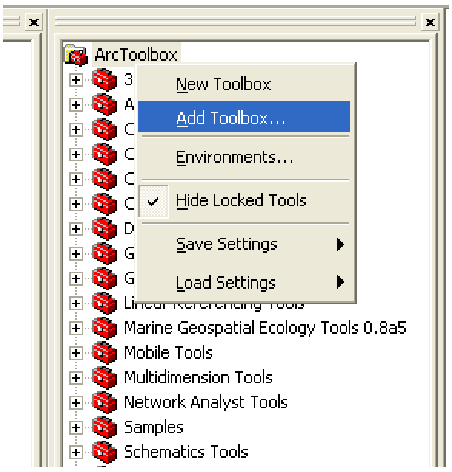


(B)

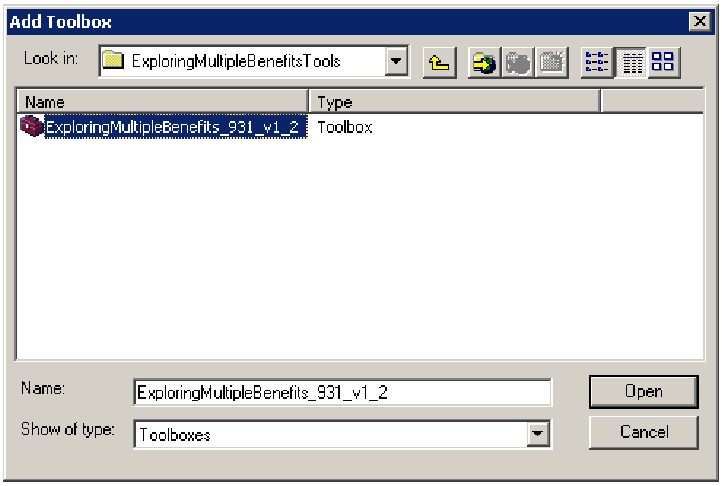
3. Add the 'ExploringMultipleBenefits' toolbox to ArcToolbox

a) In ArcMap, if the ArcToolbox is not already open, click on the red toolbox button located in the main horizontal menu bar.

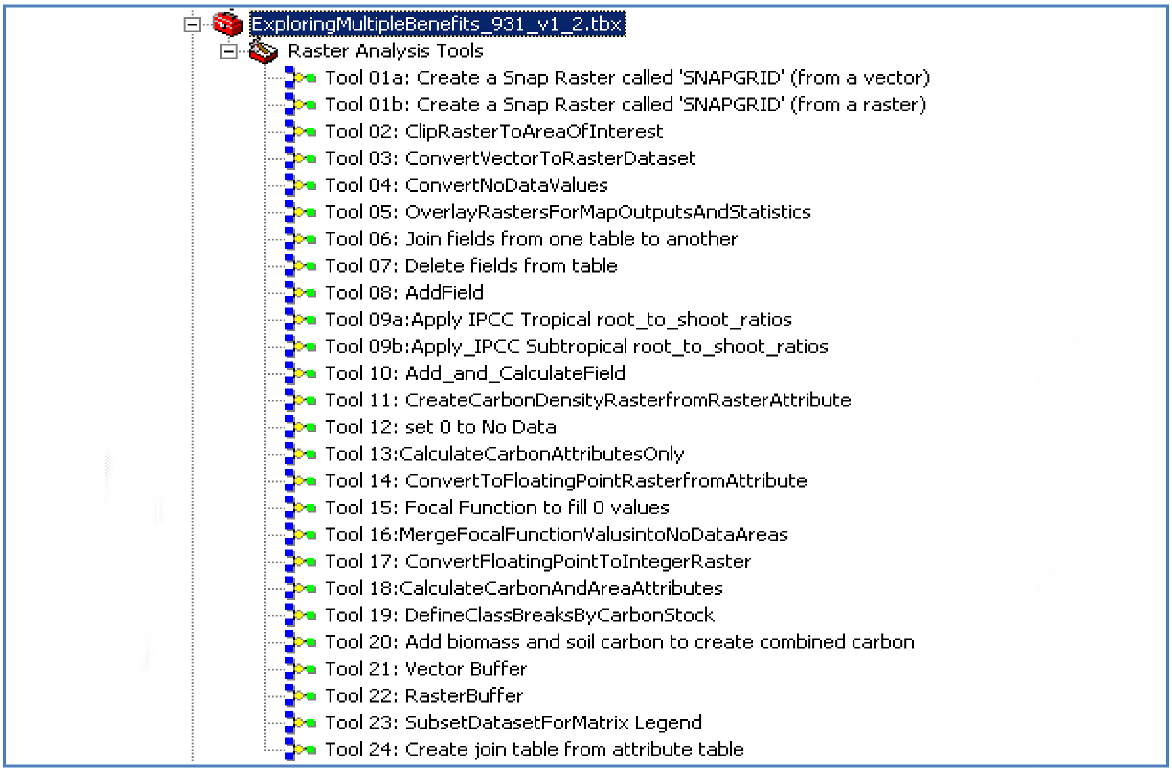
b) Right click on ArcToolbox and click Add Toolbox ------------->



c) Navigate to the folder in containing the toolbox (location determined in Step 1) and click open



d) The toolbox will appear in ArcToolBox, click the + button to expand the toolbox to see the tools.



3.3.2 GIS toolbox user manual

The ExploringMultipleBenefits toolbox is designed to make the required spatial analysis steps quicker and easier to perform. In the standard ArcGIS toolbox there are multiple ways in which users can overlay datasets. Without the ExploringMultipleBenefits toolbox, users would need to find relevant tools and understand how and when to use them. With Raster analyses in particular it is important to use and apply appropriate environment settings which are often hidden and forgotten. The ExploringMultipleBenefits toolbox not only standardises the way that analysis is undertaken in a series of simple steps, but reduces the risk of errors.

The sections below aim to provide a clear explanation of the tools and how to run them. They outline what user inputs are required for each of the defined 'parameters'. This information is also stored in the help pages, clearly visible from within the ExploringMultipleBenefits toolbox.

As a guide to this manual, each tool within the ExploringMultipleBenefits toolbox is described below with the title of the tool, how to run it, a model diagram (which novice users need not fully understand), a description of the tool, usage tips and details of what is required for each of the parameters.

Tool 01a: Create a Snap Raster called 'SNAPGRID' (from a vector)

ArcToolbox — Exploring Multiple Benefits toolbox

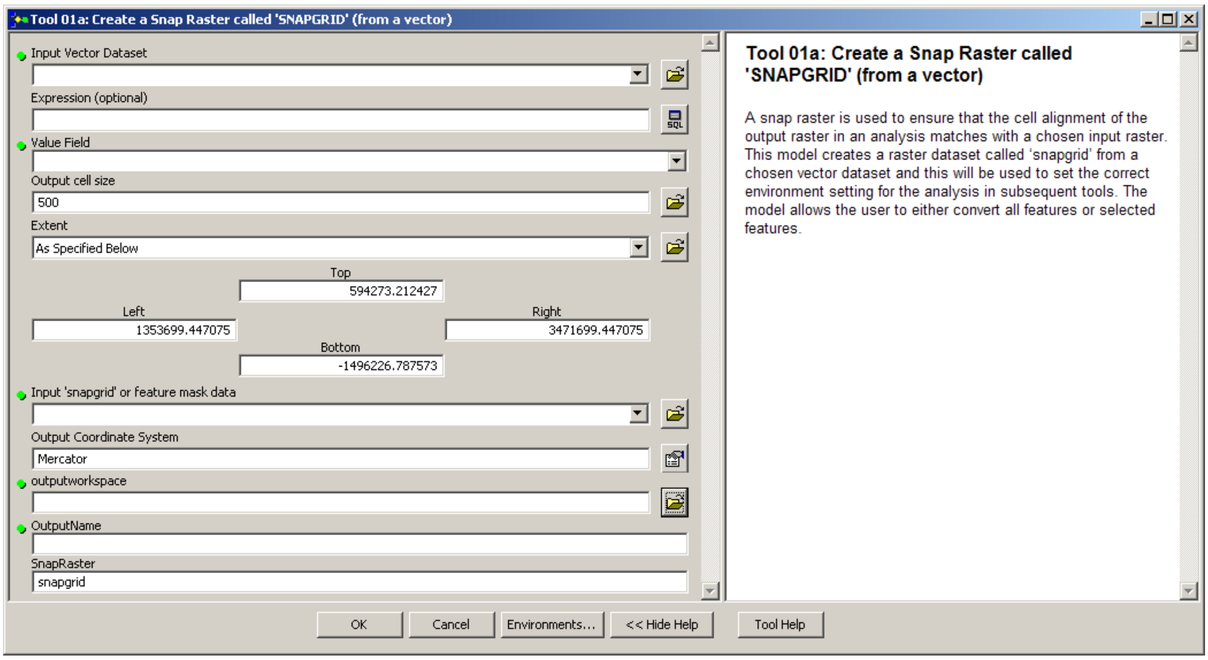
A snap raster is used to ensure that the cell alignment of the output raster in an analysis matches with a chosen input raster. This model creates a raster dataset called 'snapgrid' from a chosen vector dataset and this will be used to set the correct environment setting for the analysis in subsequent tools. The model allows the user to either convert all features or selected features.

Usage Tips
To ensure the resultant dataset is an integer raster, the field from which the raster will be created must be in the format of long integer or text. If the field is of type 'double', even if the data within that field has no decimal place, it will make the output raster floating point.

How to Run the Tool

Double click on the tool 'Tool 01a: Create a Snap Raster called 'SNAPGRID' (from a vector)'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



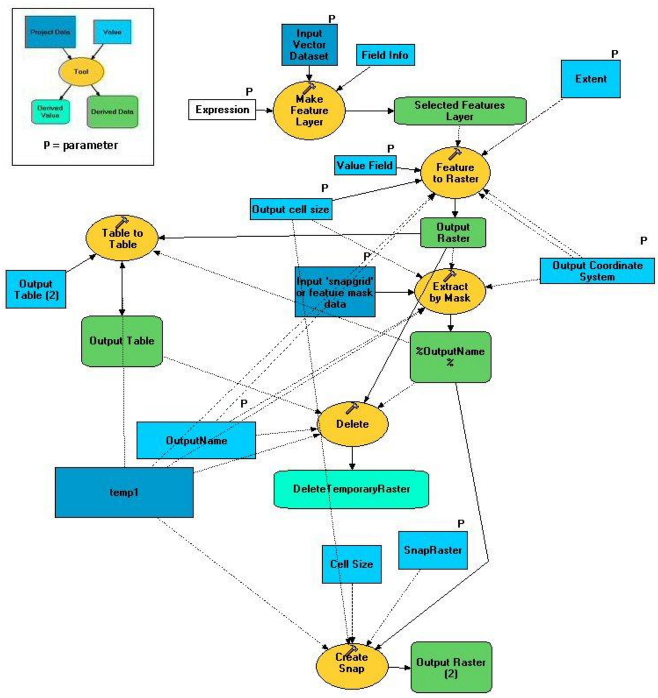
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Vector_Dataset>	Vector Dataset from which to base the 'snapgrid'
<Expression> (optional)	Expression to convert only a subset of features.
<Value_Field>	Field which will become the VALUE field in the output raster dataset. Note: if field is type double then the output will be a floating point raster dataset.
<Output_Cell_Size>	Specify cell size, preferably to be same as Input Raster
<Extent>	Set the extent to be the same as the Input vector Dataset
<Input 'snapgrid' or feature mask data>	Same as Input Vector Dataset
<Output Coordinate System>	Chosen equal area projection to be used for the analysis
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of output Raster Dataset to be created from the vector
<SnapRaster>	Name of the output Snap Raster to be created from the vector i.e. 'snapgrid'

Technical diagram



Tool 01b: Create a Snap Raster called 'SNAPGRID' (from a raster)

A snap raster is used to ensure that the cell alignment of the output raster in an analysis matches with a chosen input raster. This model creates a raster dataset called 'snapgrid' from a chosen raster dataset and this will be used to set the correct environment setting for the analysis in subsequent tools.

Usage Tips

To ensure the resultant dataset is an integer raster, the field from which the raster will be created must be in the format of long integer or text. If the field is of type 'double', even if the data within that field has no decimal place, it will make the output raster floating point. To Check the field types within the vector dataset to be converted:

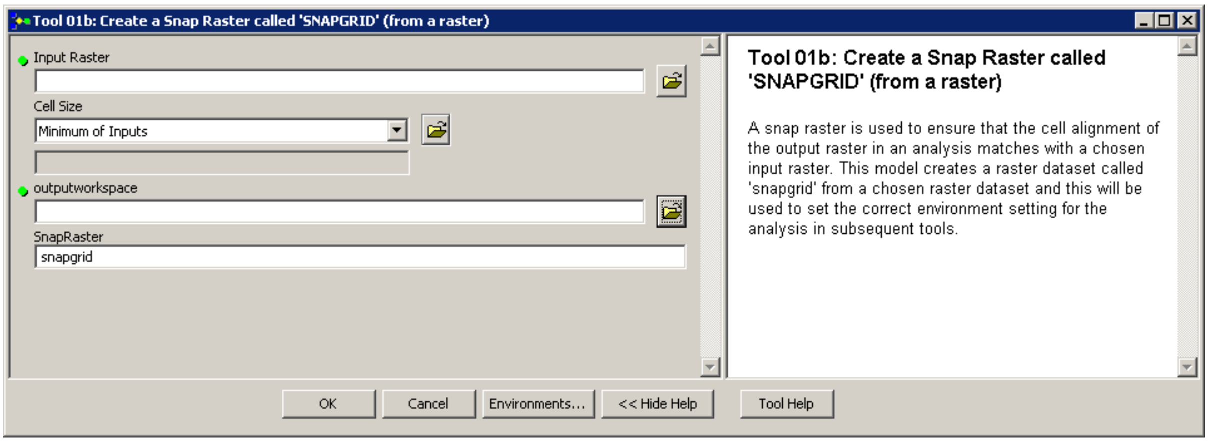
- In ArcMap, Right click on the dataset and click properties
- A window will appear. Click on the fields tab.

Information about the dataset will appear in this window, including the projection information.

How to Run the Tool

Double click on the tool 'Tool 01b: Create a Snap Raster called 'SNAPGRID' (from a raster)'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



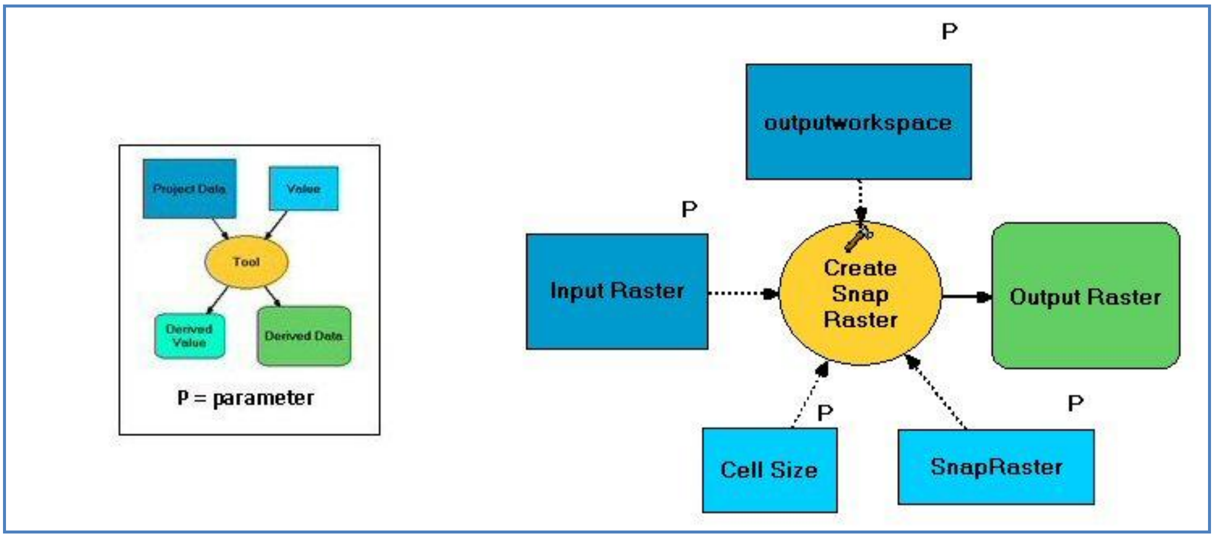
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Raster>	Raster Dataset from which to base the 'snapgrid'
<Cell Size>	Specify cell size, preferably to be same as Input Raster
<outputworkspace>	Workspace in which to save the output Raster
<SnapRaster>	Name of output Raster Dataset 'snapgrid'

Technical diagram



Tool 02: ClipRasterToAreaOfInterest

This model will use a vector or raster mask to clip a dataset to an area of interest.

Usage Tips

To check that the Input Raster and Input Clip Dataset have their projection defined:

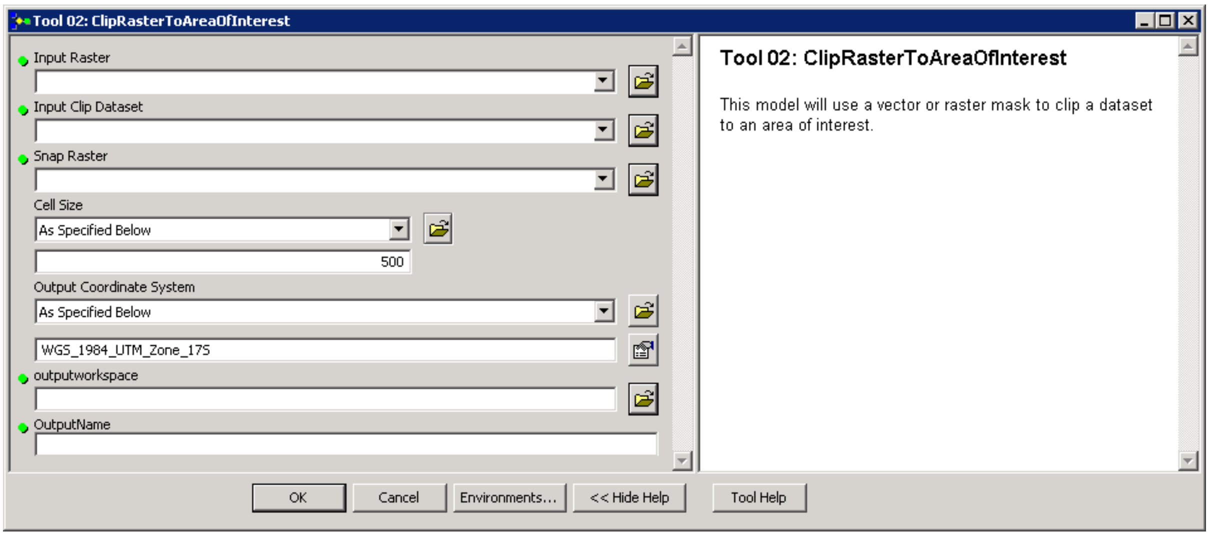
- In ArcMap, Right click on the raster dataset and click properties
- A window will appear. Click on the source tab.

Information about the raster or vector dataset will appear in this window, including the projection.

How to Run the Tool

Double click on the tool 'Tool 02: ClipRasterToAreaOfInterest'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



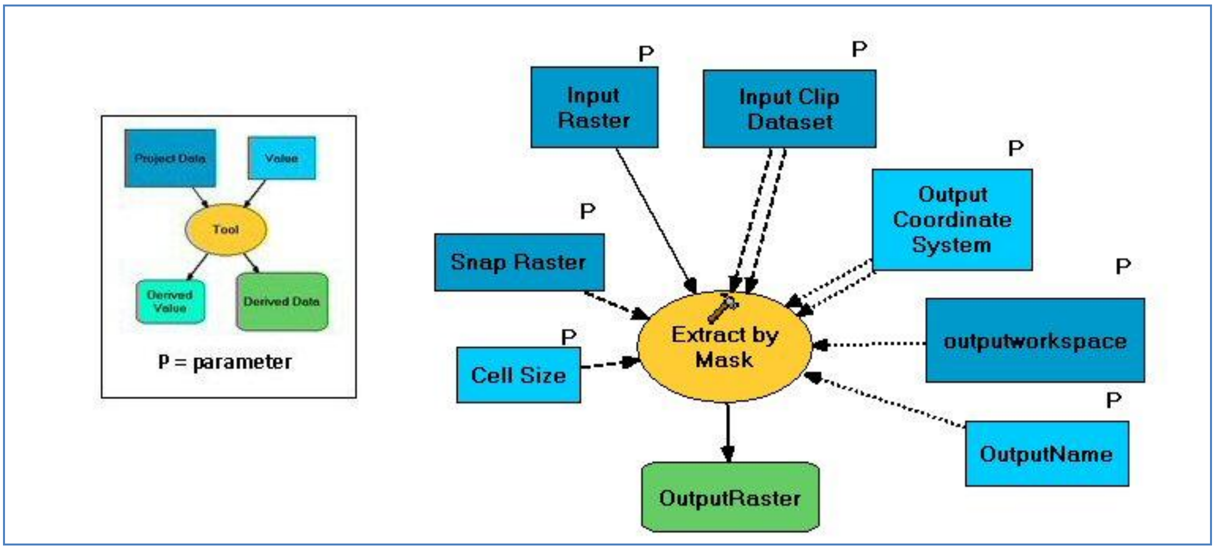
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Raster>	Input Raster dataset to be clipped.
<Input_Clip_Dataset>	Input Raster or vector dataset to be used as a mask to clip the input dataset
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<Output_Coordinate_System>	Coordinate system of the output Raster dataset (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 03: ConvertVectorToRasterDataset

This model will take a vector dataset and convert the features to a raster of a specified cellsize. The model allows the user to either convert all features or selected features. The user can also use a mask to clip the dataset to a specified area of interest.

Usage Tips

To ensure the resultant dataset is an integer raster, the field from which the raster will be created must be in the format of long integer or text. If the field is of type 'double', even if the data within that field has no decimal place, it will make the output raster floating point.

To Check the field types within the vector dataset to be converted:

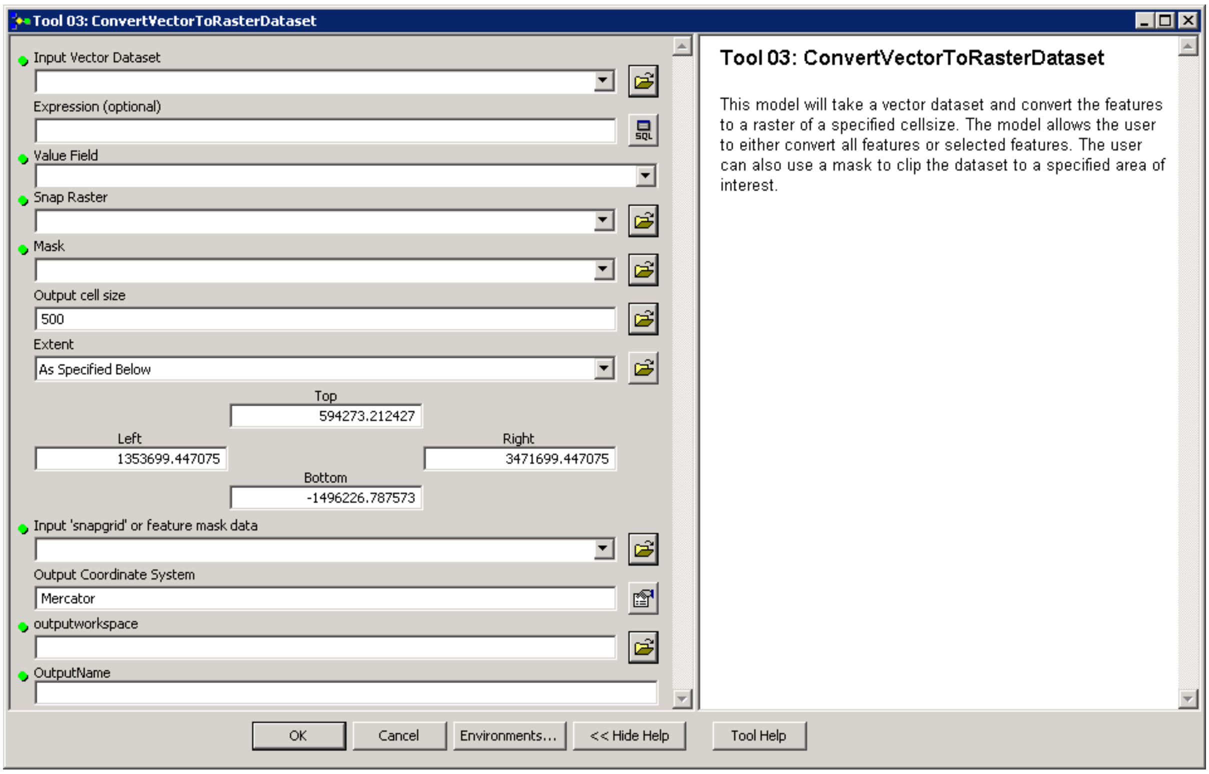
- In ArcMap, Right click on the dataset and click properties
- A window will appear. Click on the fields tab.

Information about the dataset will appear in this window, including the projection information.

How to Run the Tool

Double click on the tool 'Tool 03: ConvertVectorToRasterDataset'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



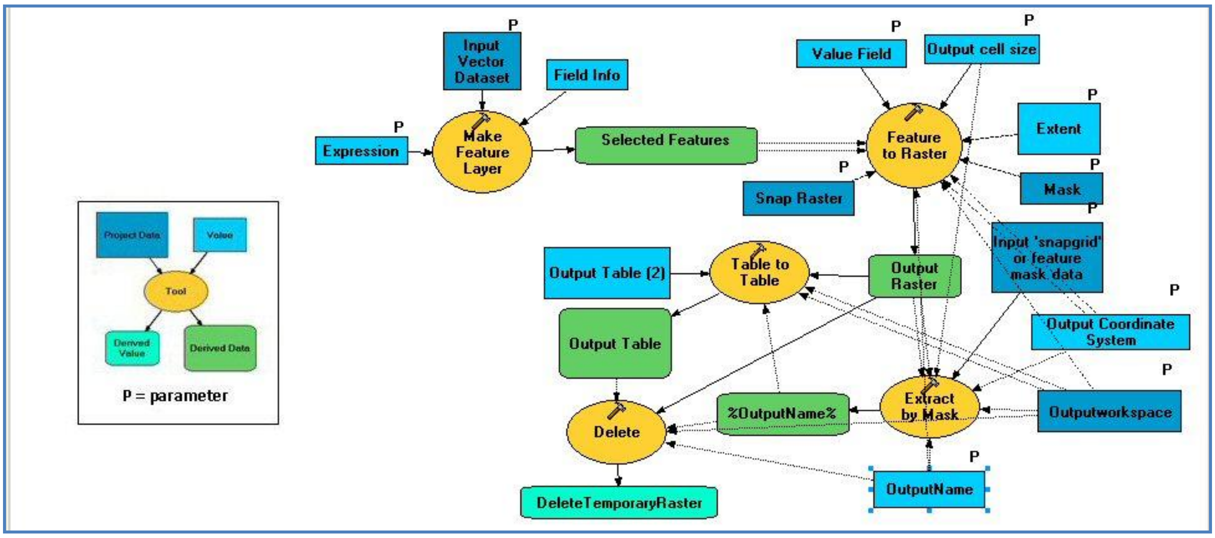
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input Vector Dataset>	Input vector dataset to be converted to raster format.
<Expression> (optional)	Expression to convert only a subset of features.
<Value Field>	Field which will become the VALUE field in the output raster dataset. Note: if field is type double then the output will be a floating point raster dataset.
<Snap Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Output cell size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<Extent>	Set the extent to be the same as the Mask_Raster
<Input 'snapgrid' or feature mask data>	Set the extent to be the same as the Mask_Raster
<Output cell size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<Output Coordinate System>	Coordinate system of the output Raster dataset (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 04: ConvertNoDataValues

ArcToolbox Exploring Multiple Benefits toolbox

In an overlay analysis, if any pixels within a set of raster datasets to be analysed have 'nodata' values, that 'nodata' area will be excluded from the whole analysis. This model takes a dataset that contains pixels of 'nodata' value and converts those pixels to a chosen value e.g. 0 or -999.

Usage Tips

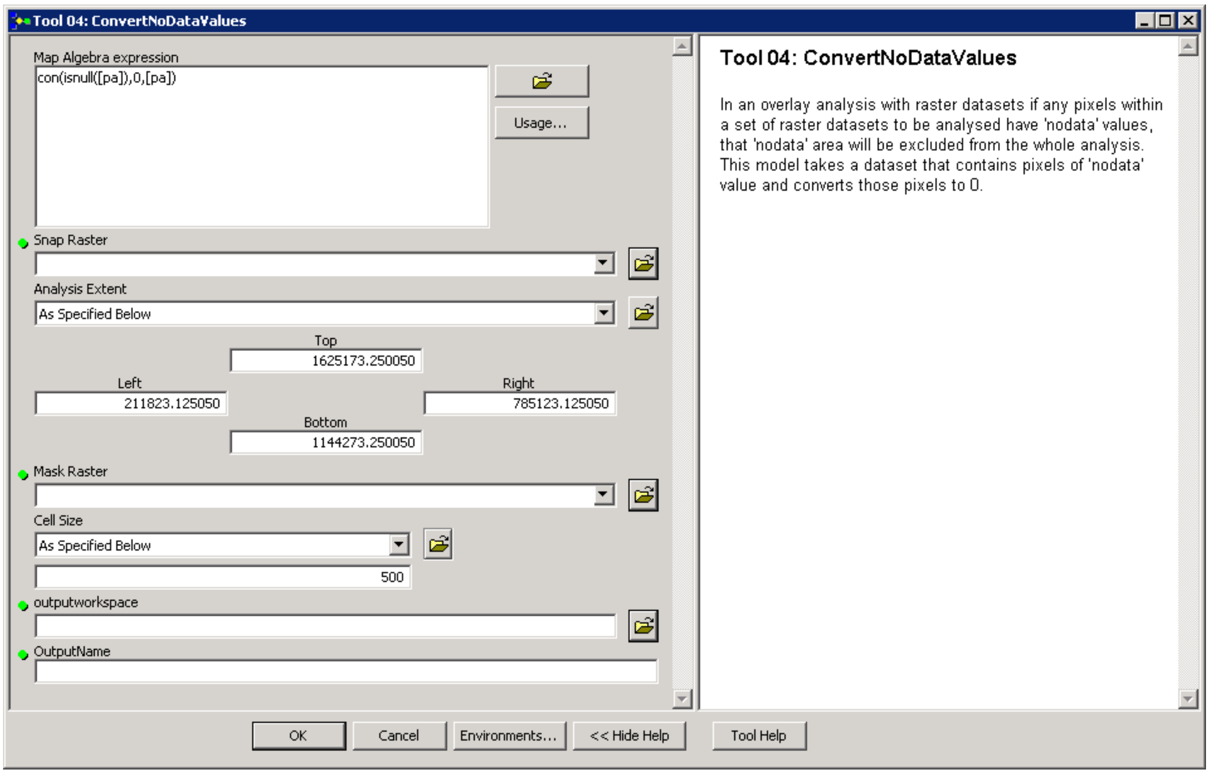
Before running the model check to see if a dataset has 'nodata' values

- View the datasets in ArcMap for visual checking.
- If uncertain, use the identify tool to check for 'nodata' values
- If there is already a 0 value in the dataset and there is a need to distinguish it from the nodata values assign a different number to the nodata cells e.g. -999.

How to Run the Tool

Double click on the tool 'Tool 04: ConvertNoDataValues'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



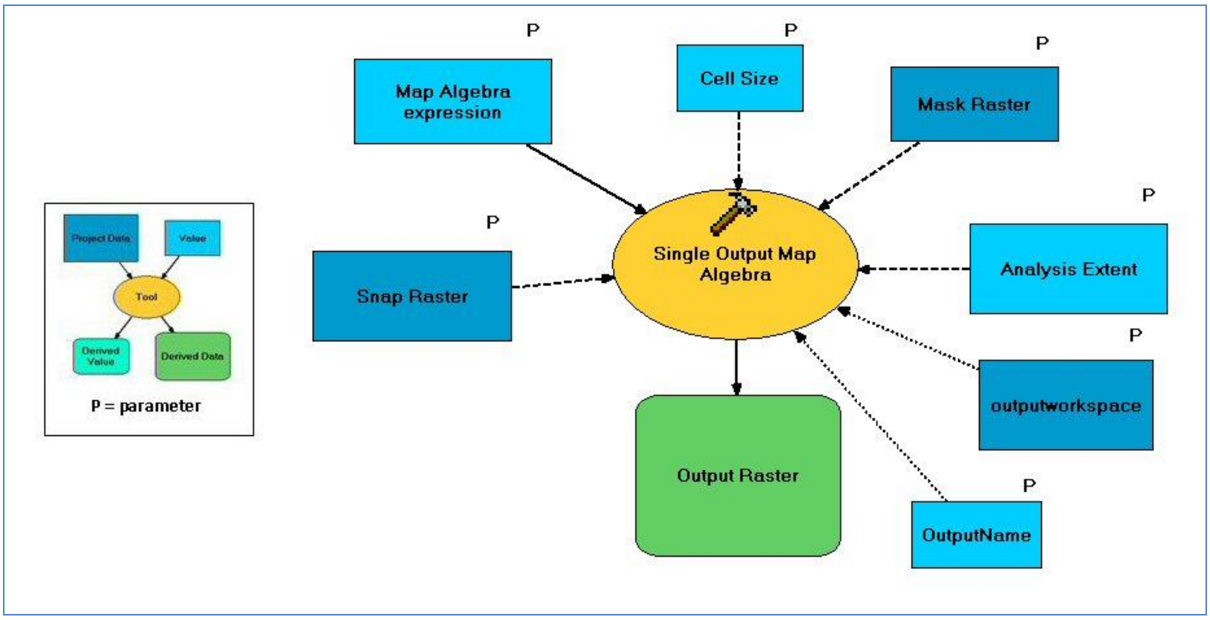
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Map_Algebra_expression>	Replace pa with the name of the raster dataset for which nodata values are to be converted to 0. *Example: The expression con(isnull([pa]),0,[pa]) takes a raster of protected areas (called pa) and converts the nodata values (areas that are not protected) to 0*
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Analysis_Extent>	Set the extent to be the same as the Mask_Raster
<Mask_Raster>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cellsize to be used for the analysis (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 05: OverlayRastersForMapOutputsAndStatistics

ArcToolbox — Exploring Multiple Benefits toolbox

This model combines multiple raster input datasets to produce an output dataset containing a unique combination of the inputs. The output raster contains a VALUE and COUNT field and individual fields for each of the VALUE fields from the input datasets, these fields are given the name of the input datasets

Usage Tips

Before running this model, ensure that all datasets have been checked and that 'Tool 3' has been used to convert any nodata values to 0. If any of the dataset have nodata values within the analysis extent, those cells will be excluded from the analysis.

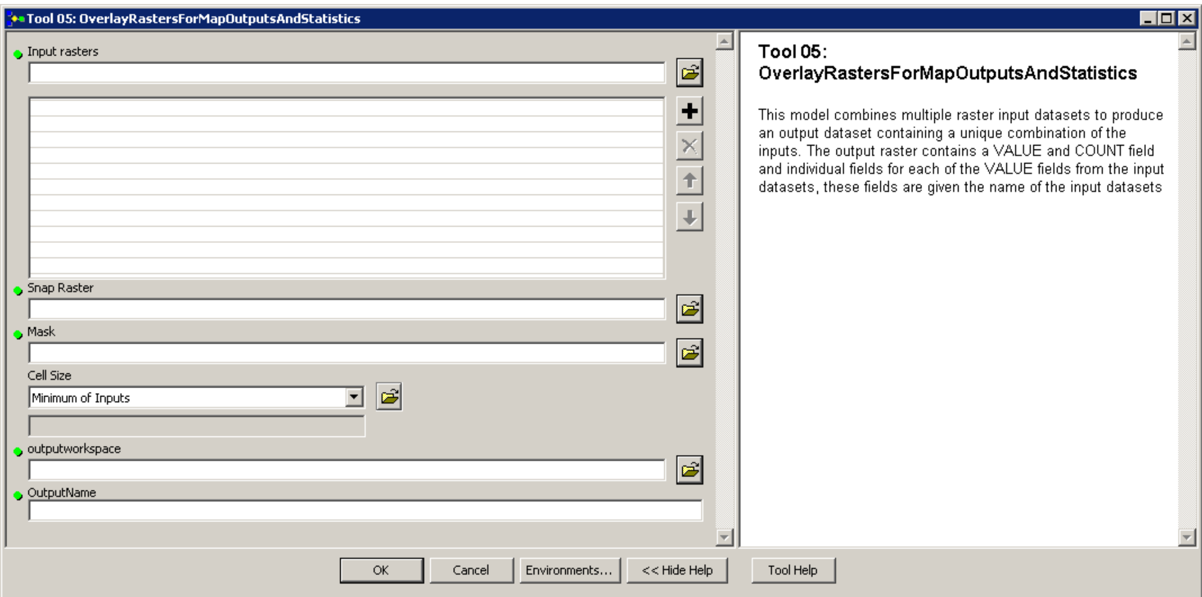
After running the model check the Output Raster in ArcMap.

The combine function will only keep the Value and Count Fields from the Raster datasets being combined. After this tool has run it may be necessary to join on any missing attributes (See Tool 06).

How to Run the Tool

Double click on the tool 'Tool 05: OverlayRastersForMapOutputsAndStatistics'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



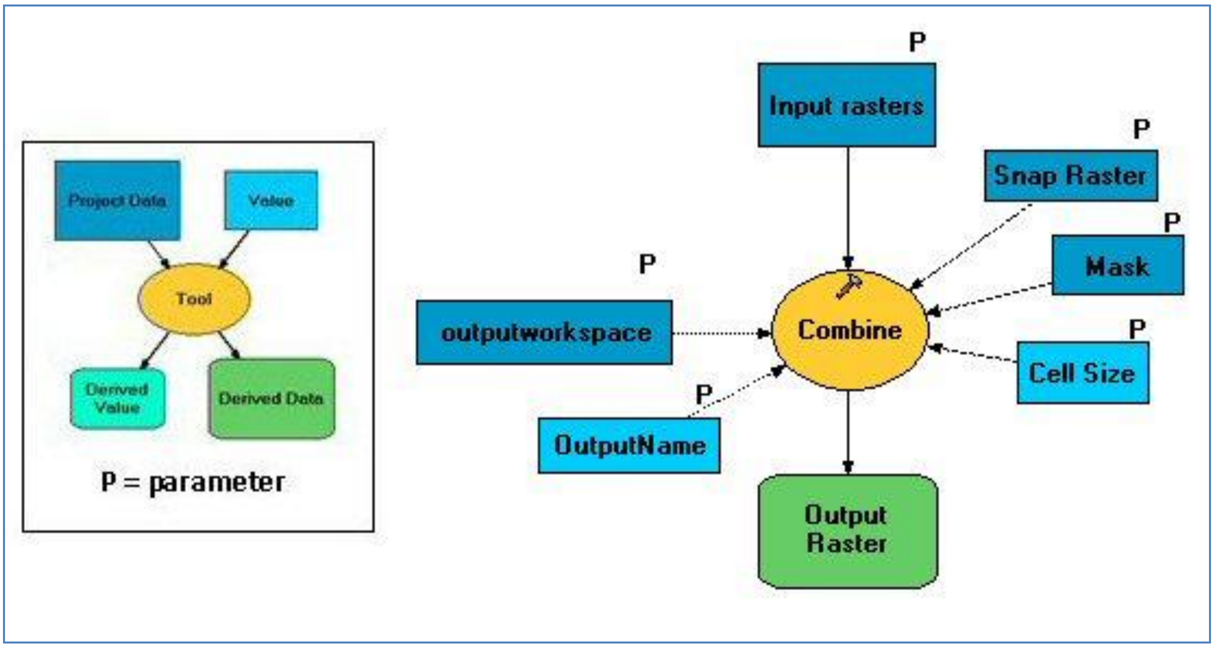
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_rasters;Input_rasters...>	Add all the input rasters to be combined.
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 06: Join fields from one table to another

This model will join on fields from an 'input' table (this includes vector and raster attribute tables) to a 'join' table based on a common field and create a new dataset containing the permanently added fields. The records in the input table are matched to the record in the join table based on the join field and the Input Field when the values are equal.

Usage Tips

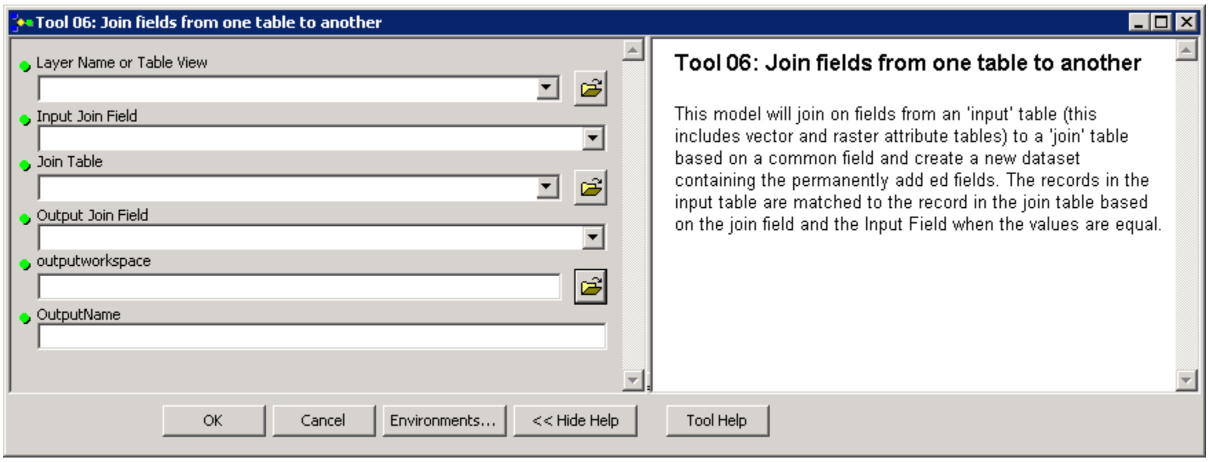
When undertaken spatial analysis using raster datasets, many of the functions only keep the VALUE and COUNT fields in the output raster dataset. Therefore it is often necessary to re-join any further attributes back on once the analysis has been run.

If the table to be joined contains many attributes that are not required. Use 'Tool 24' to create a smaller table with only the relevant fields.

How to Run the Tool

Double click on the tool 'Tool 06: Join fields from one table to another'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



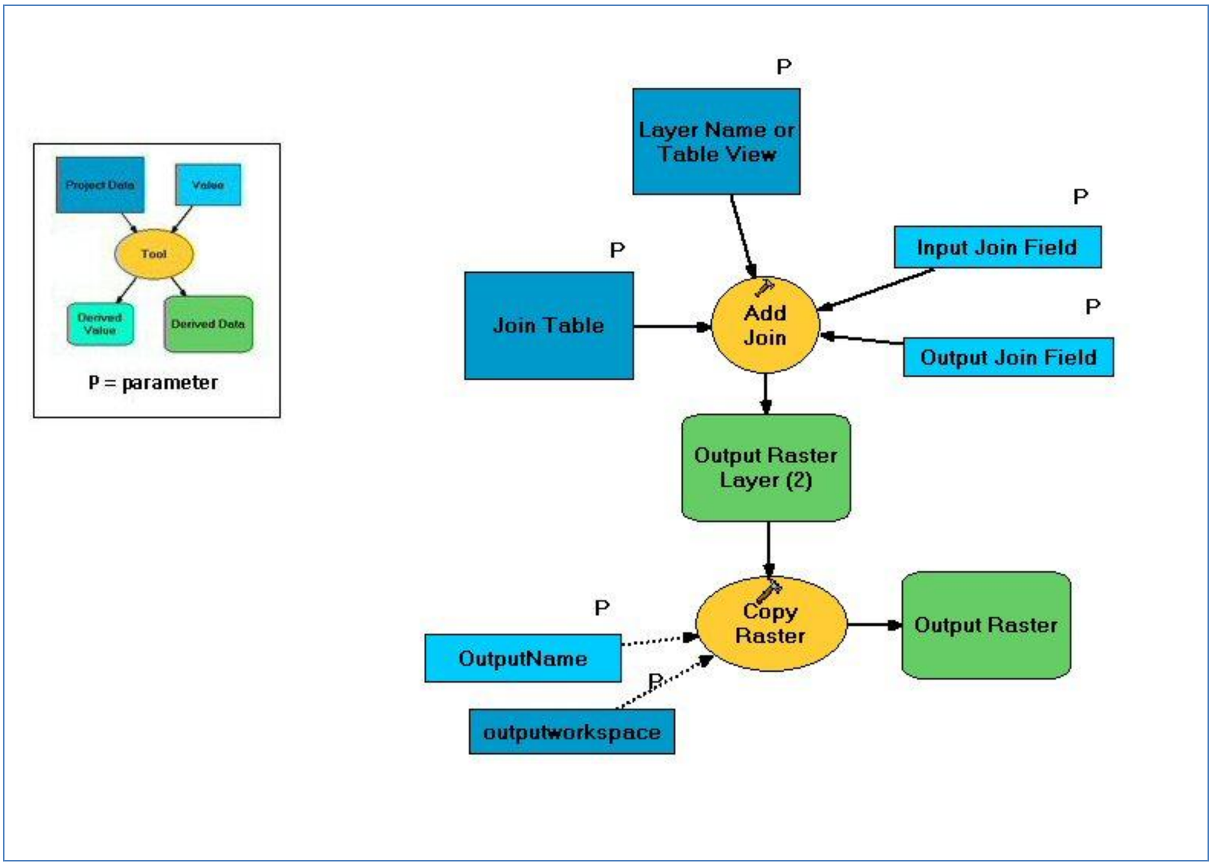
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Table>	Table or Attribute table of Dataset to which field(s) is to be joined.
<Input_Join_Field>	The field in the Input Table on which the join will be based.
<Join Table>	The table to be joined to the Input Table.
<Output_Join_Field>	The field in the Join Table that contains the values on which the join will be based.
<outputworkspace>	Workspace in which to save the output Raster.
<OutputName>	Name of the new output raster dataset.

Technical diagram



Tool 07: Delete fields from table

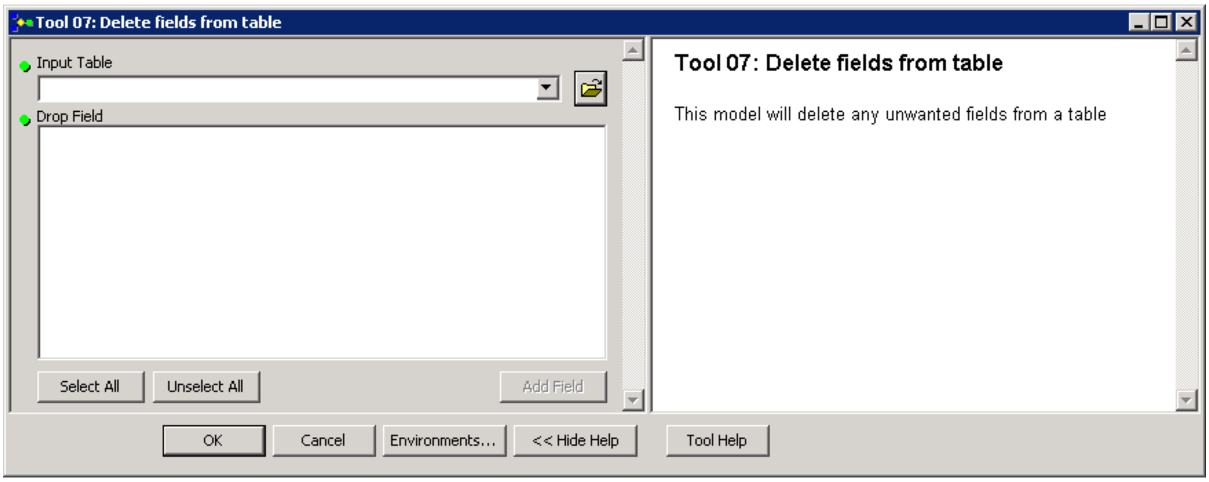
ArcToolbox — Exploring Multiple Benefits toolbox

This model will delete any unwanted fields from a table

How to Run the Tool

Double click on the tool 'Tool 07: Delete fields from table'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



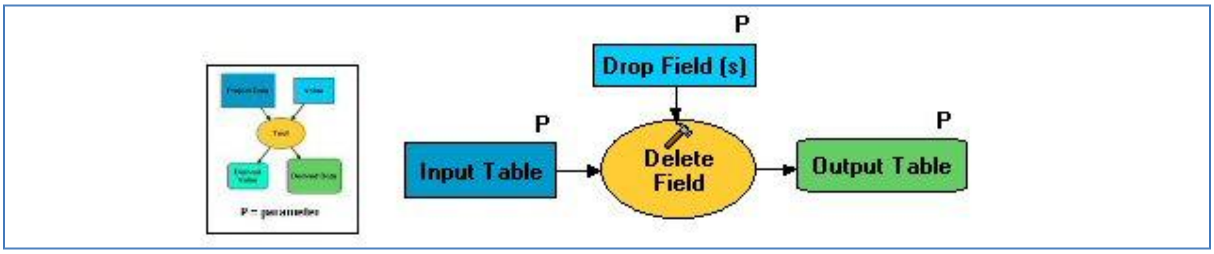
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Table>	Input Table or Attribute table of Dataset
<Drop_Field(s)>	The fields to be permanently deleted from the table

Technical diagram



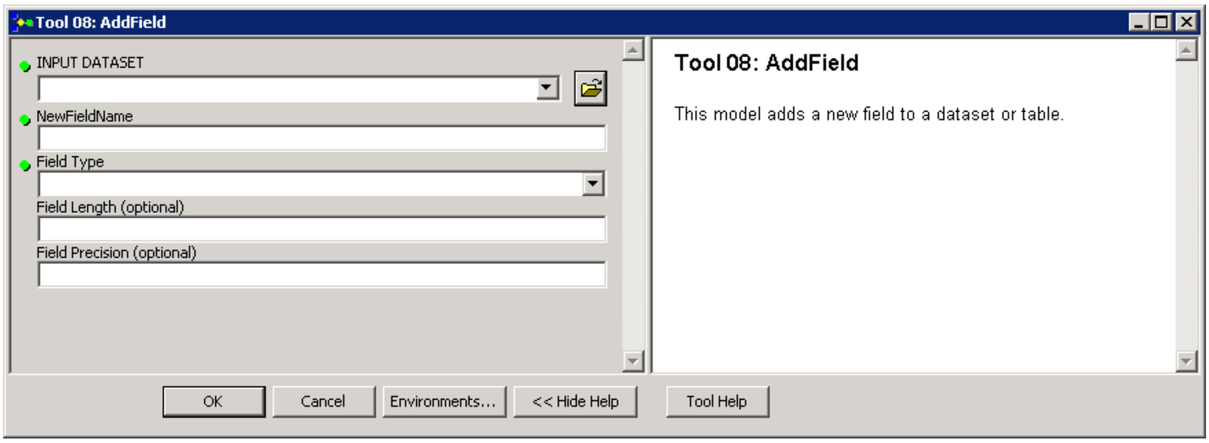
Tool 08: AddField

This model adds a new field to a dataset or table

How to Run the Tool

Double click on the tool ‘Tool 08: Add’

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



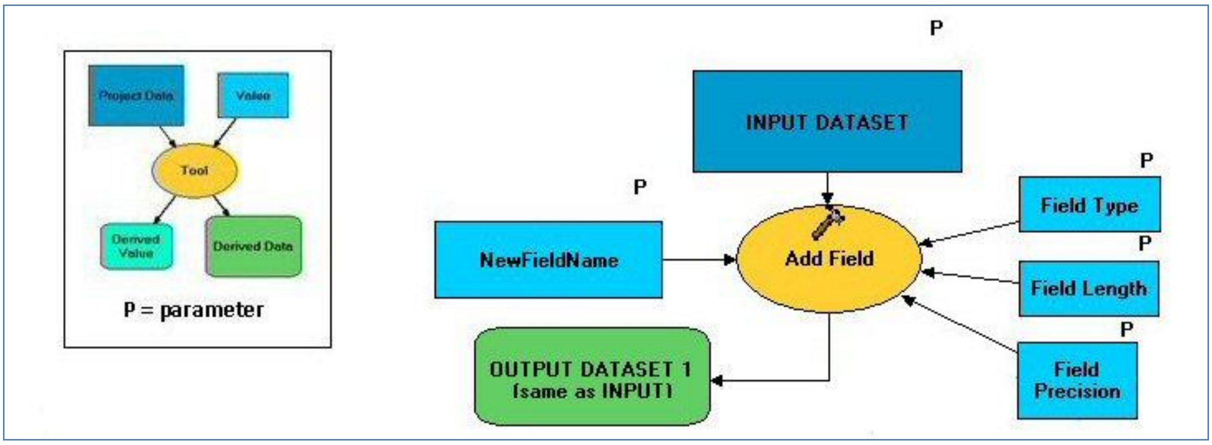
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<INPUT_DATASET>	Dataset to which new field is to be added
<NewFieldName>	Name of the New Field
<Field Type>	Type of the New Field <TEXT | FLOAT | DOUBLE | SHORT | LONG | DATE | BLOB | RASTER>
{Field_Length} (optional)	Length of the New Field
{Field Precision} (optional)	Precision of the New Field

Technical diagram



Tool 09a: Apply IPCC Tropical root_toshoot_ratios

ArcToolbox   Exploring Multiple Benefits toolbox

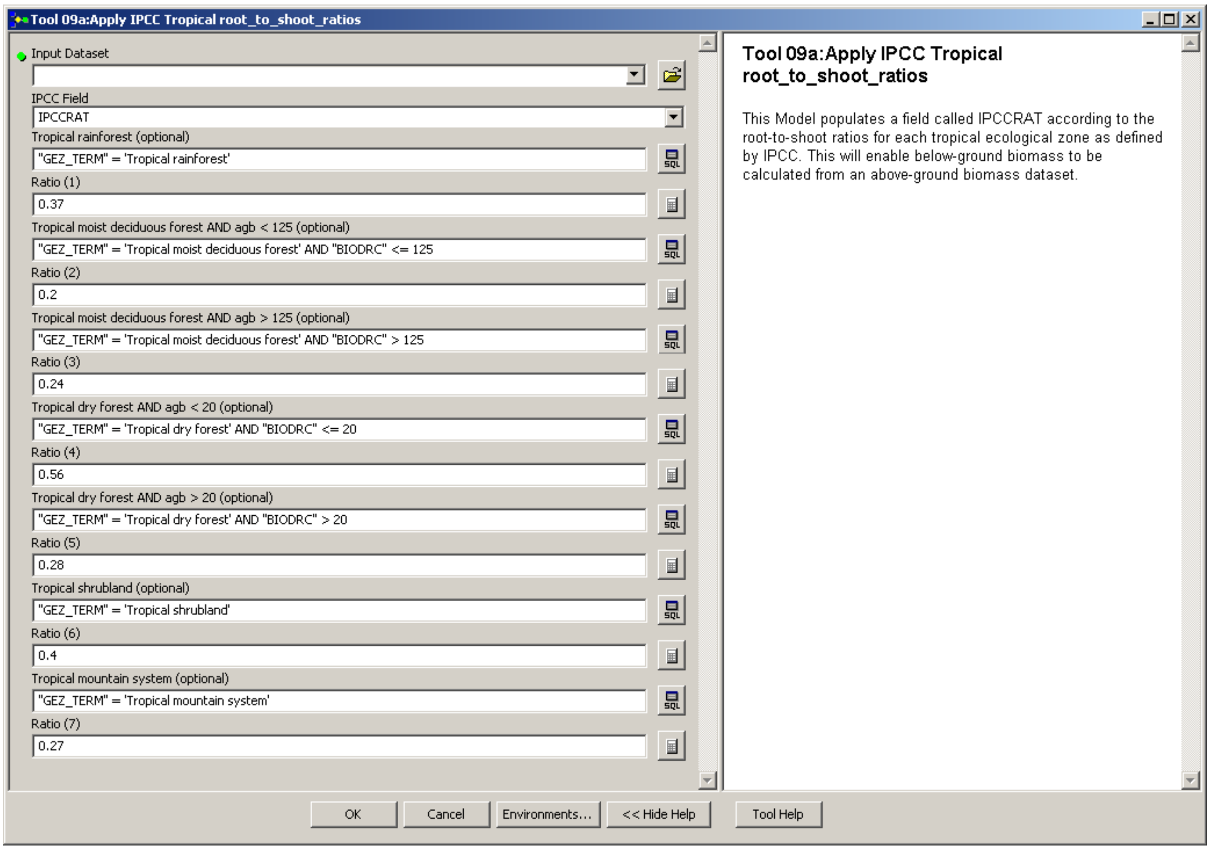
This Model populates a field called IPCCRAT according to the root-to-shoot ratios for each tropical ecological zone as defined by IPCC. This will enable below-ground biomass to be calculated from an above-ground biomass dataset.

Usage Tips Check to see which ecological zones are covered by the study area. Run this tool if the study are is within or partially within the Tropical Zones. Before running this tool it will be necessary to use 'Tool 08' to add the IPCCRAT field.

How to Run the Tool

Double click on the tool ‘Tool 09a: Apply IPCC Tropical root_to_shoot_ratios’

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



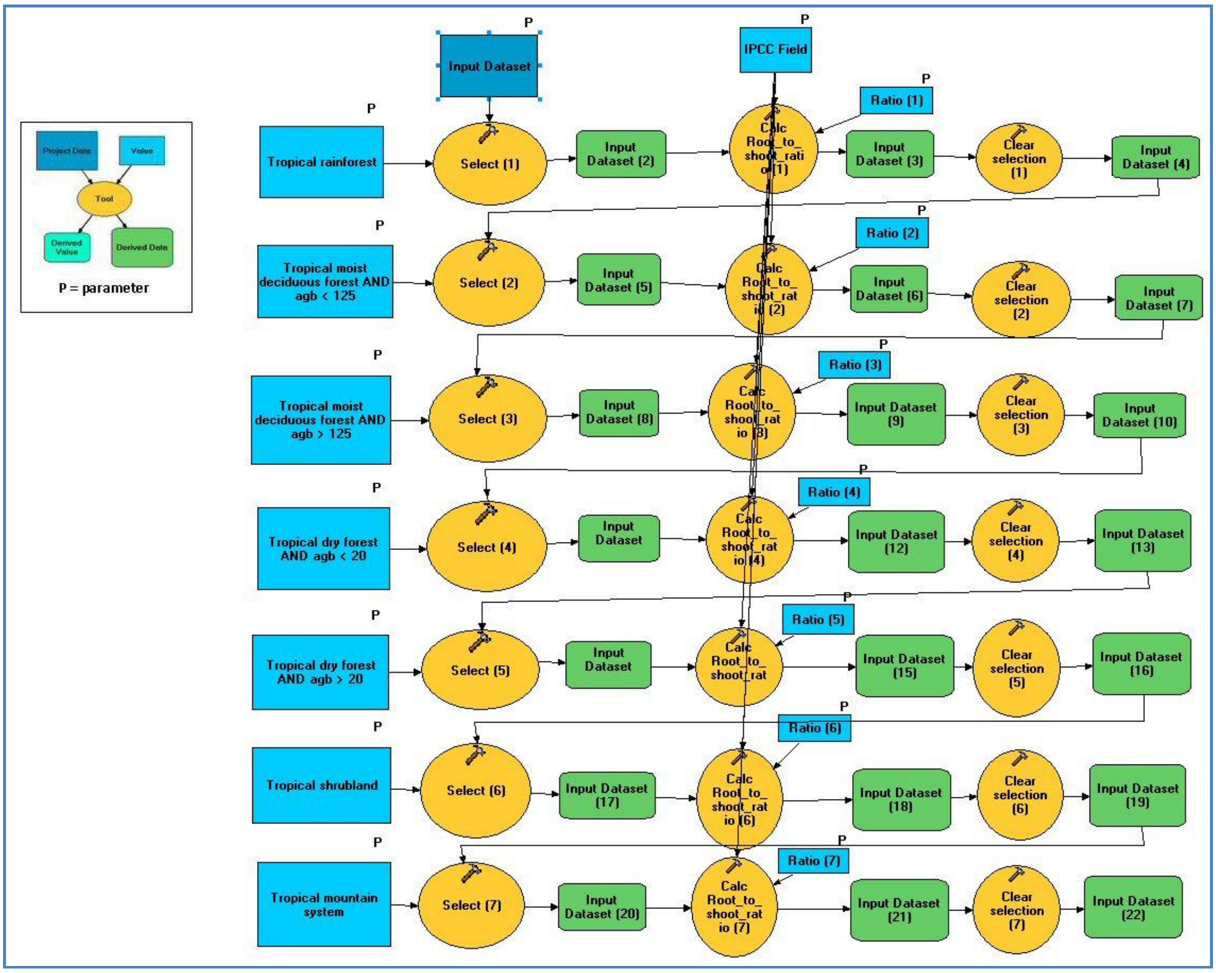
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Dataset>	Dataset containing the blank IPCC Field to be calculated.
<IPCC_Field>	The blank IPCC Field to be calculated.
<Tropical rainforest>	Expression to select' 'Tropical rainforest'
<Ratio_(1)>	Ratio value to be calculated for the above expression.
<Tropical_moist_descidous_forest>	Expression to select ''Tropical moist deciduous forest' AND 'above-ground biomass (AGB) <= 125
<Ratio_(2)>	Ratio value to be calculated for the above expression
Etc...........	

Technical diagram



Tool 09b: Apply IPCC Tropical root_toshoot_ratios

ArcToolbox — Exploring Multiple Benefits toolbox

This Model populates a field called IPCCRAT according to the root-to-shoot ratios for each subtropical ecological zone as defined by IPCC. This will enable below-ground biomass to be calculated from an above-ground biomass dataset.

Usage Tips

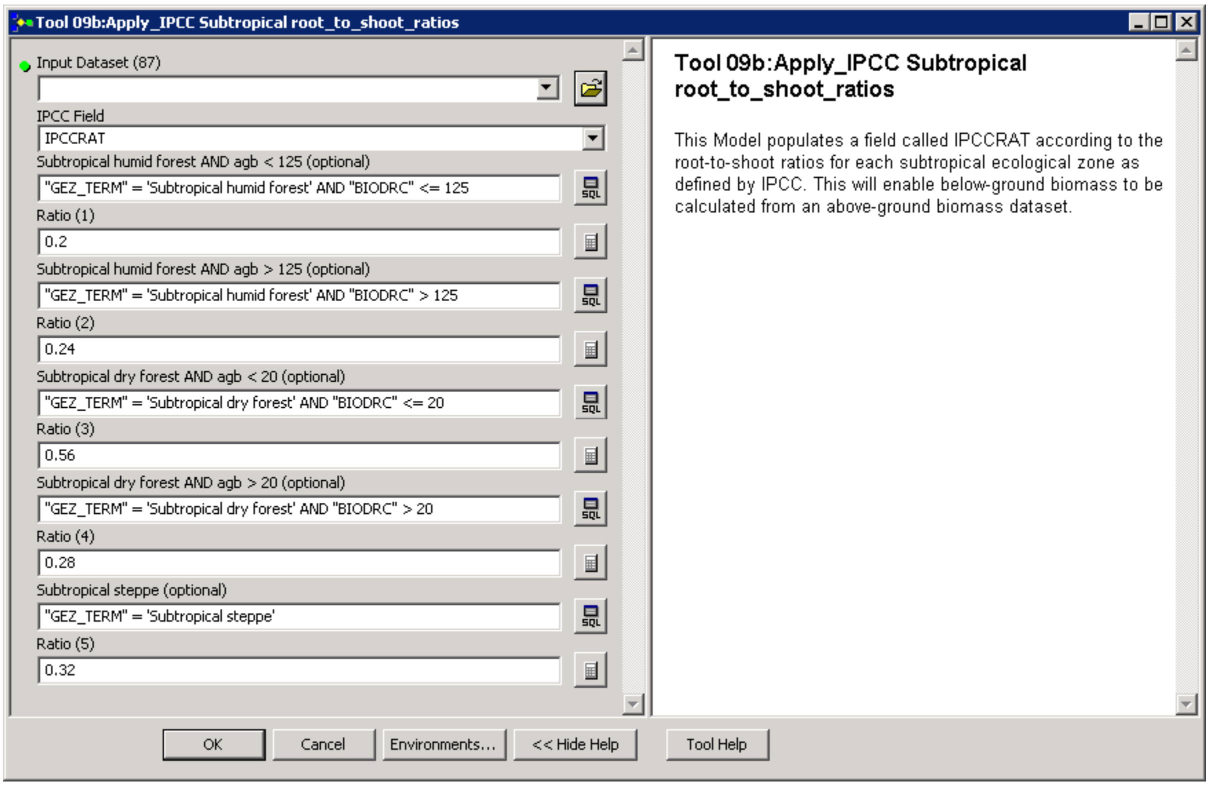
Check to see which ecological zones are covered by the study area. Run this tool if the study are is within or partially within the Subtropical Zones.

Before running this tool it will be necessary to use 'Tool 08' to add the IPCCRAT field.

How to Run the Tool

Double click on the tool 'Tool 09b: Apply IPCC subtropical root_to_shoot_ratios'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



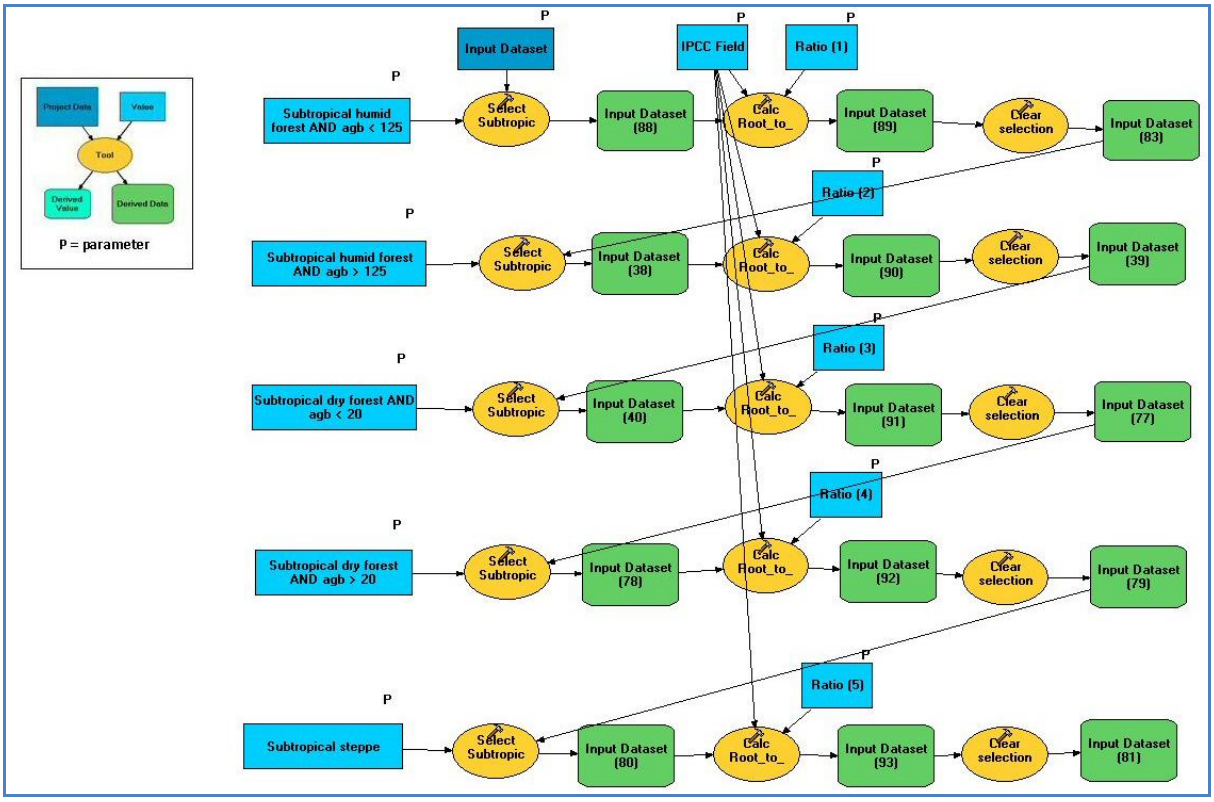
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Dataset>	Dataset containing the blank IPCC Field to be calculated.
<IPCC_Field>	The blank IPCC Field to be calculated.
<Subtropical humid forest AND agb < 125>	Expression to select' 'Subtropical humid forest with above ground biomass < 125 ton/ha.'
<Ratio_(1)>	Ratio value to be calculated for the above expression.
<Subtropical humid forest AND agb >125>	Expression to select ''Tropical moist deciduous forest' AND 'above-ground biomass (AGB) > 125
<Ratio_(2)>	Ratio value to be calculated for the above expression
Etc...........	

Technical diagram



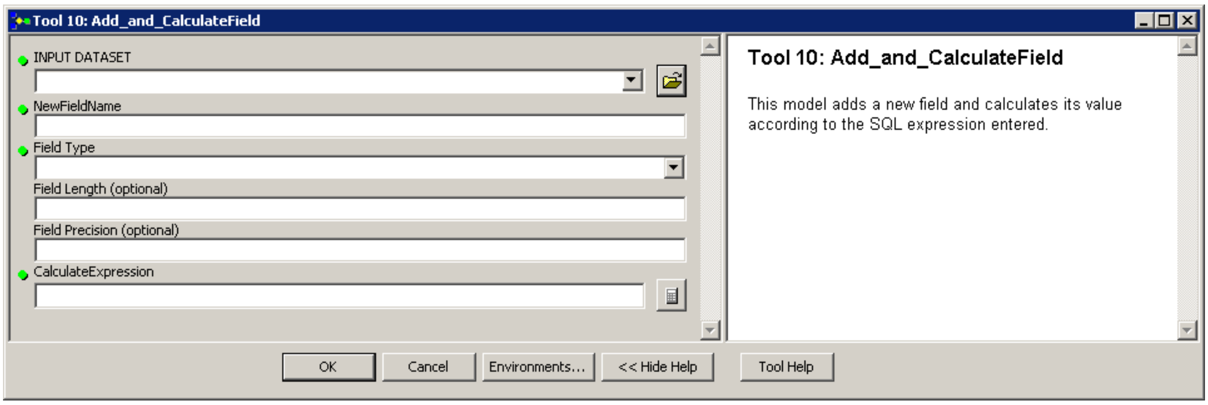
Tool 10: Add_and_CalculateField

This model adds a new field and calculates its value according to the SQL expression entered.

How to Run the Tool

Double click on the tool 'Tool 10: AddFieldAndCalculateField'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



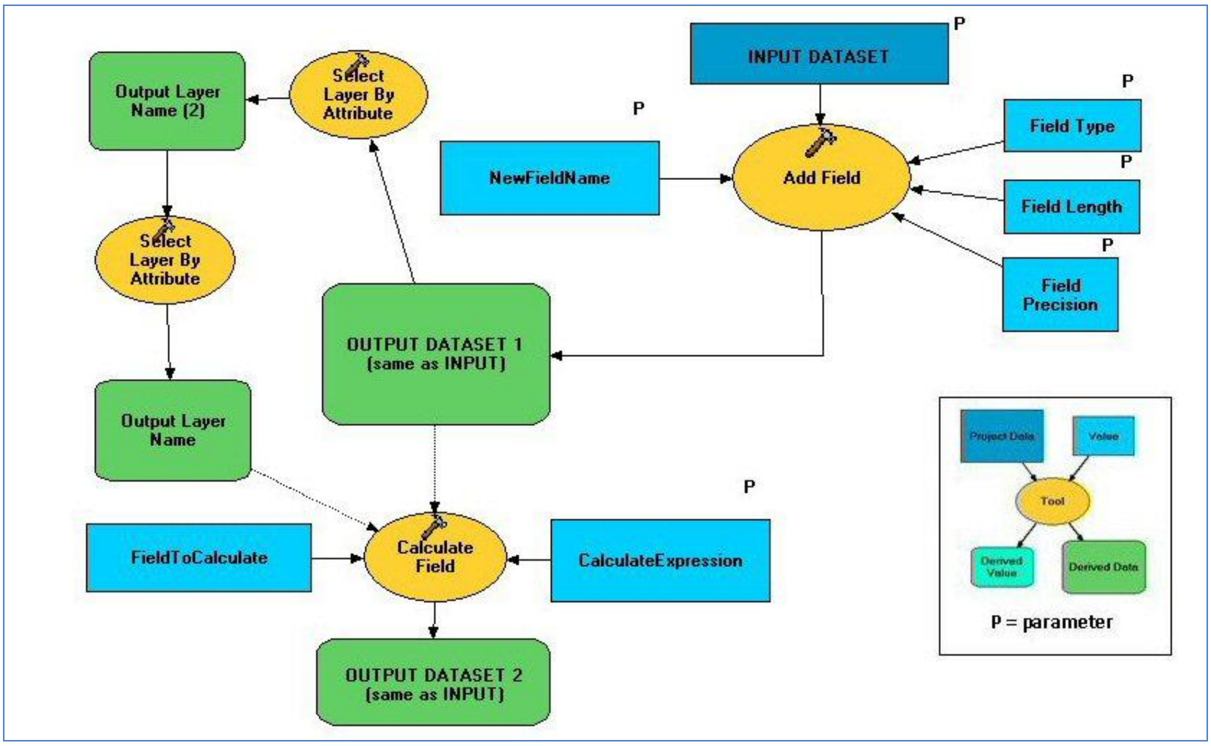
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

<table>
<tr><th>Expression</th><th>Explanation</th></tr>
<tr><td><INPUT_DATASET></td><td>Dataset to which new field is to be added</td></tr>
<tr><td><NewFieldName></td><td>Name of the New Field</td></tr>
<tr><td><Field Type></td><td>Type of the New Field
<TEXT | FLOAT | DOUBLE | SHORT | LONG | DATE | BLOB | RASTER></td></tr>
<tr><td>{Field_Length} (optional)</td><td>Length of the New Field</td></tr>
<tr><td>{Field Precision} (optional)</td><td>Precision of the New Field</td></tr>
<tr><td><CalculateExpression></td><td>The SQL Expression to calculate the field</td></tr>
</table>

Technical diagram



Tool 11: CreateCarbonDensityRasterfromRasterAttribute

ArcToolbox   Exploring Multiple Benefits toolbox

This model will take a raster landcover dataset which contains a Field containing carbon values, and a carbon dataset will be generated from that attribute.

Usage Tips

To ensure the resultant dataset is an integer raster, the field from which the raster will be created must be in the format of long integer or text. If the field is of type 'double', even if the data within that field has no decimal place, it will make the output raster floating point.

To Check the field types within the vector dataset to be converted :

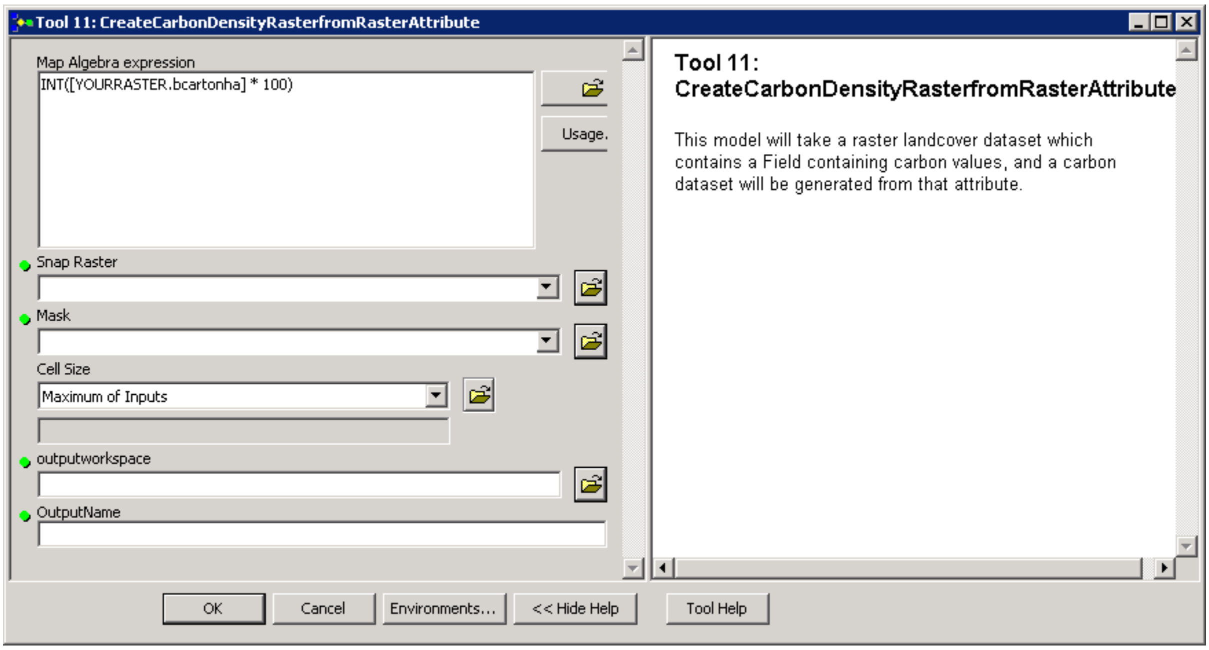
- In ArcMap, Right click on the dataset and click properties
- A window will appear. Click on the fields tab.

Information about the dataset will appear in this window, including the projection information.

How to Run the Tool

Double click on the tool 'Tool 11: CreateCarbonDensityRasterfromRasterAttribute'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



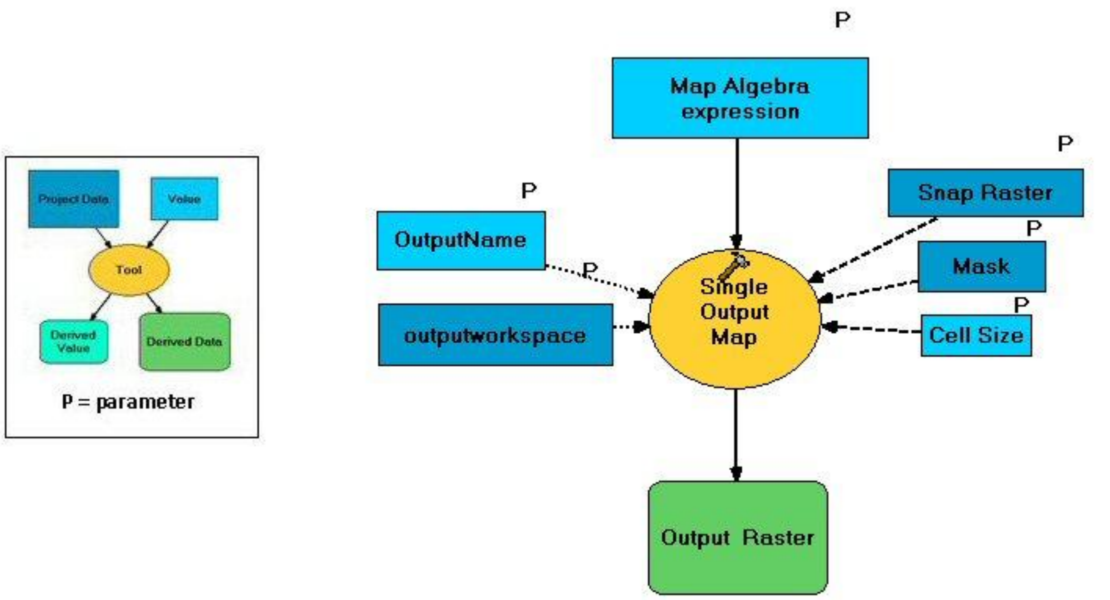
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
Map_Algebra_expression>	The int command converts each cell value of a raster to an integer by truncation so to keep 2 decimal places multiply the raster values by 100. e.g. a value of 2.51 becomes 251 in the output raster In the example, landcov is the name of the raster and bcartonha is the name of the field containing the carbon values.
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



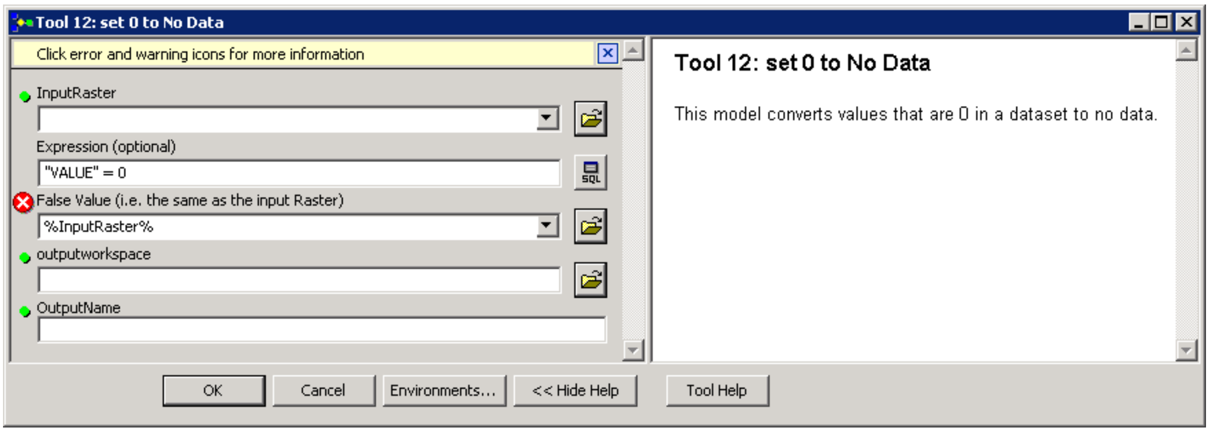
Tool 12: Set 0 to No Data

This model converts values that are 0 in a dataset to no data.

How to Run the Tool

Double click on the tool 'Tool 12: Set 0 to No Data'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



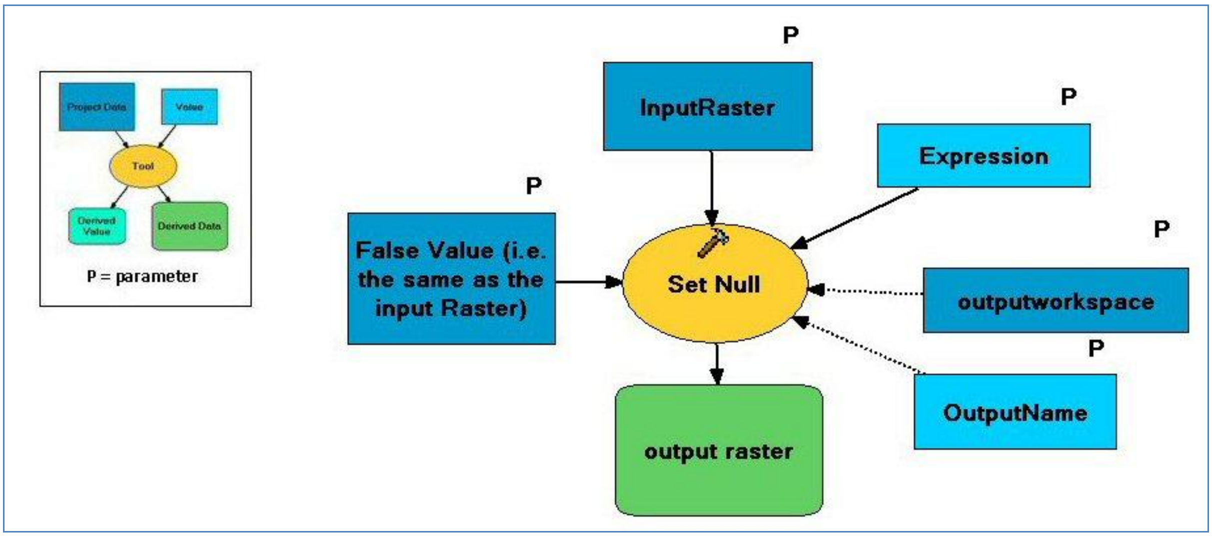
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<InputRaster>	Input Raster dataset containing the 0 values
<Expression>	Select the values to be converted to no data e.g. "Value = 0"
<False Value (i.e. the same as the input Raster)	If the values are not equal to the expression above retain their original values.
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 13: CalculateCarbonAttributesOnly

ArcToolbox

Exploring Multiple Benefits toolbox

This model adds carbon attribute fields to the input carbon dataset for which value is carbon in tonnes/ha * 100. The model adds and calulates fields for carbon in tonnes/ha and carbon stock in tonnes.

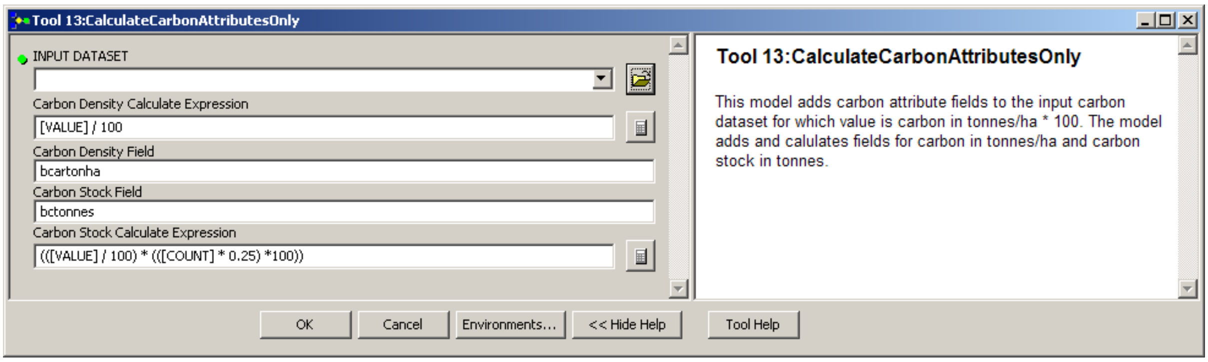
Usage Tips

Remember to change the value in the 'Carbon Stock Calculate expression' as it uses the Count * the area in square kilometres. The illustration is for a 0.5km resolution dataset so the count is multiplied by 0.25

How to Run the Tool

Double click on the tool 'Tool 12:CalculateCarbonAttributesOnly'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



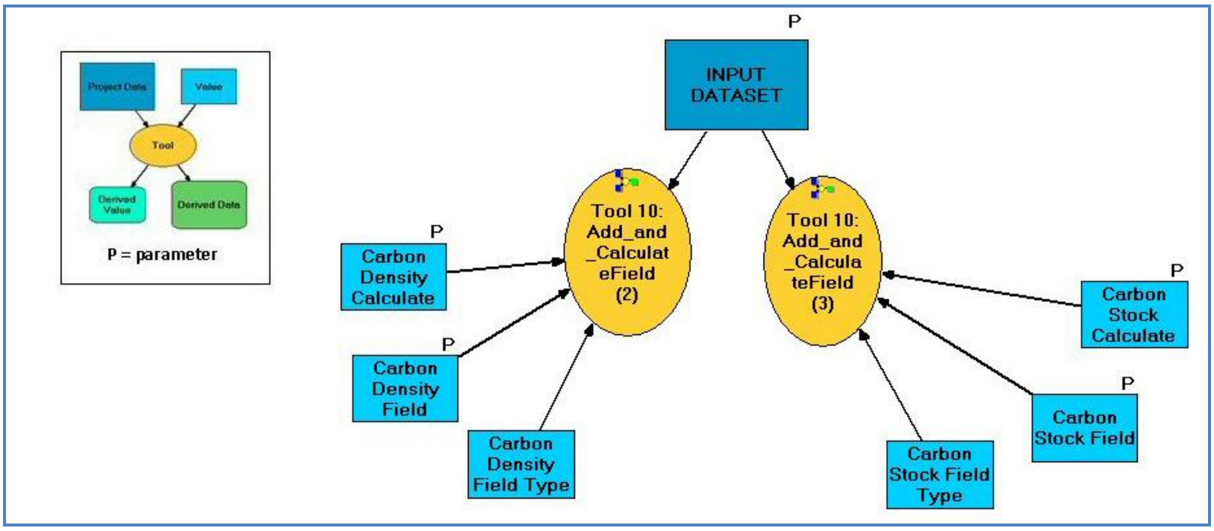
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<INPUT_DATASET>	Dataset to which new field is to be added
<Carbon Density Calculate Expression>	The SQL Expression to calculate the carbon density field e.g. [VALUE] / 100
<Carbon_Density_Field>	New field to contain carbon density values
<Carbon_Stock_Field>	New field to contain carbon stock values
<Carbon_Stock_Calculate_ Expression>	Calculates the carbon stock (the amount of carbon in grid cells of that value by multiplying the amount of carbon in tonnes/ha by the area. e.g. for a raster of 500m cell size carbon stock = (([VALUE] / 100) * (([COUNT] * 0.25) *100))

Technical diagram



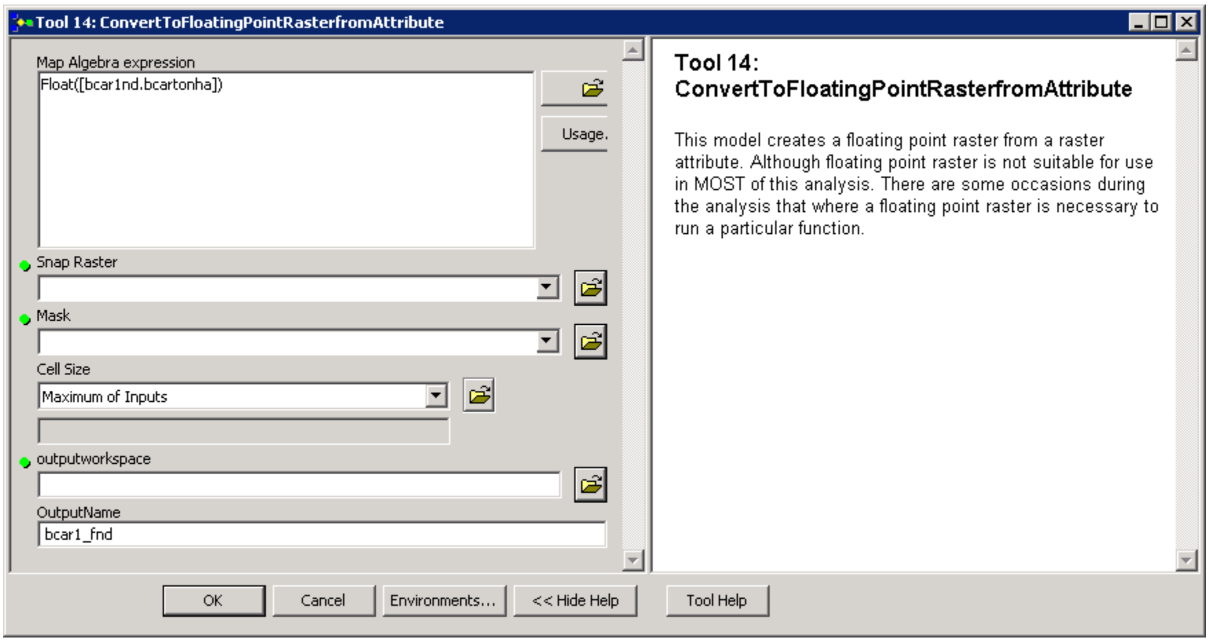
Tool 14: ConvertToFloatingPointRasterFromAttribute

This model creates a floating point raster from a raster attribute. Although floating point raster is not suitable for use in MOST of this analysis. There are some occasions during the analysis that where a floating point raster is necessary to run a particular function.

How to Run the Tool

Double click on the tool ‘Tool 14: ConvertToFloatingPointRasterFromAttributer’

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



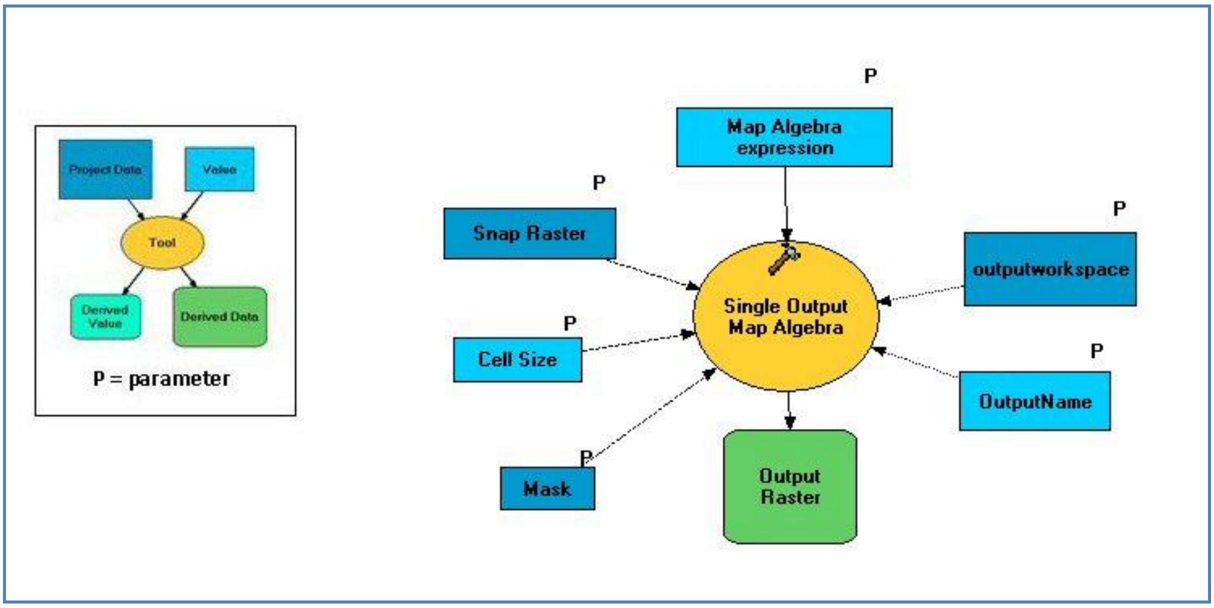
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Map_Algebra_expression>	Example syntax: Float([yourraster.yourattribute]) The float command converts each cell value of a raster to a floating point raster and keeping all decimal places. The resulting raster does not have an attribute table.
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 15: Focal Function to fill missing values

This model will allow users to use the Focal functions (e.g. Focal mean or focal majority) within ArcGIS to fill cells with missing values with either their average nearest neighbour in a specified neighbourhood or their majority nearest neighbour e. g. in a 5 by 5 rectangle surrounding the cell.

Usage Tips

Choosing the Focal Mean or Focal majority functions will depend upon the missing values to be filled. If the values are quantitative with lots of decimal it is likely that a focal mean is required whereas if the data are thematic a focal majority would be used.

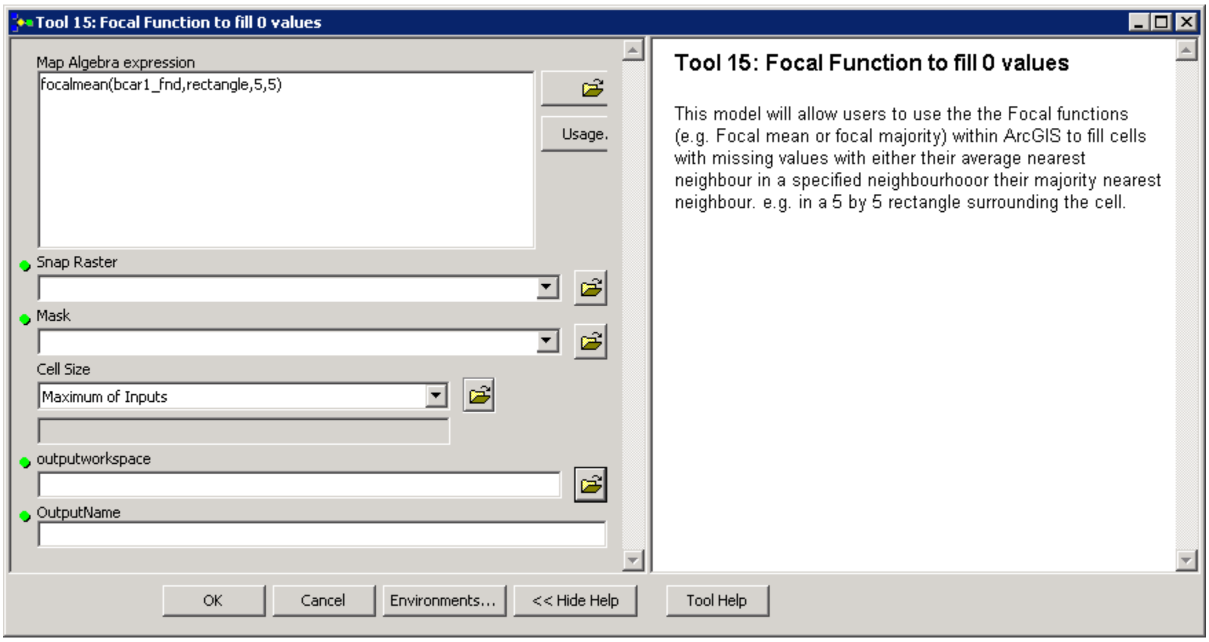
Note: the focal functions require the data to be a floating point grid and the missing values to be no data rather than 0, therefore the following tools may need to be run prior to running this tool :
Tool 12: set 0 to No Data and Tool 14: ConvertToFloatingPointRasterfromAttribute

BEWARE**:** When running these commands ArcGIS not only changes the missing values but alters the other values too. It is therefore necessary to run Tool 16:MergeFocalFunctionValusintoNoDataAreas to merge only the filled values back into the original raster after running this tool

How to Run the Tool

Double click on the tool ‘Tool 15: Focal Function to fill missing values’

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



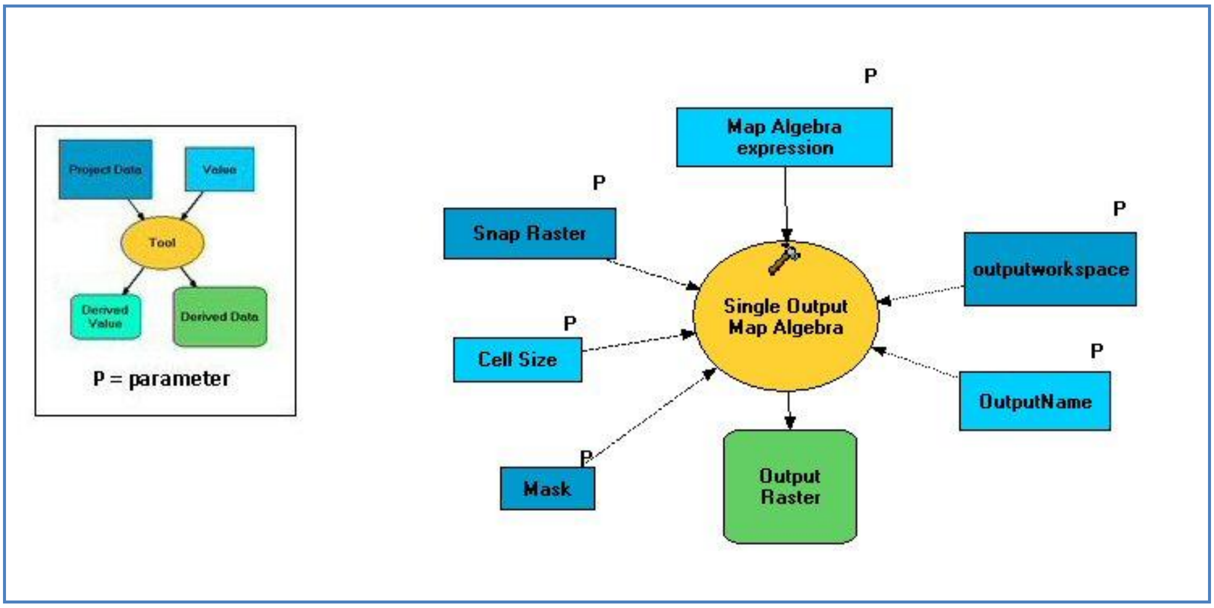
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Map_Algebra_Expression>	The focal function to fill the missing cell values e.g. to fill cells with a missing value looking in a neighbourhood of 5 by 5 cells the map Algebra expression will be a focal mean or focal majority e.g. focalmean(bcar1_fnd, rectangle,5,5).
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 16: MergeFocalMeanIntoNoDataAreas

ArcToolbox Exploring Multiple Benefits toolbox

This model will merge a number of raster datasets together in order of priority. The order of input determines the priority of the raster, with the last raster listed having the lowest priority.

Usage Tips

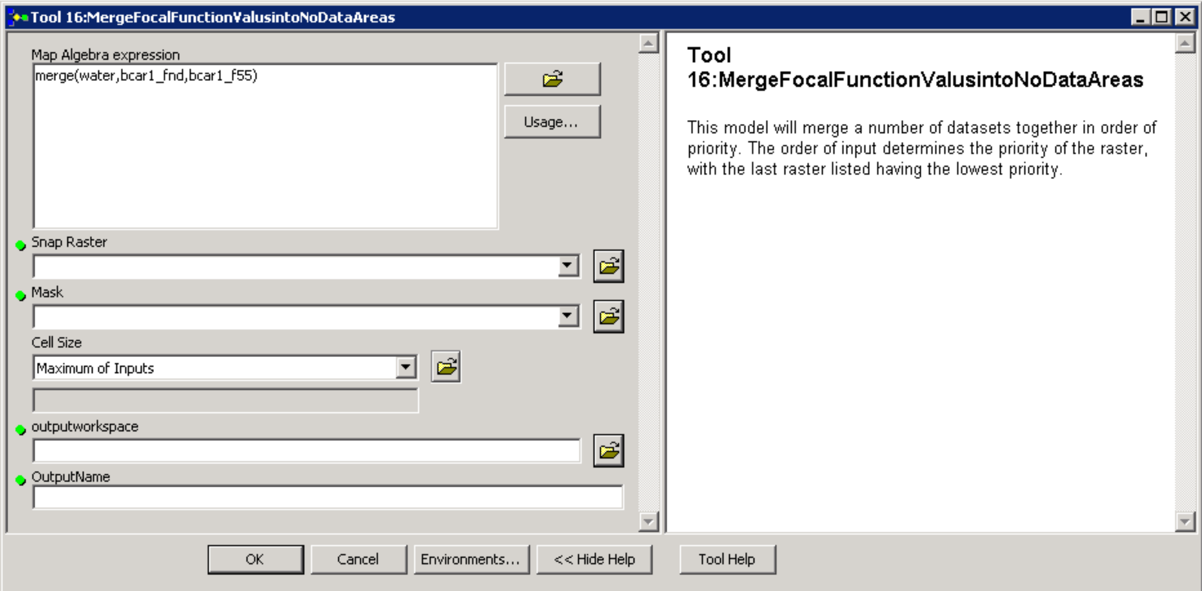
This model should be used after running 'Tool 15: Focal Function to fill missing values'. This is to ensure that the original values in the raster dataset remains unaltered and only those missing values that have been filled by the focal function are used.

Note: The raster dataset that is listed first in the merge command takes precedence where there are data values. Where there are nodata values the values in next raster's values will be incorporated.

How to Run the Tool

Double click on the tool 'Tool 15: Focal Function to fill missing values'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



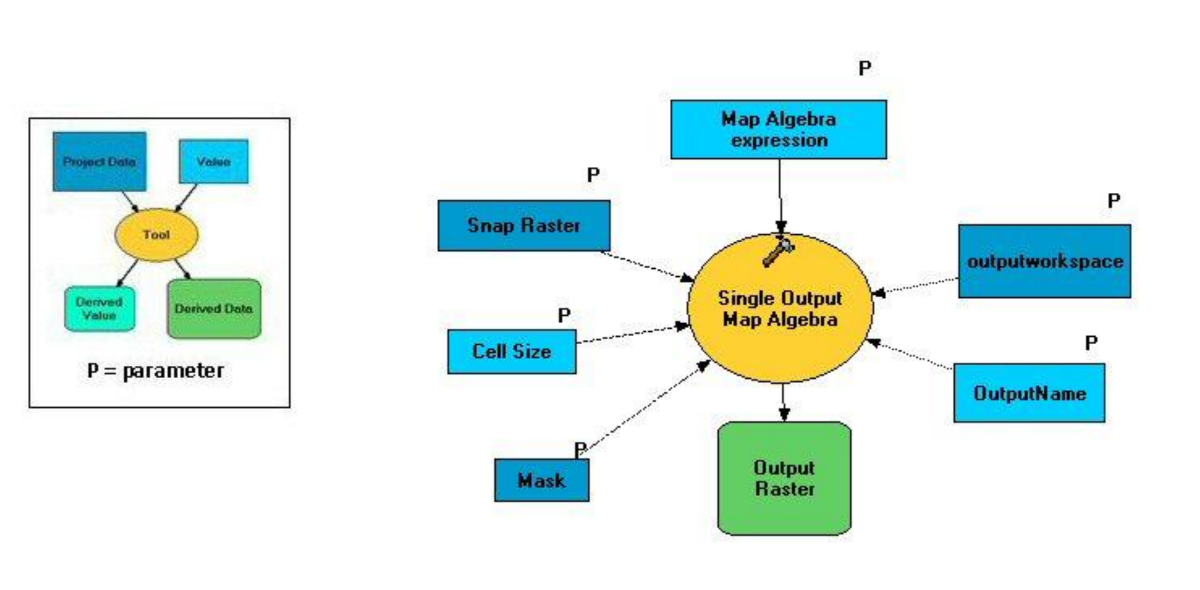
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Map_Algebra_Expression>	The merge function that will merge the datasets together in order of priority.
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 17: ConvertFloatingPointToIntegerRaster

A Floating point raster is not suitable for use in this analysis; however, some datasets are floating points (because they need decimal places e.g. a population density raster). This means for use in this analysis they need to be converted from a floating point into an integer raster. This model will multiply the values in the floating point raster by a factor of 10 to keep 1 decimal place, 100 for 2 decimal places, 100 for 3 decimal places and so on.

Usage Tips

To Check whether a raster is floating point or integer:

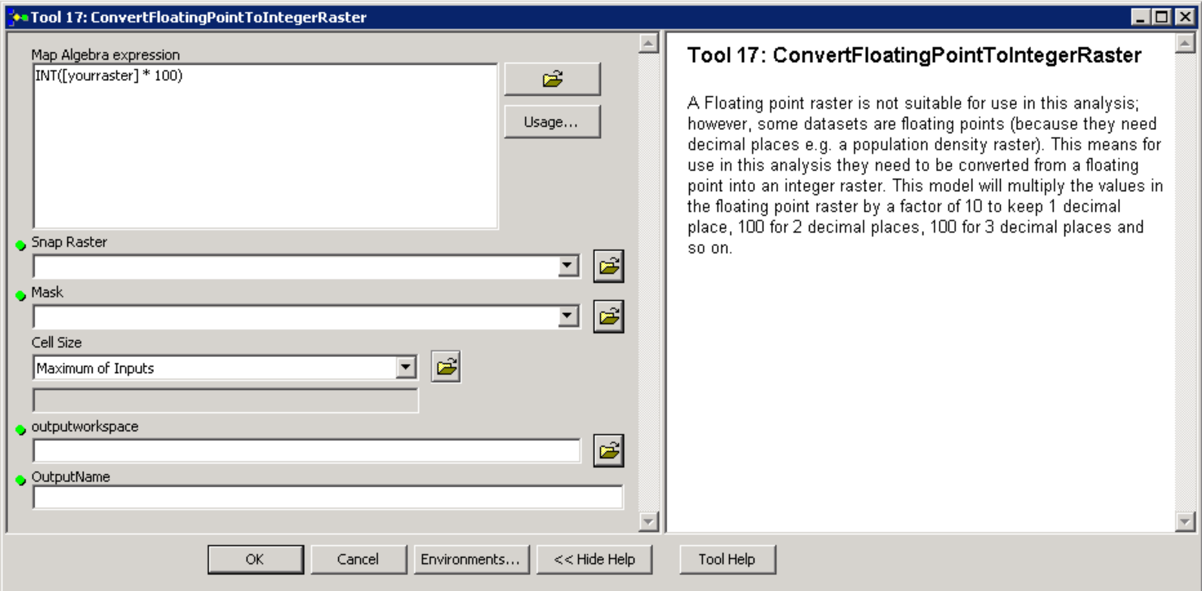
- In ArcMap, Right click on the raster dataset and click properties
- A window will appear. Click on the source tab.

Information about the raster will appear in this window, including the Source Type, Pixel Type and Pixel Depth. This will tells you whether the dataset is a floating point or integer raster.

How to Run the Tool

Double click on the tool ‘Tool 17: ConvertFloatingPointToIntegerRaster’

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



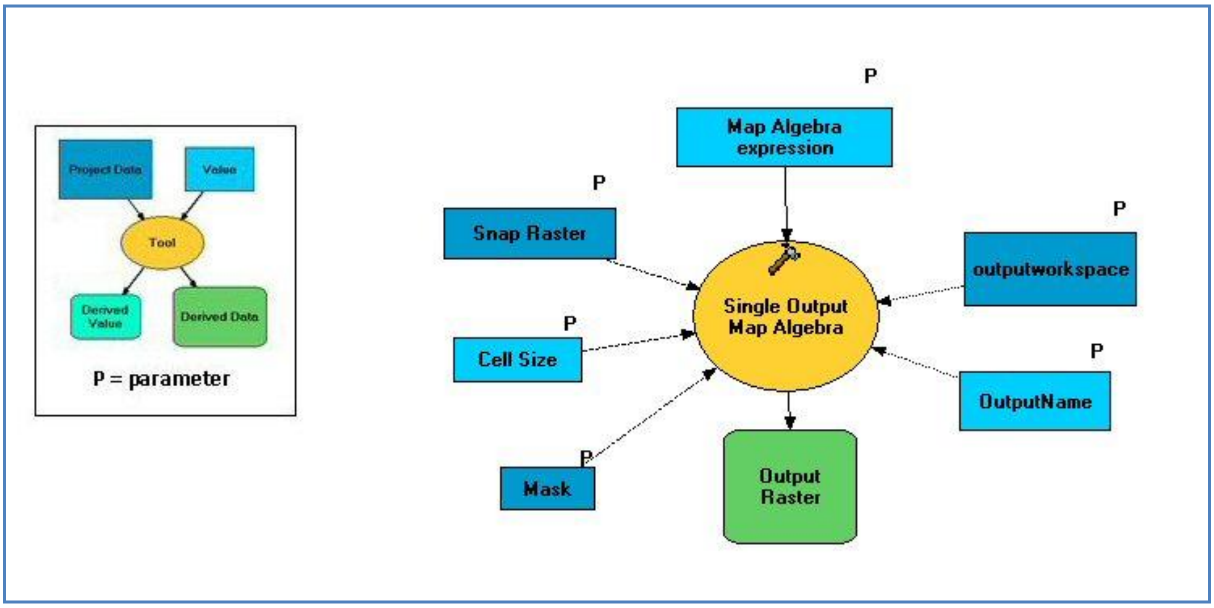
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Map_Algebra_expression>	Example syntax: INT([yourraster] * 100) The int command converts each cell value of a raster to an integer by truncation so to keep 2 decimal places multiply the raster values by 100. e.g. a value of 2.51 becomes 251 in the output raster
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



Tool 18:CalculateCarbonAndAreaAttributes

ArcToolbox Exploring Multiple Benefits toolbox

This model adds carbon attribute fields to the input carbon dataset for which value is carbon in tonnes/ha * 100. The model adds and calculates an area field in km2, an area field in ha, carbon in ton/ha and carbon stock in tonnes.

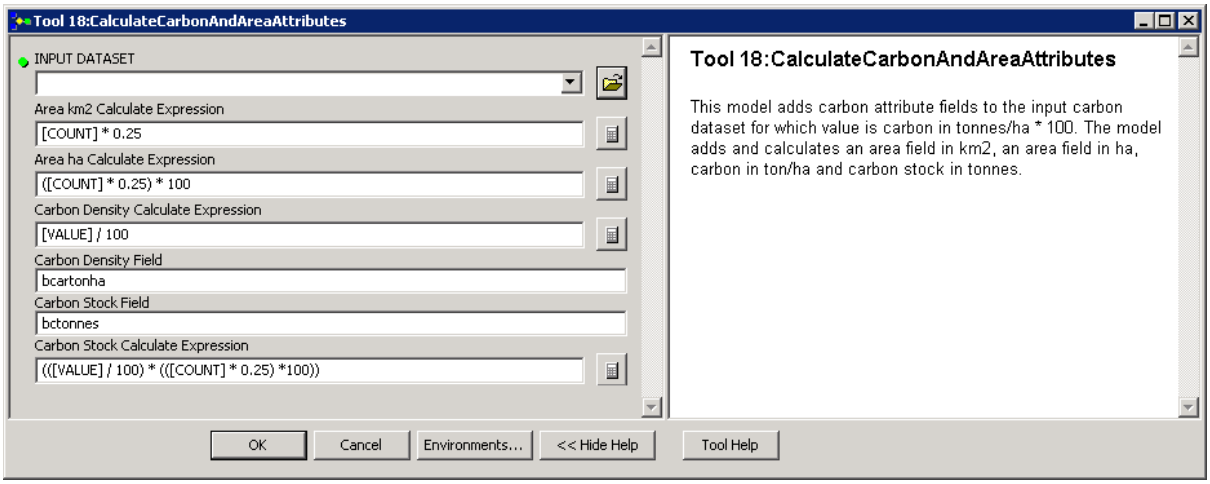
Usage Tips

Remember to change the value in the Area km2, Area ha, and Carbon Stock Calculate expression fields as they use the Count Field to calculate the area based o the cell size. The illustration is for a 0.5km resolution dataset so the count is multiplied by 0.25

How to Run the Tool

Double click on the tool 'Tool 18:CalculateCarbonAndAreaAttributes'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



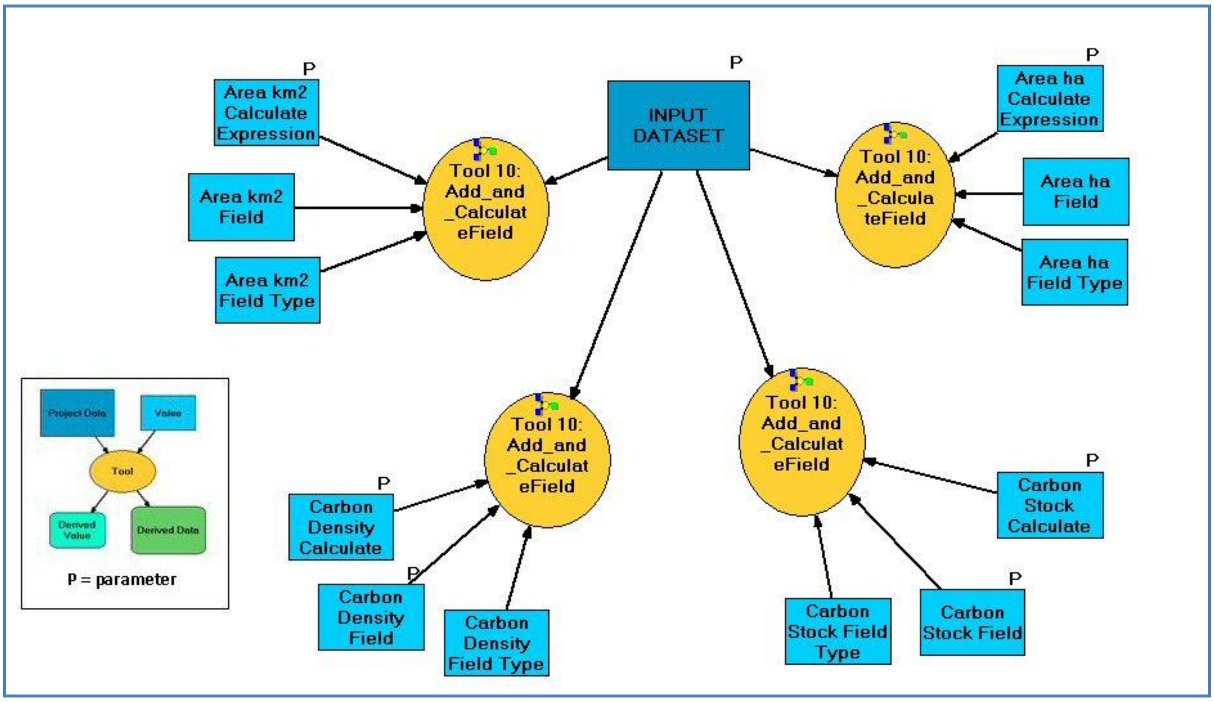
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<INPUT_DATASET>	Dataset to which new field is to be added
<Area km2 Calculate Expression>	Calculates the area_km2 field based on the count and cell size. For a raster dataset with cell size of 500, the area in km = [COUNT] * 0.25
<Area ha Calculate Expression>	Calculates the area_ha field based on the count and cell size. For a raster dataset with a cell size of 500, the area in ha = ([COUNT] * 0.25) * 100
<Carbon Density Calculate Expression>	The SQL Expression to calculate the carbon density field e.g. [VALUE] / 100
<Carbon Density Field>	Field to contain the carbon density values.
<Carbon Stock Field>	Field to contain the carbon stock values
<Carbon Stock Calculate Expression>	Calculates the carbon stock (the amount of carbon in grid cells of that value by multiplying the amount of carbon in tonnes/ha by the area. e.g. for a raster of 500m cell size carbon stock = (([VALUE] / 100) * (([COUNT] * 0.25) *100))

Technical diagram



Tool 19: DefineClassBreaksByCarbonStock

ArcToolbox Exploring Multiple Benefits toolbox

This model defines class breaks for a carbon dataset based on the carbon stock (in tonnes) rather than by area covered by a particular carbon density class. ArcGIS cannot do this automatically. The model adds and calculates fields called cumstk (cumulative stock) and stkprop (stock proportion) to the carbon dataset. The stkprop field ranges from 0 - 100 so therefore to display the carbon using the carbon density field in tonnes/ha the 5 classes breaks would be at 20, 40, 60, 80 and 100.

Usage Tips

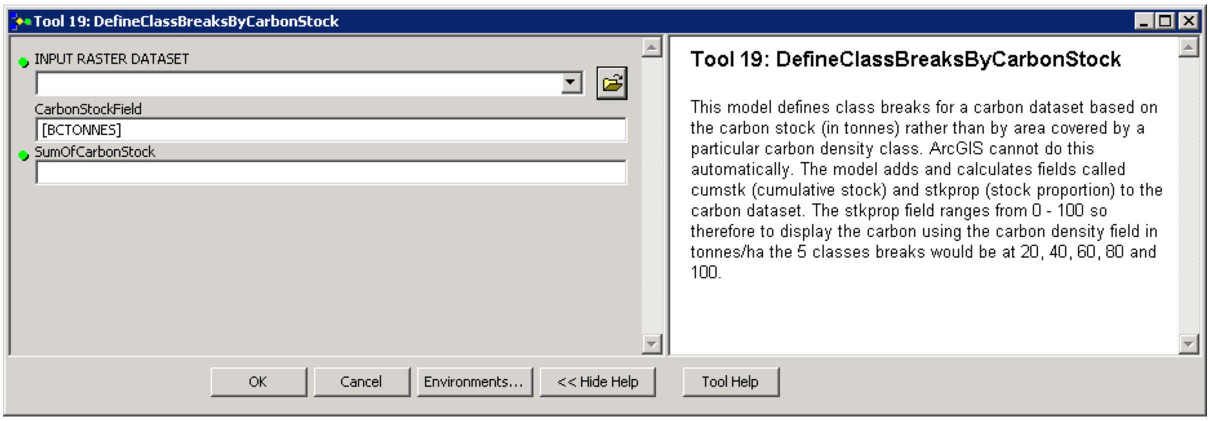
BEFORE running the tool, obtain sumofcarbonstock by:

- In ArcMap, Open the carbon attribute table. Make sure no records are selected.
- Right click on the bctonnes field
- Click Statistics
- In the Statistics window highlight the value for Sum
- Right Click and Copy
- Right Click and paste the value in SumOfCarbonStock

How to Run the Tool

Double click on the tool 'Tool 19: DefineClassBreaksByCarbonStock'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



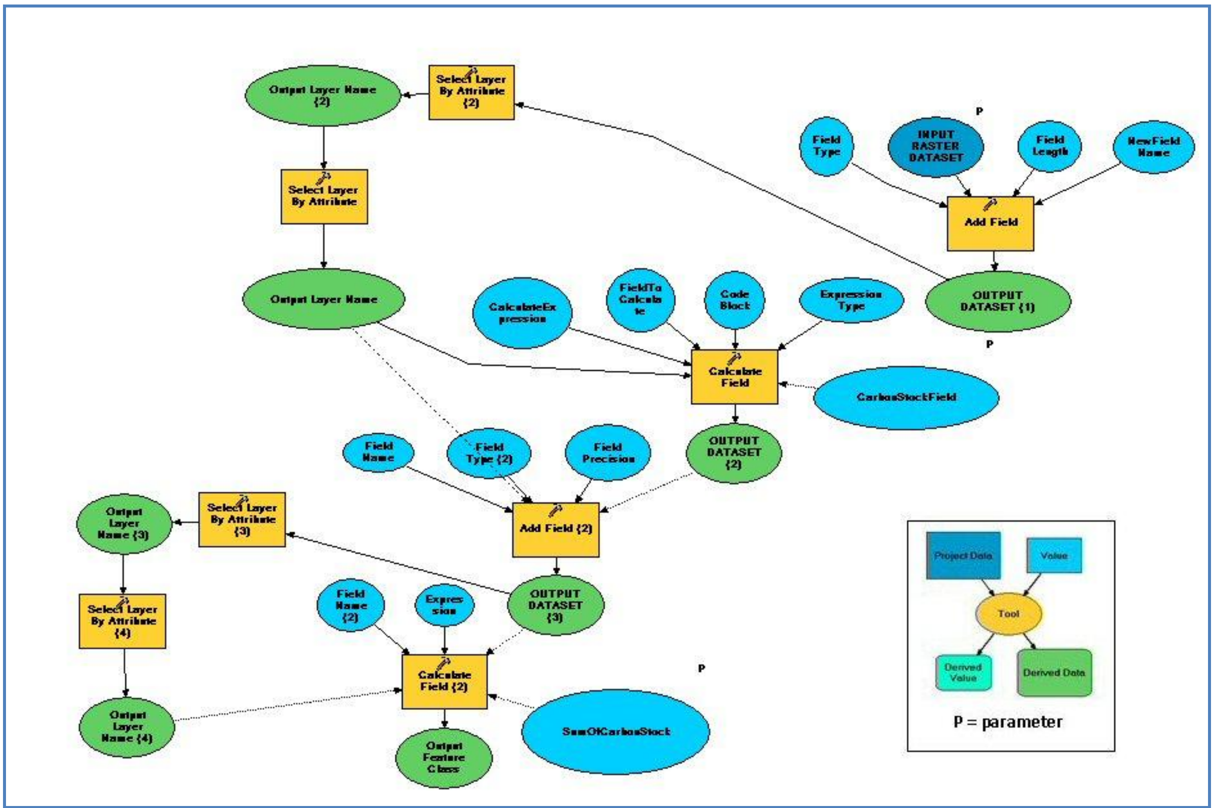
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<INPUT_RASTER_DATASET>	Input carbon density Raster
<CarbonStockField>	Field containing the Carbon Stock in tonnes
<SumOfCarbonStock>	Carbon Stock for whole dataset (in tonnes). See Usage Tip.

Technical diagram



Tool 20: Add biomass and soil carbon to create combined carbon

ArcToolbox   Exploring Multiple Benefits toolbox

This model adds the values of two raster datasets on a cell-by-cell basis.

Usage Tips

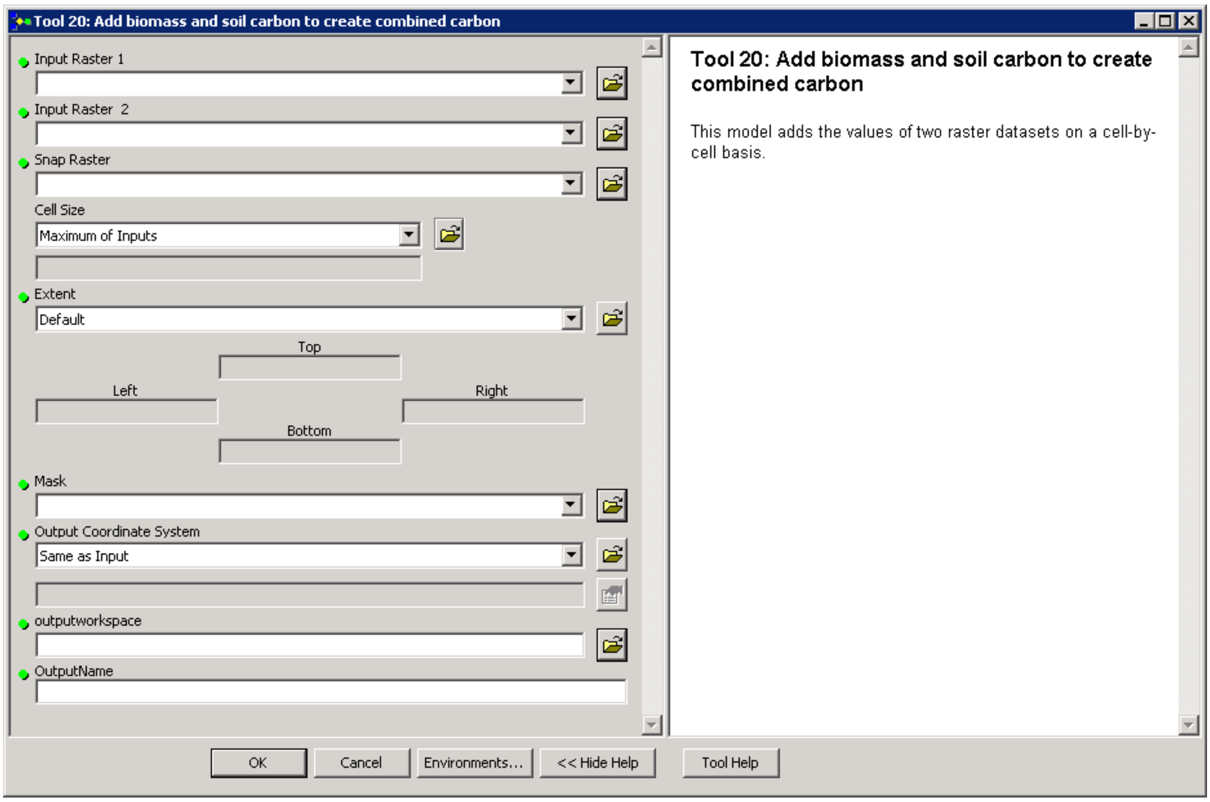
The model will only add the contents of the VALUE fields, it will ignore any further attributes.
Before running the tool make sure that the units in the two datasets are the same.

When adding the biomass carbon and soil carbon, the units will be in tonnes/ha * 100 if the methods within this manual are being followed. Hence, after running this tool it will be necessary to run ‘Tool 18:CalculateCarbonAndAreaAttributes’

How to Run the Tool

Double click on the tool 'Tool 20: Add biomass and soil carbon to create combined carbon'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



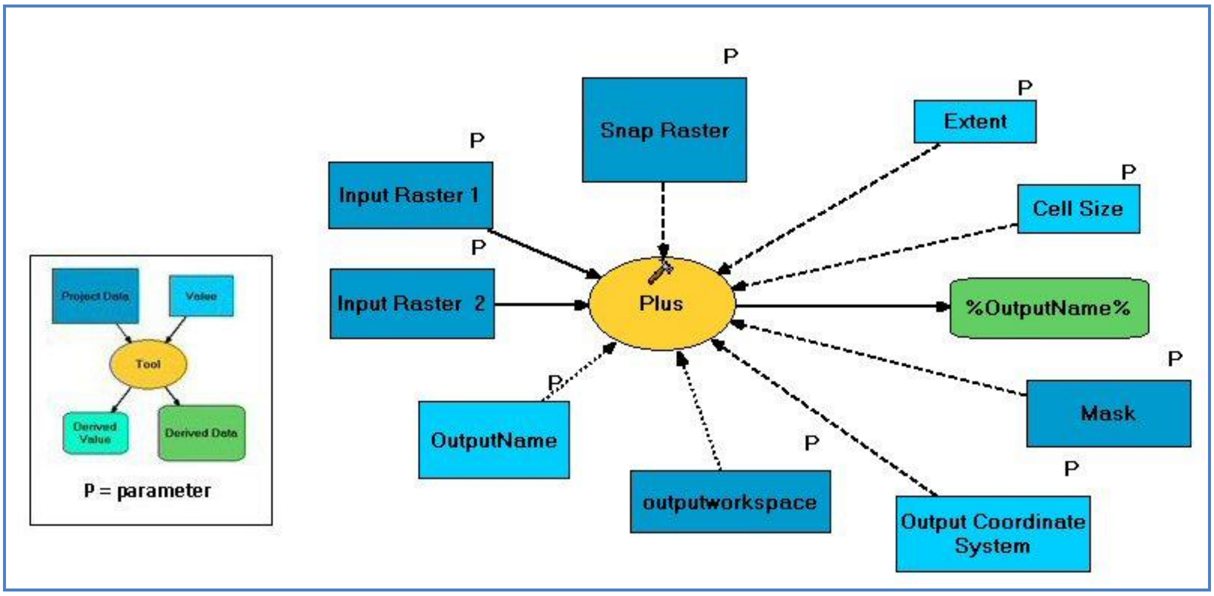
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Raster_1>	Input Raster 1
<Input_Raster_2>	Input Raster 2
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<Extent>	Set the extent to be the same as the Mask_Raster
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
Output_Coordinate_System	Coordinate system of the output Raster dataset (this will be the same as the Snap Raster).
<outputworkspace>	Workspace in which to save the output Raster
<OutputName>	Name of the new output raster dataset

Technical diagram



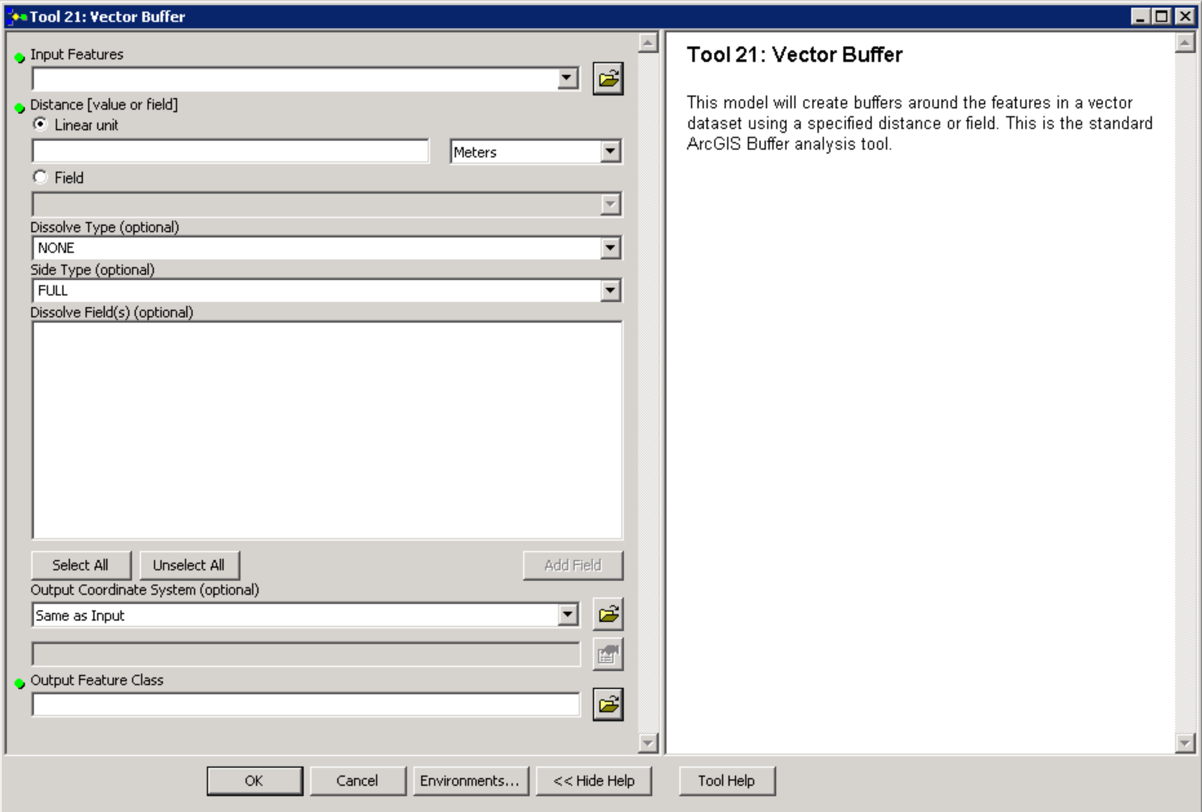
Tool 21: Vector Buffer

This model will create buffers around the features in a vector dataset using a specified distance or field. This is the standard ArcGIS Buffer analysis tool.

How to Run the Tool

Double click on the tool 'Tool 21: Vector Buffer'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



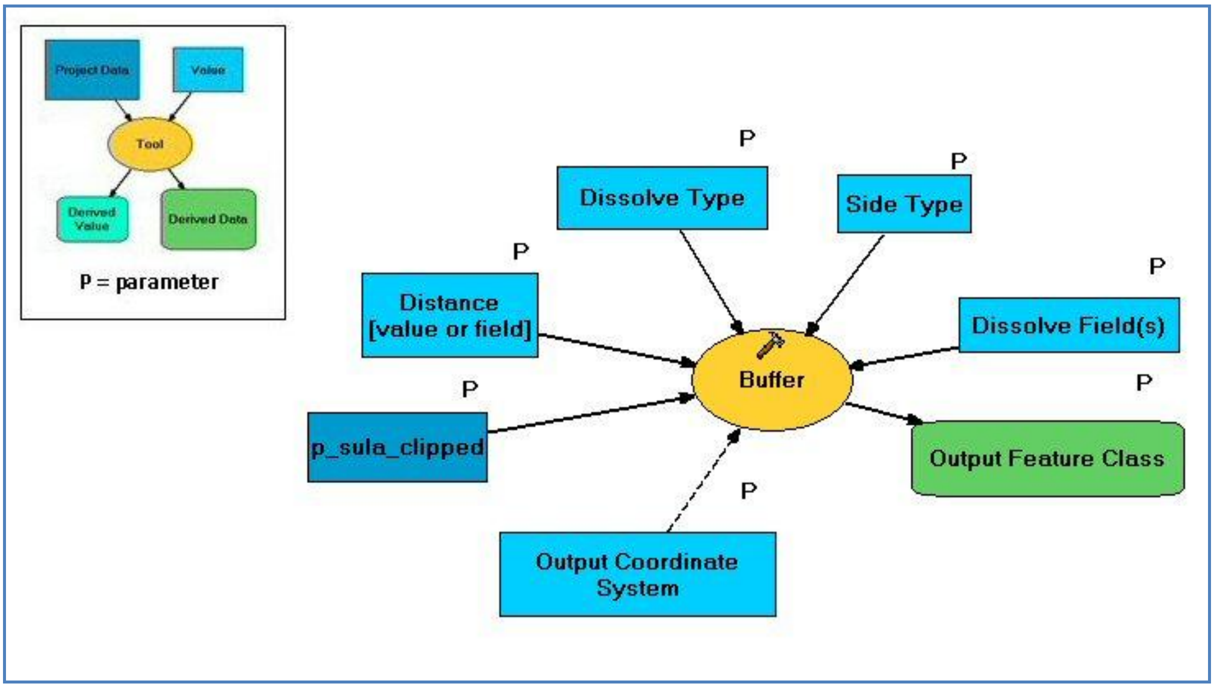
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Features>	The feature layer or feature class to be buffered.
<distance_value_or_field>	Distance value and unit or Field containing distance value.
<Side type>	Options to buffer to one side of a line or outside polygons: FULL—A buffer will be generated on both sides of the line. If the input is a polygon, the result will include the area inside the polygon. This is the default. LEFT—The buffer will be generated on the LEFT side of the line. RIGHT—The buffer will be generated on the RIGHT side of the line. OUTSIDE_ONLY—The area inside the input polygon features will be excluded from the resulting buffer.
<Dissolve_Type>}	Specifies whether a dissolve will be performed to remove buffer feature overlap. NONE—Individual buffer for each feature is maintained, regardless of overlap. This is the default. ALL—Dissolves all the buffers together into a single feature and removes any overlap. LIST—Dissolves by a given list of fields.
<Dissolve_Fields>	List of field(s) for the dissolve. Buffer polygons that share the same set of values in their Dissolve Field(s) will be dissolved together. The Add Field button, which is used only in ModelBuilder, allows you to add expected fields so you can complete the dialog box and continue to build your model.
Output_Coordinate_System	Coordinate system of the output dataset.
<Output Feature Class>	Location and name of the new output buffered dataset

Technical diagram



Tool 22: Raster Buffer

ArcToolbox — Exploring Multiple Benefits toolbox

This model will create buffers around the features in a raster dataset.

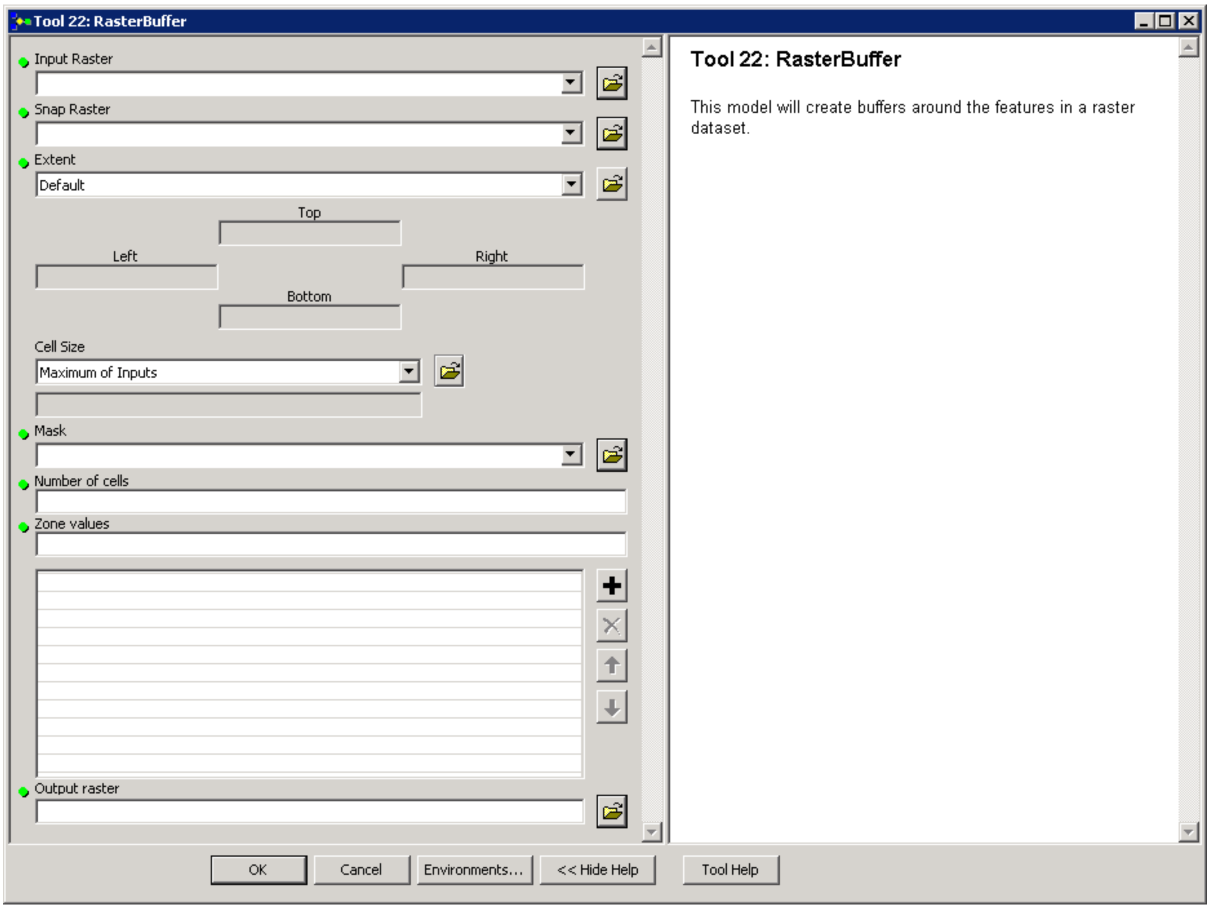
Usage Tips

The model will expand specified cell values by a specified number of cells. The dataset should contain just those values to be expanded and the values in that dataset should be all the same e.g. all values equal to one.

How to Run the Tool

Double click on the tool 'Tool 22: Raster Buffer'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



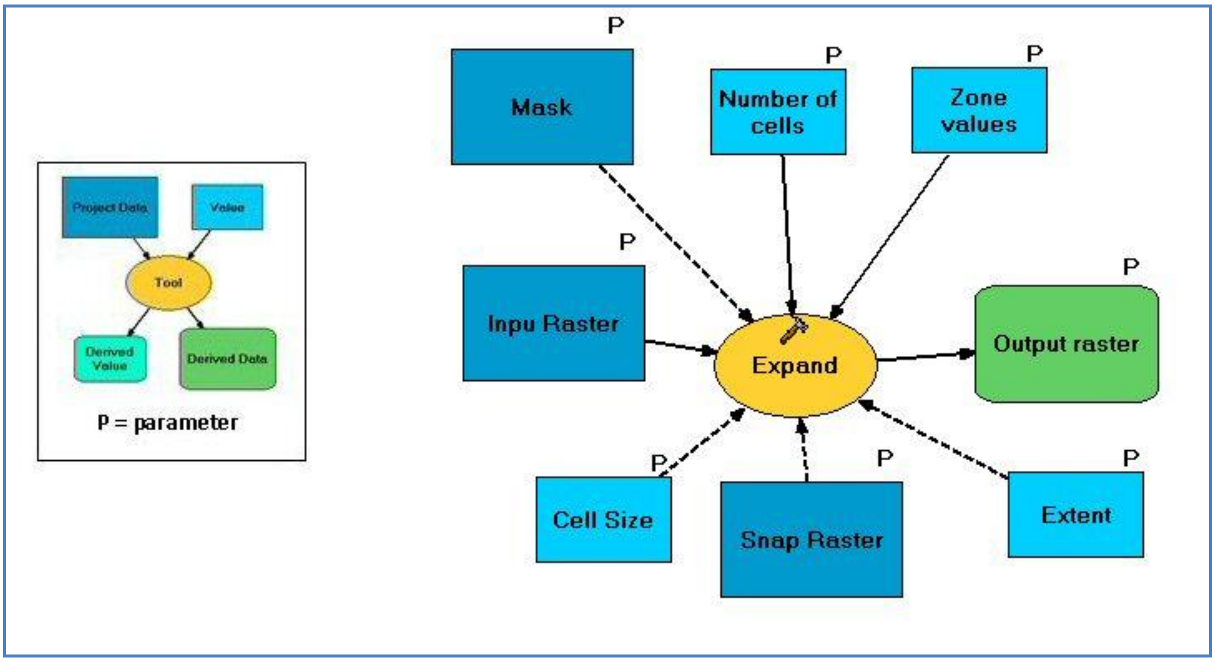
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Raster>	Input Raster to be buffered
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Extent>	Set the extent to be the same as the Mask_Raster
<Cell_Size>	Specify the output cell size to be used for the analysis (this will be the same as the Snap Raster).
<Mask>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Number_of_ cells>	The number of cells to expand each specified zone by.
<Zone_values>	The list of zone values to expand. E.g. the list of cell values to expand.
<Output_raster>	Name and location of the new buffered raster

Technical diagram



Tool 23: SubsetDatasetForMatrix Legend

There is no easy way to generate a matrix legend based on two themes in ArcGIS. This model helps the user to subset a raster dataset ready for display with a matrix style legend.

Usage Tips

Chose two themes to map. EXAMPLE: Amphibian Species Richness and Carbon.

<u>Before running this model the following manual steps are required</u> to prepare the dataset:

- The data need to be grouped into classes. Decide on how many groups (classes) you want. In this case the carbon data will be classified into 6 classes and the species richness into 5 classes.
- Add 2 fields to the attribute table (TCARCLASS and AMPSRCLASS) and calculate the class breaks for the carbon (TCARCLASS) and the Amphibian Species Richness (AMPSRCLASS).
- Add a third field (TMP) of type STRING
- Calculate TMP to equal [TCARCLASS]&[AMPSRCLASS]
- Add a fourth field (TC_ASR) of type Long Integer
- Calc TC_ASR to equal [TMP]
- Delete field TMP

The definitions of numbers for the combined species/carbon field (TC_ASR) are:
10 (1 referring to Low carbon, and 0 referring to no species)
11 Low carbon, low species richness
12 Low carbon, medium low species richness
13 Low carbon, medium species richness
14 Low carbon, medium high species richness
15 Low carbon, high species richness
...

60 Very High carbon, no species
61 Very High carbon, low species richness
62 Very High carbon, medium low species richness
63 Very High carbon, medium species richness
64 Very High carbon, medium high species richness
65 Very High carbon, high species richness
Etc.

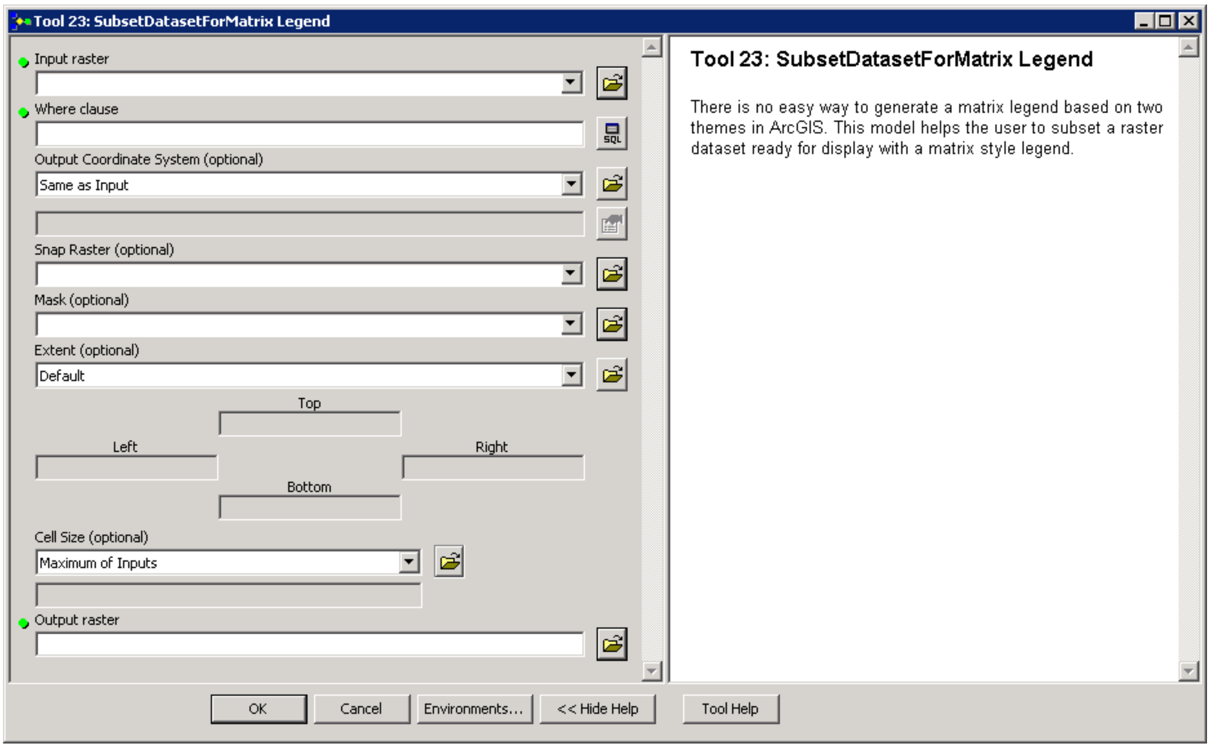
A new raster from the attribute field TC_ASR must them be created so that the TC_ASR field becomes the VALUE field in the new raster.

Now this tool can be run. it will subset the dataset to enable the display the data in ArcMap.

How to Run the Tool

Double click on the tool 'Tool 23: SubsetDatasetForMatrixLegend'

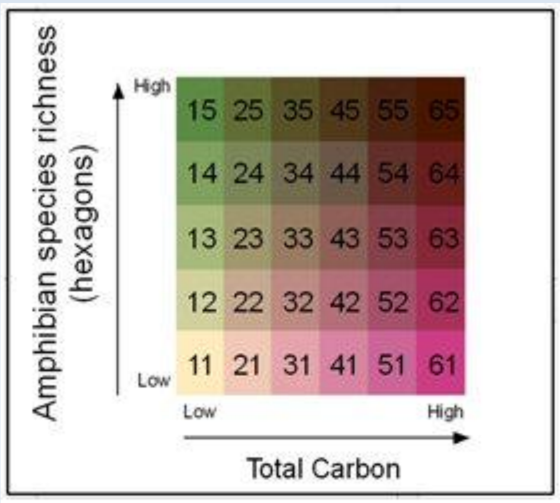
In the box which appears (see below), fill in the white boxes (parameters) accordingly.



When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	**Explanation**
<input_raster>	Name of the input raster dataset containing the combined field - the dataset created in the manual steps (in the example above TC_ASR).
<output_coordinate_system>	Coordinate system of the output Raster dataset. Set it to be the same as your Carbon Raster (which should be in an equal area projection).
<Snap_Raster>	The snap raster is used to ensure that the cell alignment of the output raster matches to a chosen existing raster. Set the Snap Raster to be the same as the Mask_Raster
<Analysis_Extent>	Set the extent to be the same as the Mask_Raster
<Mask_Raster>	The mask will be used to Identify those cells within the analysis extent that will be considered. Set the analysis mask to ensure that processing will occur on all the cells within the analysis extent. Set the mask to be the same as the Snap_Raster.
<Cell_Size>	Specify the output cellsize to be used for the analysis (this will be the same as the Snap Raster).
<Where_clause>	The illustration below helps demonstrate how you will need to define the colour ramps.  You will first need to choose colours for:- a. low species richness - low carbon (11) b. low species richness – high carbon (15) c. low species richness – very high carbon (61) d. high species richness – very high carbon (65) So, for example, you will need to produce a colour ramp from 11 to 15 so you would run this model once with the 'where clause':- "VALUE" >=11 AND VALUE <=15 Similarly you will need to produce a colour ramp from 11 (21,31,41,51) 61 so you would run this model again but this time with the where clause]:-"VALUE" =11 OR VALUE = 21 OR VALUE = 31

	OR VALUE = 41 OR VALUE = 51 OR VALUE = 61 and the same for ramping colours from 61 to 65 and the same for ramping the colours from 15 (25,35,45,55) 65 This will then give you the colours in-between and you will then be able to ramp the colours and subset the data a few more times for 21-25, 31-35 and 51-55.
<Output_Raster>	Name of the new output raster dataset

Tool 24: Create join table from attribute table

ArcToolbox   Exploring Multiple Benefits toolbox

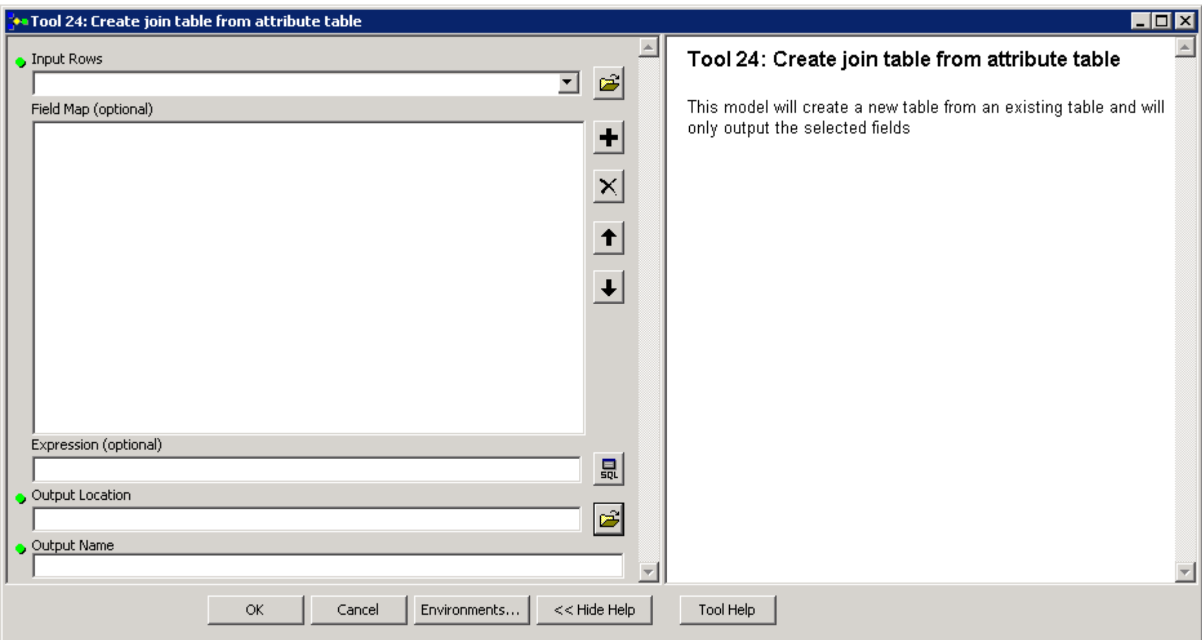
This model will create a new table from an existing table and will only output the selected fields

Usage Tips
If the table to be joined contains many attributes that are not required, use this tool to create a smaller table with only the relevant fields.

How to Run the Tool

Double click on the tool 'Tool 24: Join fields from one table to another'

In the box which appears (see below), fill in the white boxes (parameters) accordingly.



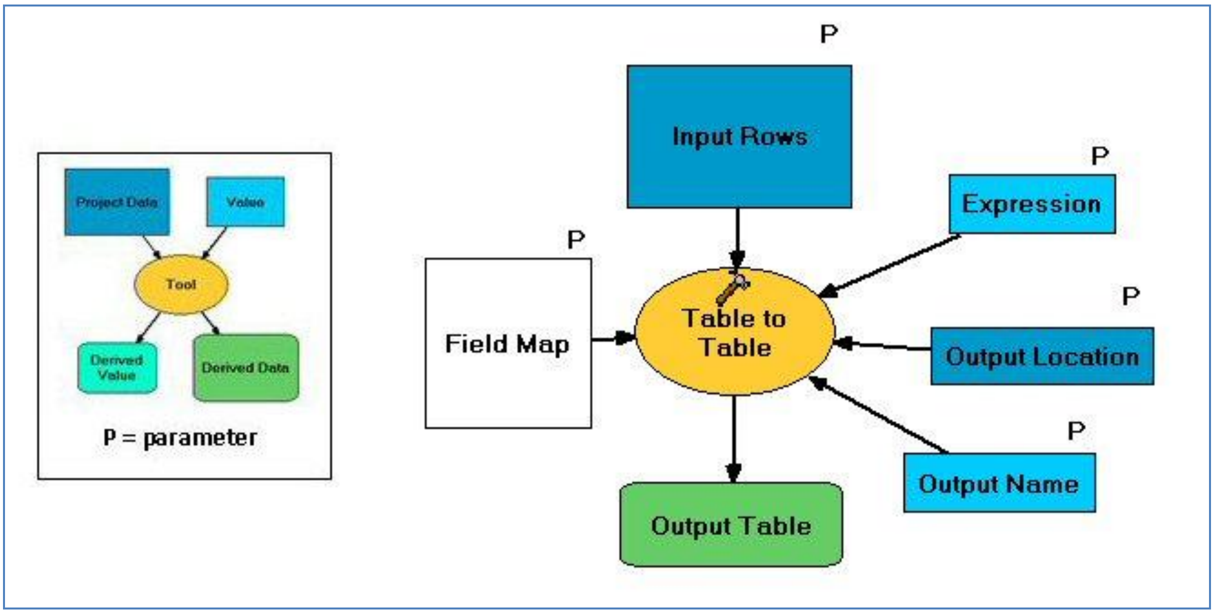
When each white box is clicked on, explanations/help will appear in the panel on the right. The parameter descriptions are also described below.

Click OK to run the tool.

Parameter Descriptions

Expression	Explanation
<Input_Rows>	Table or Attribute table of Dataset
<Field Map>	The fields in the Input Table which will be kept in the output table.
<Expression> (optional)	The table to be joined to the Input Table.
<Output Location>	Workspace in which to save the output Raster.
<OutputName>	Name of the new output raster dataset.

Technical diagram



3.3.3 An example workflow using the ExploringMultipleBenefits Toolbox

- Set the dataframe to the projection that will be used for the analysis (an equal area projection)
- Decide which dataset to use as a base (mask) for the analysis (e.g. an accurate polygon vector layer of the country boundary) and add to ArcMap

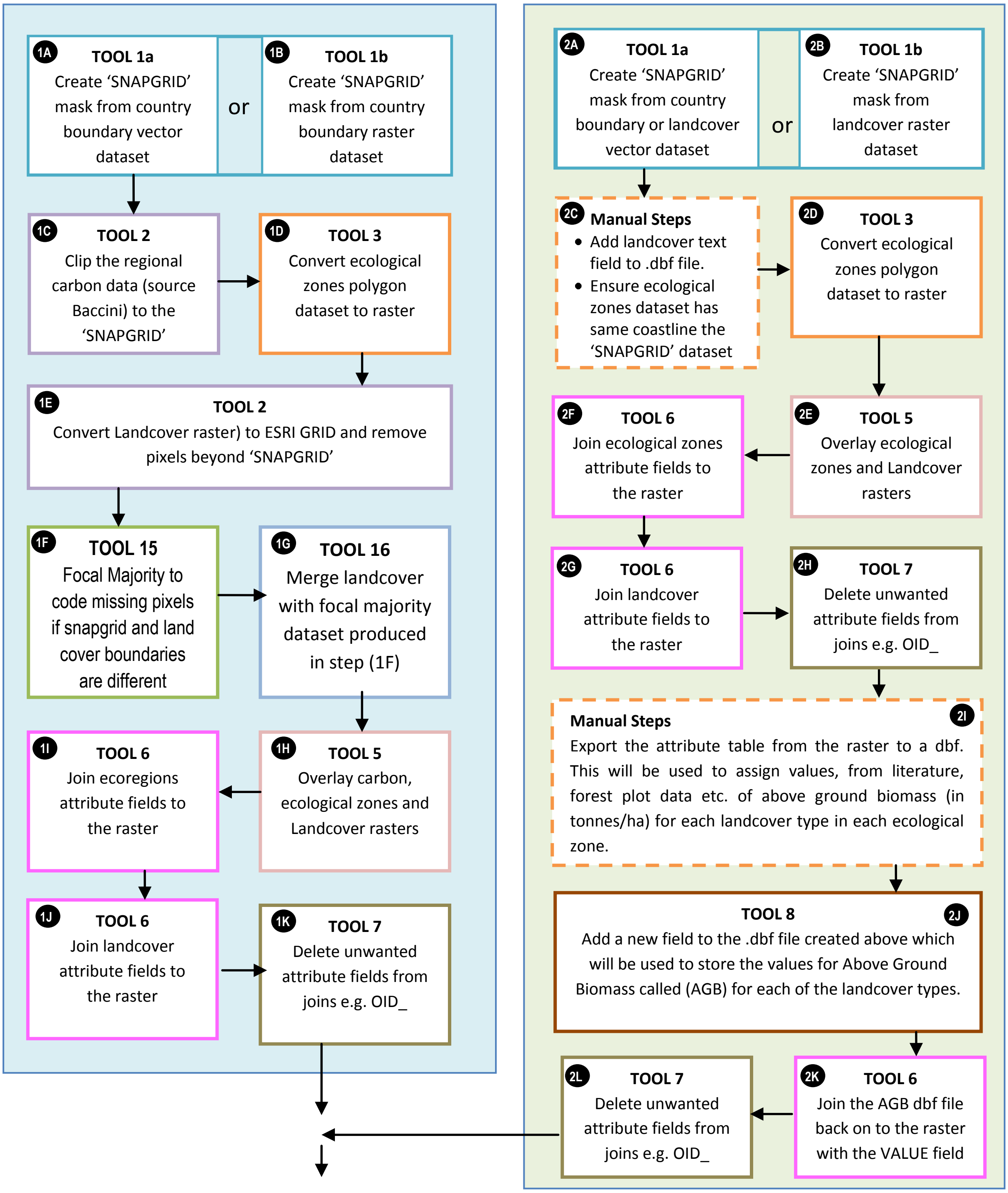
Methodologies for creating a biomass carbon dataset

Approach 1 (e.g. starting with an above ground biomass dataset from remotely sensed data).

Example for Democratic Republic of the Congo

Approach 2 (starting with a landcover dataset and assigning carbon values to each landcover type).

Example for Central Sulawesi, Indonesia.



3A **TOOL 8**
Add a field for IPCCRAT
(IPCC root-to-shoot ratio)

3B **TOOL 9a (for tropical regions)**
(and/or 9b or 9c for sub-tropical and temperate regions)

(This tool will Calculate IPCC root-to-shoot ratio's according to IPCC table 4.4 (below)

TABLE 4.4
RATIO OF BELOW-GROUND BIOMASS TO ABOVE-GROUND BIOMASS (R)

Domain	Ecological zone	Above-ground biomass	R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]	References
Tropical	Tropical rainforest		0.37	Fittkau and Klinge, 1973
	Tropical moist deciduous forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany *et al.*, 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany *et al.*, 2006
	Tropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany *et al.*, 2006
		above-ground biomass [illegible]	[illegible]	[illegible]

3C **TOOL 10**
Add and calculate field for above ground carbon

3D **TOOL 10**
Add and calculate field for below ground carbon

3E **TOOL 10**
Add and calculate field for above + below ground carbon

Additional steps to deal with '0' values in the 'Baccini' dataset (or similar)

3F **Manual Steps**

At this stage there are still 0 values in the raster dataset because the Baccini dataset only refers to forest biomass and has 0 values for biomass less than 9 tonnes/ha. Select the 0 values from the raster attribute table and export them to a .dbf file.

Note: *For the Democratic Republic of the Congo, decisions were made to assign values from the Ruesch and Gibbs global estimates for Agriculture..., Savanna..., Tree Savanna....and Woodland classes (http://cdiac.ornl.gov/epubs/ndp/global_carbon/carbon_documentation.html). (These were selected and calculated manually in the attribute table of raster dataset (BIOECO3). The rest of the pixels were few and scattered so average nearest neighbours are assigned in subsequent steps using the toolbox.*

3G **TOOL 11**
Create biomass carbon raster from carbon attribute field

3H **TOOL 3**
Convert Water Bodies to Raster

3I **TOOL 12**
Set 0 to no data in the biomass carbon raster

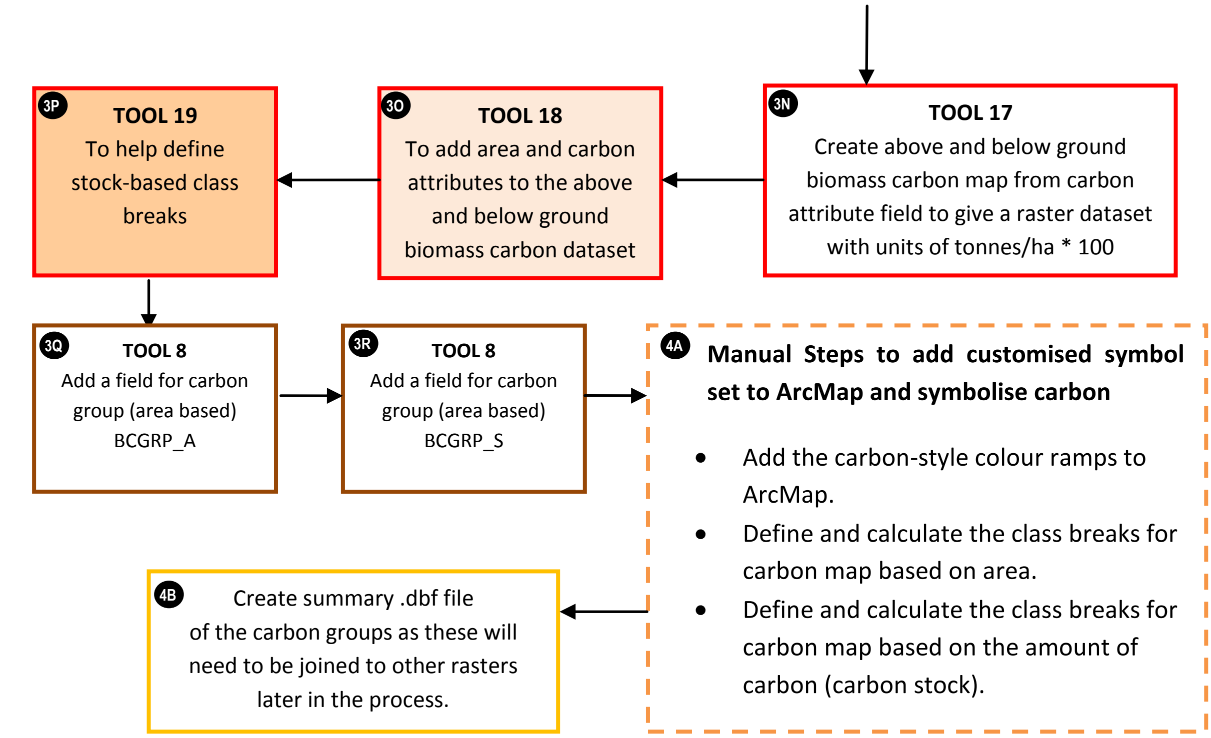
3J **TOOL 13**
Add carbon attributes to biomass carbon raster

3K **TOOL 14**
Convert carbon raster to floating point

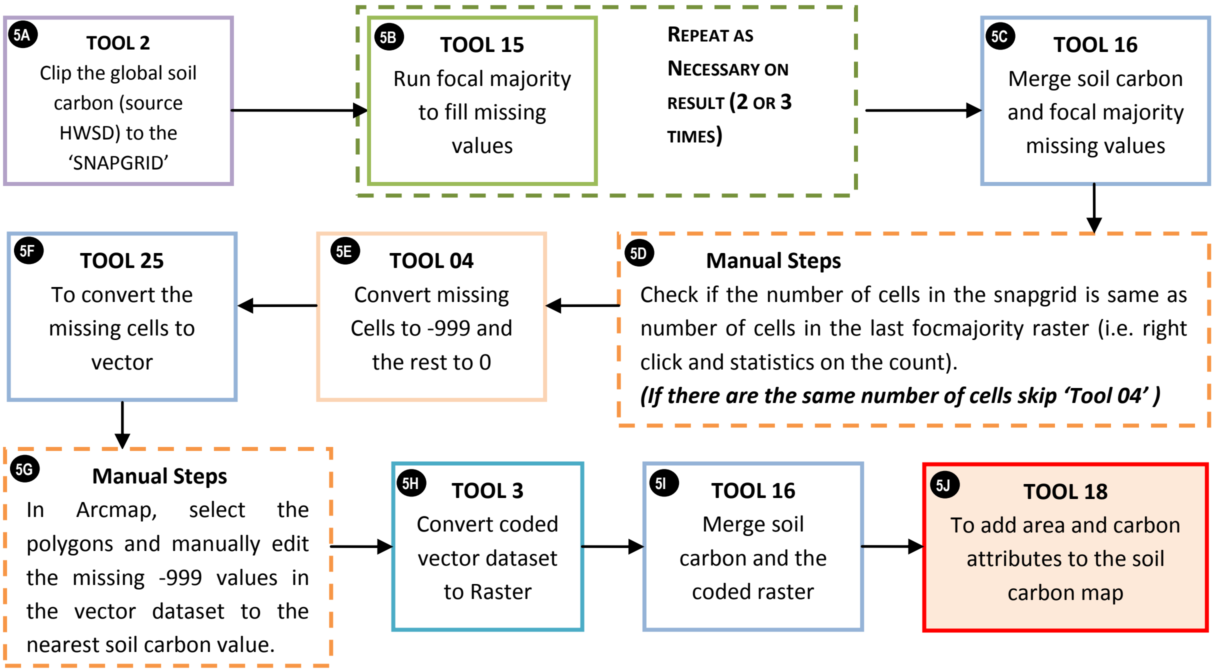
3L **TOOL 15**
Run focal mean to fill 0 values

3M **TOOL 16**
Merge water and focal mean into no data areas

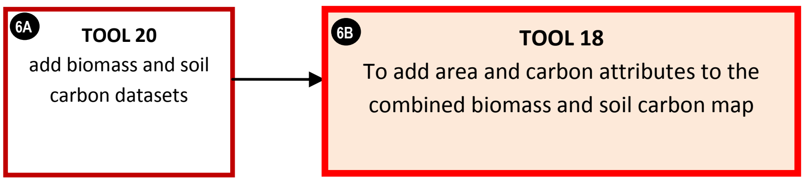
REPEAT AS NECESSARY



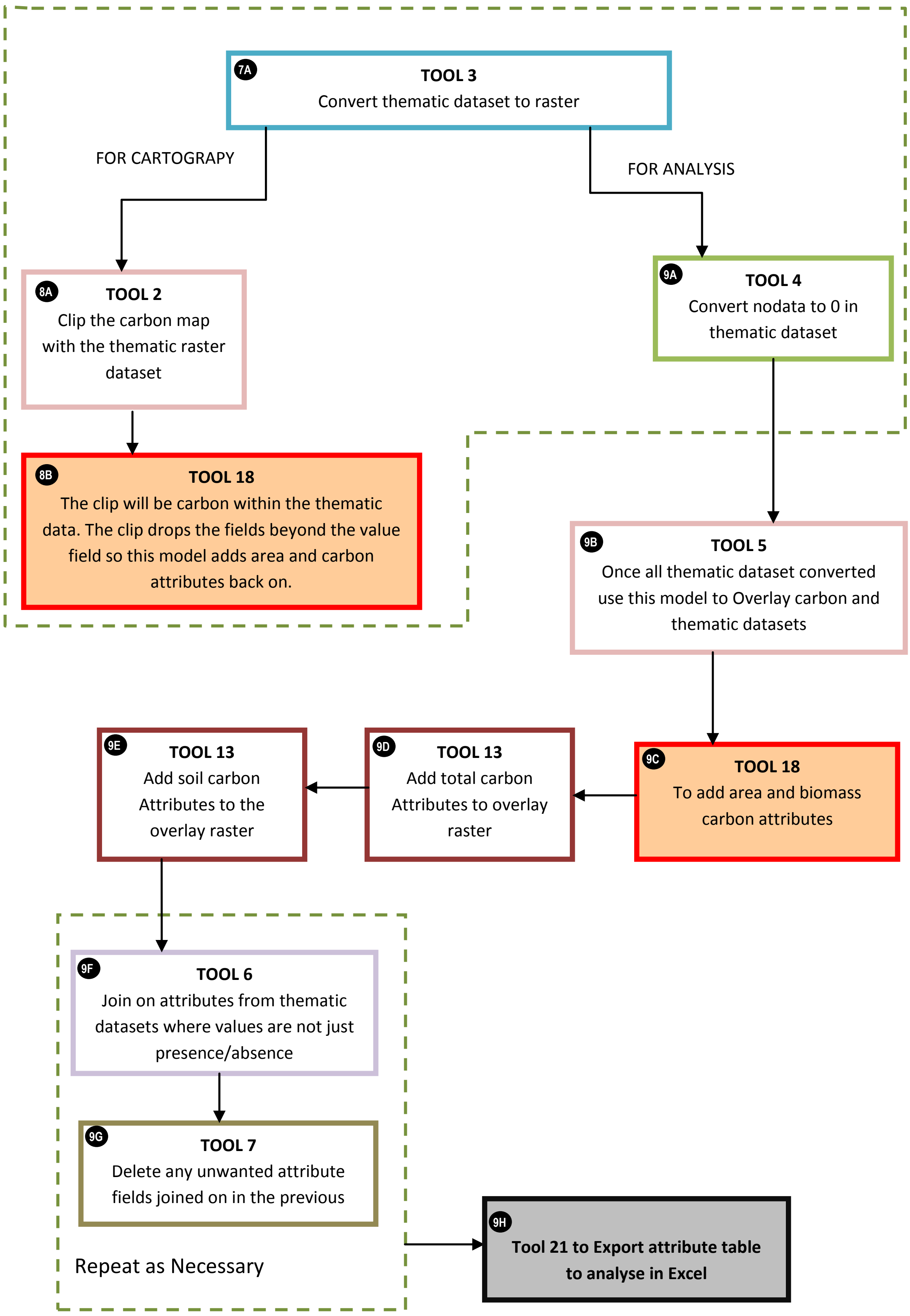
Flow Diagram to illustrate methodology for adding soil carbon produced from the global Harmonised World Soils Database



Flow Diagram to illustrate methodology for creating the combined biomass and soil carbon



Flow Diagram to illustrate methodology for producing overlay analysis with the carbon map



EXAMPLE: Exploring multiple benefits in the Democratic Republic of the Congo using Approach 1

Method

Several data sources were brought together to generate a biomass carbon map for the Democratic Republic of the Congo, comprising above- and below-ground biomass. The above-ground biomass was derived from a model for tropical Africa, which used remotely-sensed MODIS NBAR data from 2000-2003 (Baccini *et al*. 2008). Ecosystem-specific conversion factors (IPCC 2006) were used to add below-ground biomass to this map, with the factors allocated by FAO ecological zones (FAO 2001). The carbon mass of the resulting total was estimated as half the biomass (Gibbs & Brown 2007).

The above-ground biomass model data represented woody above-ground biomass only and excluded areas containing <9 tons of biomass per hectare. To improve the dataset, water bodies were erased and a landcover types dataset from the Universite Catholique de Louvain (UCL) and global biomass carbon estimates (Ruesch & Gibbs 2008) were used to substitute areas where the landcover types were Agriculture or Savanna . A negligible number of remaining pixels with 0 values were allocated nearest neighbour averages, giving a final map of biomass carbon.

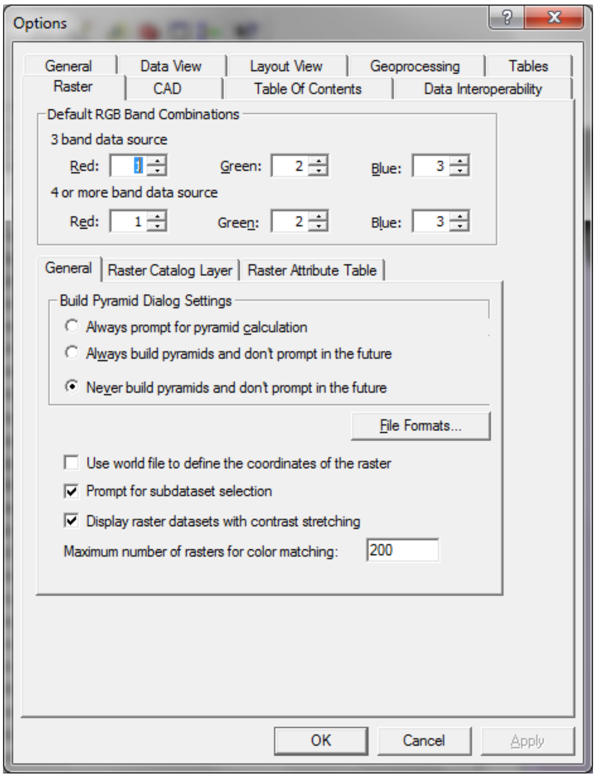
Data sources:

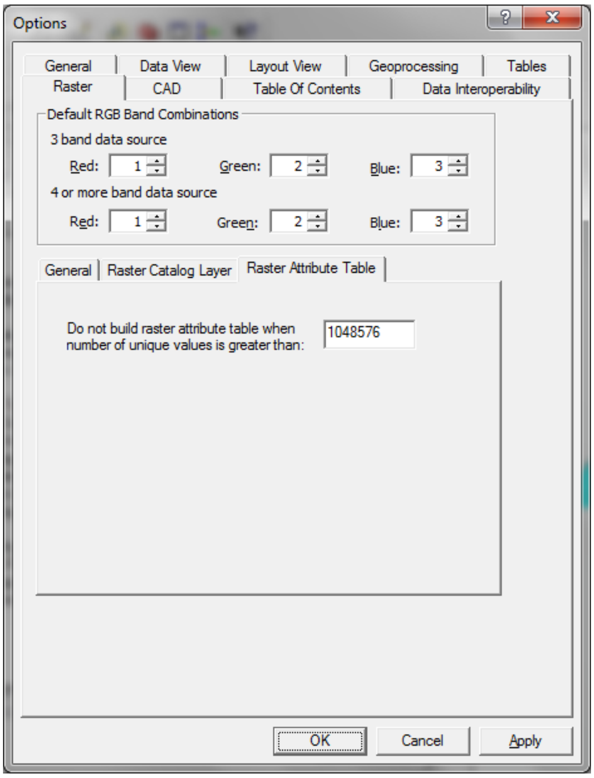
- Baccini, A., Laporte, N., Goetz, S. J., Sun, M., Dong, H., 2008. A first map of tropical Africa's above-ground biomass derived from satellite imagery. Environmental Research Letters 3 (4), 045011+.
- IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories (eds. Eggleston, H.S. et al.). Institute for Global Environmental Strategies, Japan.
- FAO 2001. Global Forest Resources Assessment 2000. FAO Forestry Paper 140. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Gibbs, H.K., Brown, S. 2007. Geographical distribution of woody biomass carbon stocks in tropical Africa: an updated database for 2000. Carbon Dioxide Information Center, Oak Ridge National Laboratory, Oak Ridge, TN. [http://cdiac.ornl.gov/epubs/ndp/ndp0555/ndp05b.html].
- Ruesch, A., Gibbs, H.K. 2008. New IPCC Tier-1 Global Biomass Carbon Map For the Year 2000. Available online from the Carbon Dioxide Information Analysis Center [http://cdiac.ornl.gov/], Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Initial setup

Ensure that the build pyramids setting have been switched off.

- From the main ArcGIS Menu click on Tools-options. Click on the Raster Tab. You should see 'Build pyramids Dialog Settings', if not and click on the' General' tab next to the 'Raster Catalog Layer tab'. Then, Under the Build pyramids Dialog Settings' click on the options to 'Never build pyramids and don't prompt in the future'.





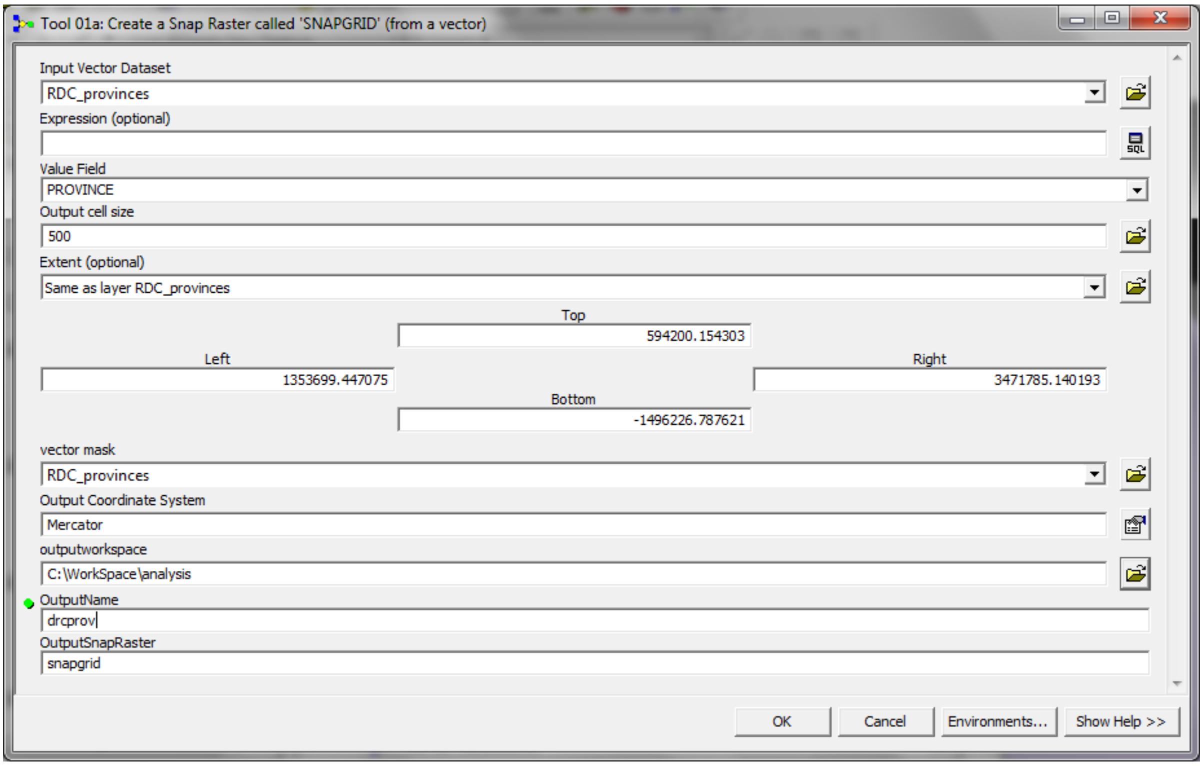
- Click on Raster Attribute Table
- Change the value in "Do not build raster attribute table when number of unique values is greater than " to 1048576 (this is the limit in excel)
- Click ok (to close the options window)
- Right click on the dataframe and set data frame to the chosen equal area projection (e.g. Mercator projection)
- Select the vector dataset (DRC_provinces.shp) to use as a base (mask) for the analysis and add it into the arcmap session.

❖ **(1A) Create 'SNAPGRID' mask from country boundary vector dataset**

Run **Tool 01a: Tool 01a: Create a Snap Raster called 'SNAPGRID' (from a vector)**

This step converts the vector layer of the country with different values for each province to raster and creates a dataset called 'snapgrid' which is used as the country level mask and snap raster throughout the whole this analysis.

- The input vector dataset = DRC_provinces
- Value Field = 'province'
- Output cell size = 500
- Extent = Same as layer RDC_provinces
- Vector mask = RDC_provinces
- Output coordinate system = e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = drcprov
- OutputSnapRaster = snapgrid



Add C:\WorkSpace\analysis\snapgrid, DRCprov and DRCProv.dbf to the ArcMap session.

Open the attribute table of the 'snapgrid' and note in the count field. This is the number of cells in the snapgrid dataset. This will be a useful reference throughout the subsequent analysis to check the total number of cells in the raster datasets that are createdmatch the number of cells in the snapgrid. A mismatch in the number of cells (usually too few cells) will indicate that a problem has occurred in the processing.

Note: The 'DRCProv.dbf provides the meanings of the 'VALUE' field in the DRCprov raster and will be used later to join the 'PROVINCE' field back on to the dataset.

The snapgrid is a vital part of the Raster analysis and will be used as both a snap grid and mask so it is very important that this dataset is checked to ensure that it covers the whole extent required and that the cell size is appropriate for the analysis being undertaken.

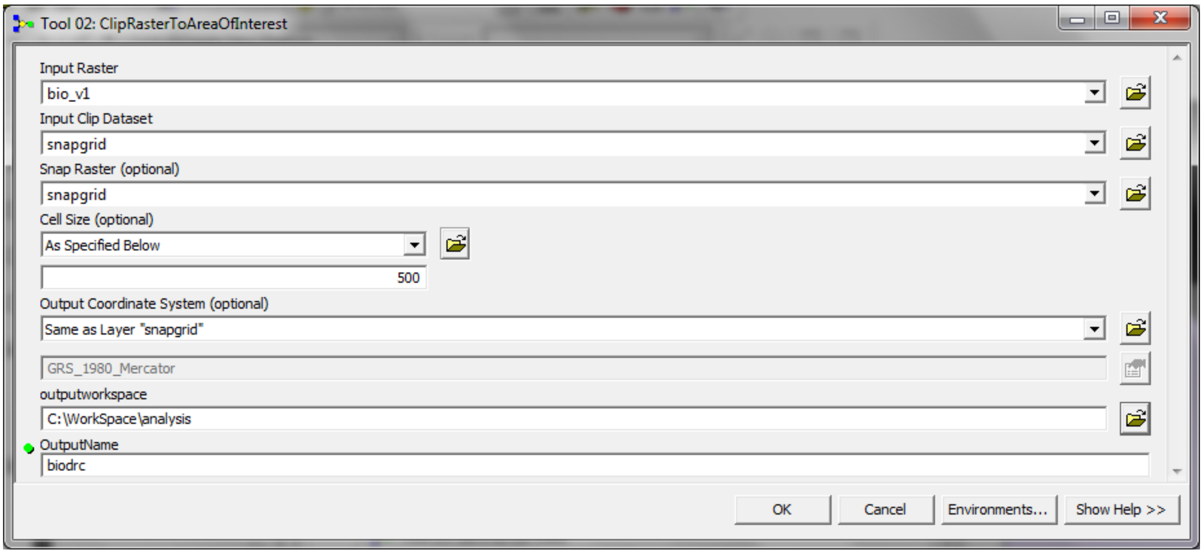
Approach1: Generate a Biomass Carbon Map

❖ **(1C) Clip the regional carbon data (source Baccini) to the 'SNAPGRID'**

*Run **Tool 02: ClipRasterToAreaOfInterest***

This step clips the Baccini Africa above-ground biomass dataset to the country extent using the 'snapgrid' created in the previous step.

- Input Raster = bio_v1 (baccini biomass raster for africa)
- Input Clip Dataset = snapgrid
- Snap Raster = snapgrid
- Cellsize = 500
- Output coordinate system = Same as Layer 'snapgrid'
- Output workspace = C:\WorkSpace\analysis
- OutputName = biodrc



Add C:\WorkSpace\analysis\biodrc raster to the ArcMap session.
Check that the number of cells matches with the number of cells in the snapgrid (open the attribute table, right click on the count field, click on statistics and look at the value for Sum)

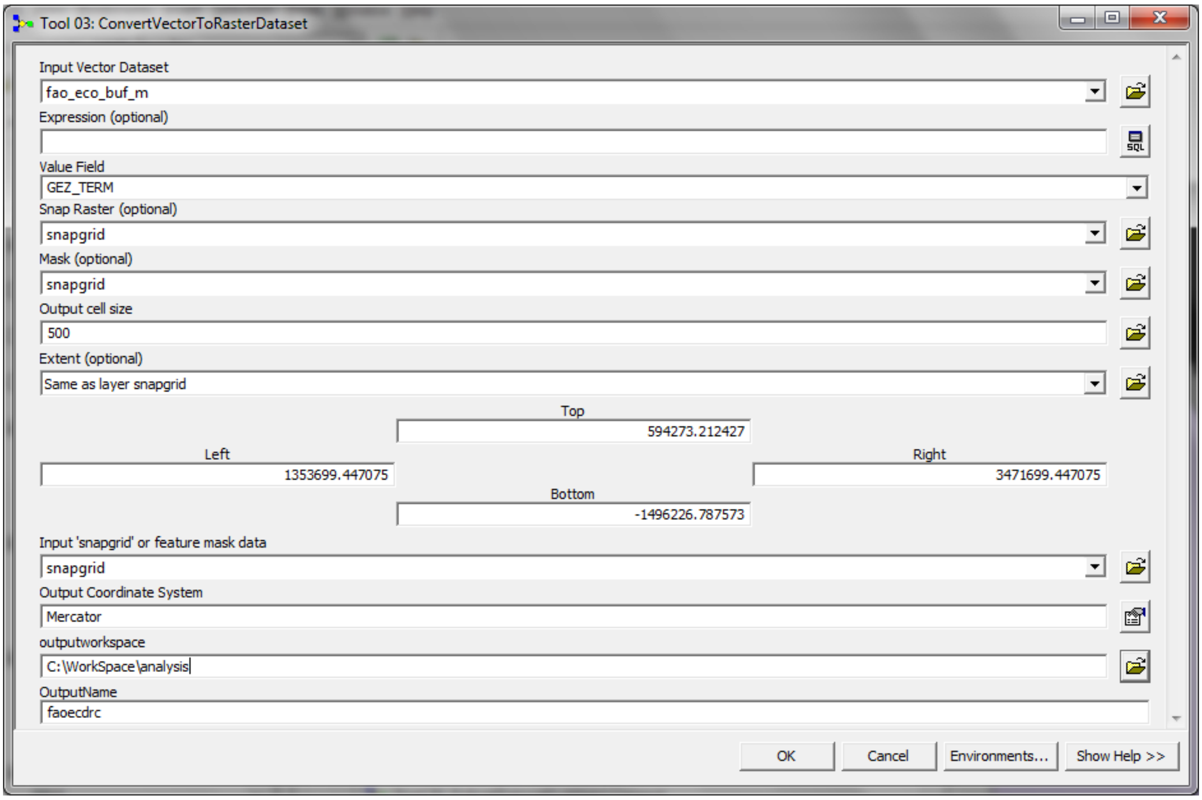
❖ **(1D) Convert ecoregions polygon dataset to raster**

Note: *the FAO ecological zone layer has a general coastline so before running the model, we manually extend the coastal section out so that it goes beyond DCR Land Coastline (or run a buffer to extend the boundary our beyond the coastline).*

Run **Tool 03: ConvertVectorToRasterDataset**

This step converts the FAO ecological zones to raster and clips it to the extent of the 'snapgrid'.

- The input vector dataset = fao_eco_buf_m
- Value Field = 'GEZ_TERM'
- Output cell size = 500
- Snap Raster = snapgrid
- Mask =snapgrid
- Extent = Same as Layer snapgrid
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = faoecodrc



Add C:\WorkSpace\analysis\faoecodrc and faoecodrc.dbf to the ArcMap session.
Check that the number of cells matches with the number of cells in the snapgrid (open the attribute table, right click on the count field, click on statistics and look at the value for Sum)

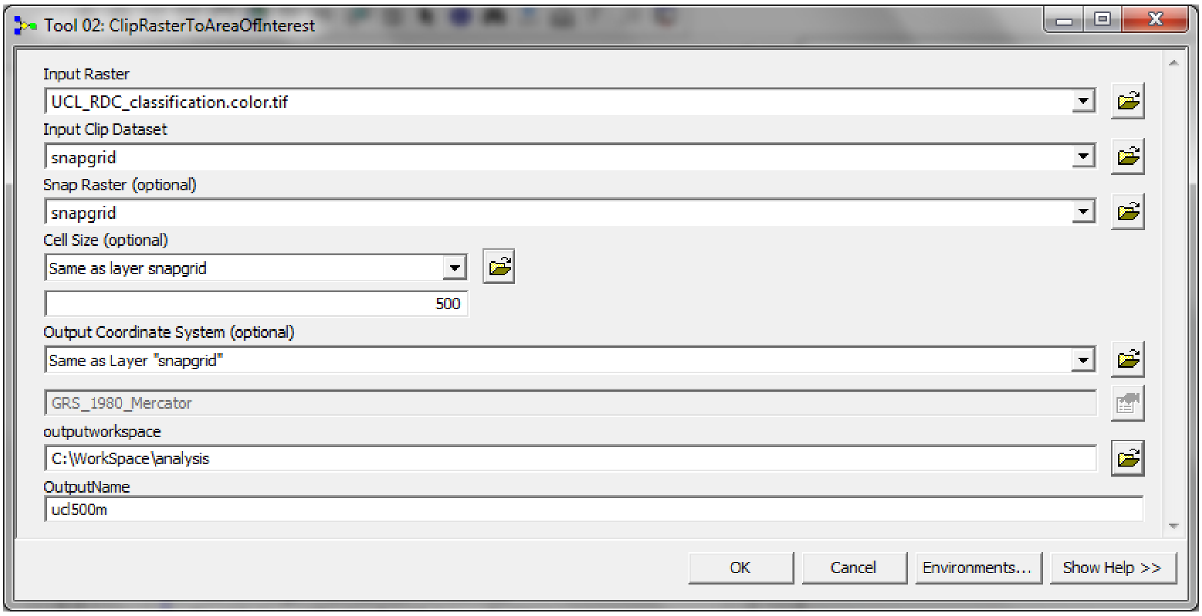
Note: The faoecodrc.dbf provides the meanings of the 'VALUE' field in the faoecodrc raster and will be used later to join the 'GEZ_TERM' field back on to the dataset.

- **(1E) Convert Landcover raster) to ESRI GRID and remove pixels beyond 'SNAPGRID'**

Run **Tool 02: ClipRasterToAreaOfInterest**

This step should be run even if the raster dataset is already a country level dataset. It ensures that the landcover dataset is clipped to the same extent as the 'snapgrid' and that the output cell size is consistent with the rest of the analysis. It removes any pixels beyond the extent of the snapgrid.

- Input Raster = UCL_RDC_classification.color.tif
- Input Clip Dataset = snapgrid
- Snap Raster = snapgrid
- Cellsize = 500
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = ucl500m



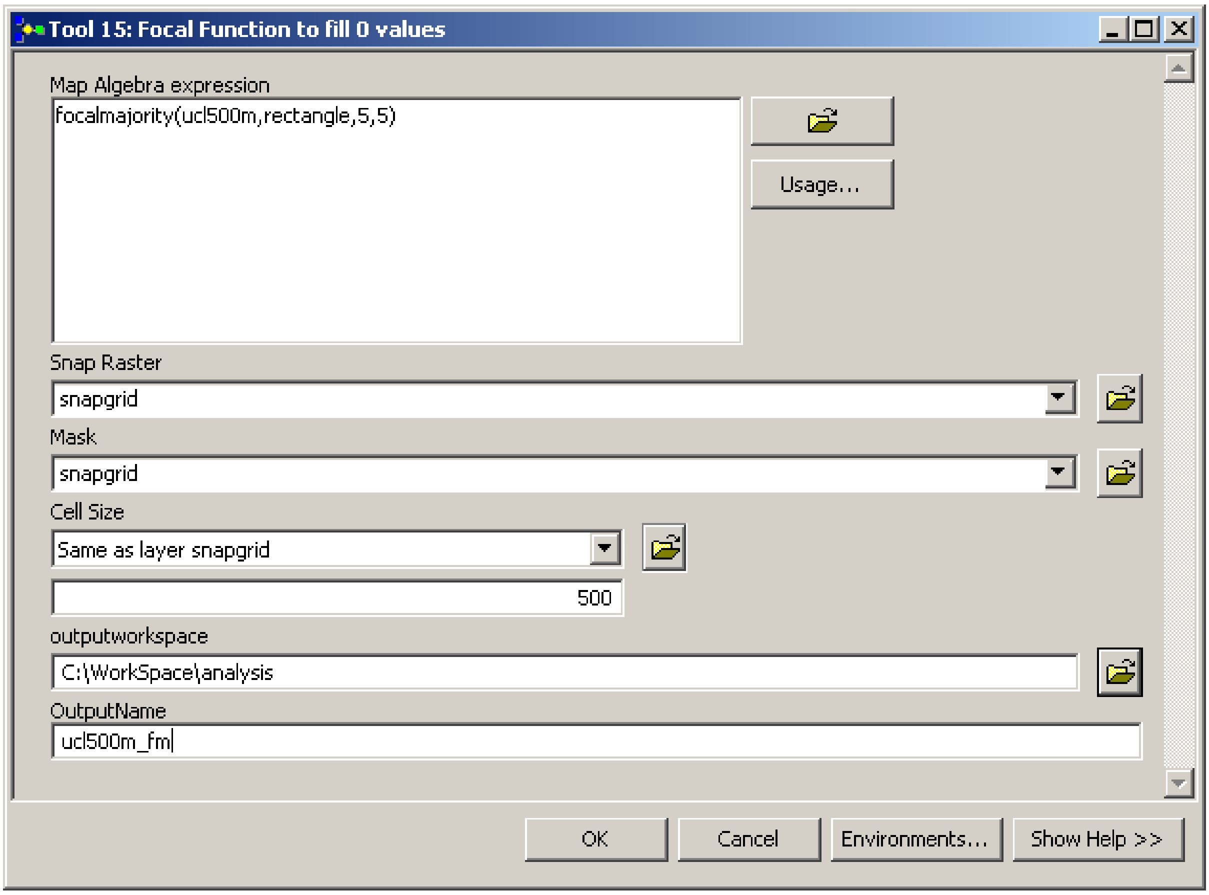
Add C:\WorkSpace\analysis\ucl500m to the ArcMap session.
Check that the number of cells matches with the number of cells in the snapgrid (open the attribute table, right click on the count field, click on statistics and look at the value for Sum)

- **(1F) TOOL 15 Focal Majority to code missing pixels if snapgrid and land cover boundaries are different**

Run **Tool 15: Focal Function to fill 0 values**

The landcover dataset had a slightly different country boundary to the 'snapgrid'. The previous step removed any pixels beyond the extent of the 'snapgrd'. In some areas the boundary of the landcover dataset fell short of the 'snapgrid'. This step ensures that any cells within the snapgrid' area that are not present in the landcover dataset are kept and these cells are given the value of their majority nearest neighbours.

- Map Algebra expression = focalmajority(ucl500m,rectangle,5,5)
- Snap Raster = snapgrid
- Mask = snapgrid
- Cellsize = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = ucl500m_fm

❖ 

Add C:\WorkSpace\analysis\ucl500m_fm to the ArcMap session.

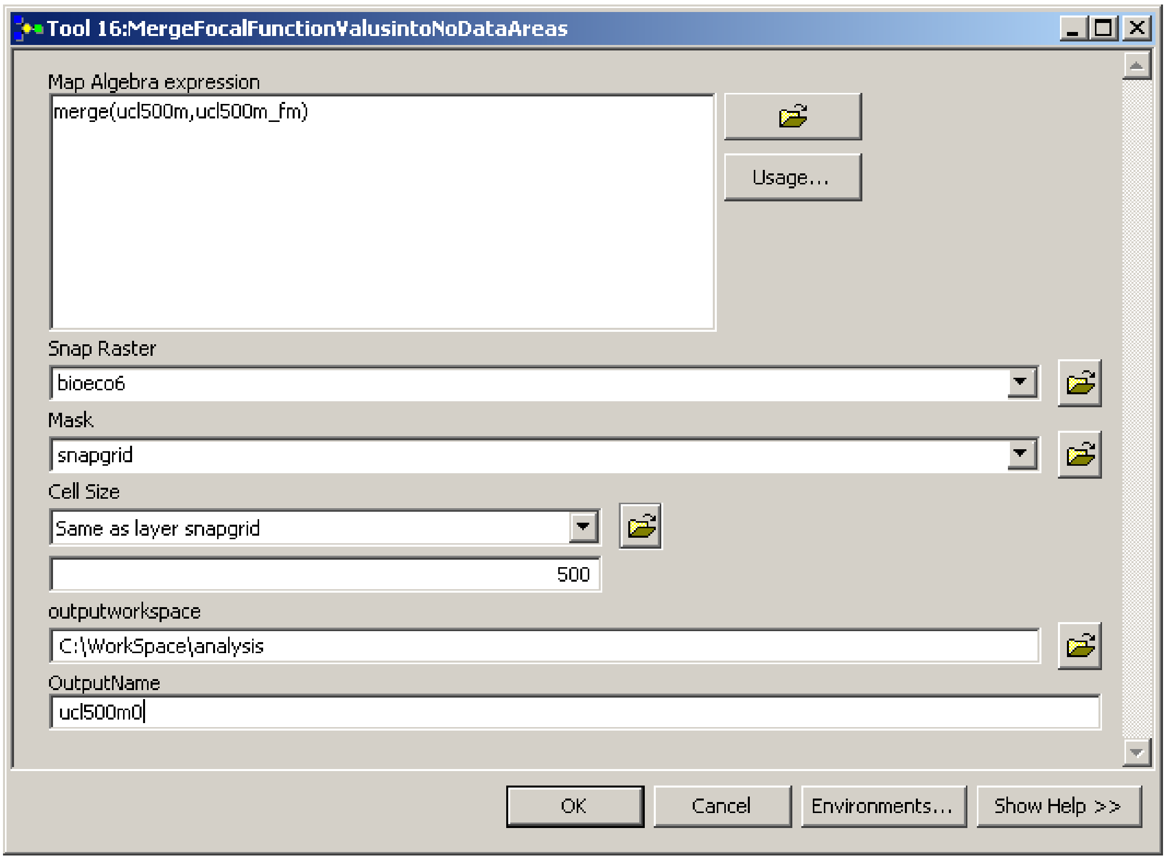
Check that the number of cells matches with the number of cells in the snapgrid (open the attribute table, right click on the count field, click on statistics and look at the value for Sum)

❖ **(1G) Merge landcover with focal majority dataset produced in step (1F)**

Run **Tool 16:MergeFocalFunctionValusintoNoDataAreas**

This step merges the values filled by the focal majority back into the landcover dataset. landcover dataset created in (IE). This step is necessary as the focal majority can also alter values of cells that you don't want to change

- Map Algebra expression = merge(ucl500m,ucl500m_fm)
- Snap Raster = snapgrid
- Mask = snapgrid
- Cellsize = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = ucl500m0



Add C:\WorkSpace\analysis\ucl500m0 to the ArcMap session.

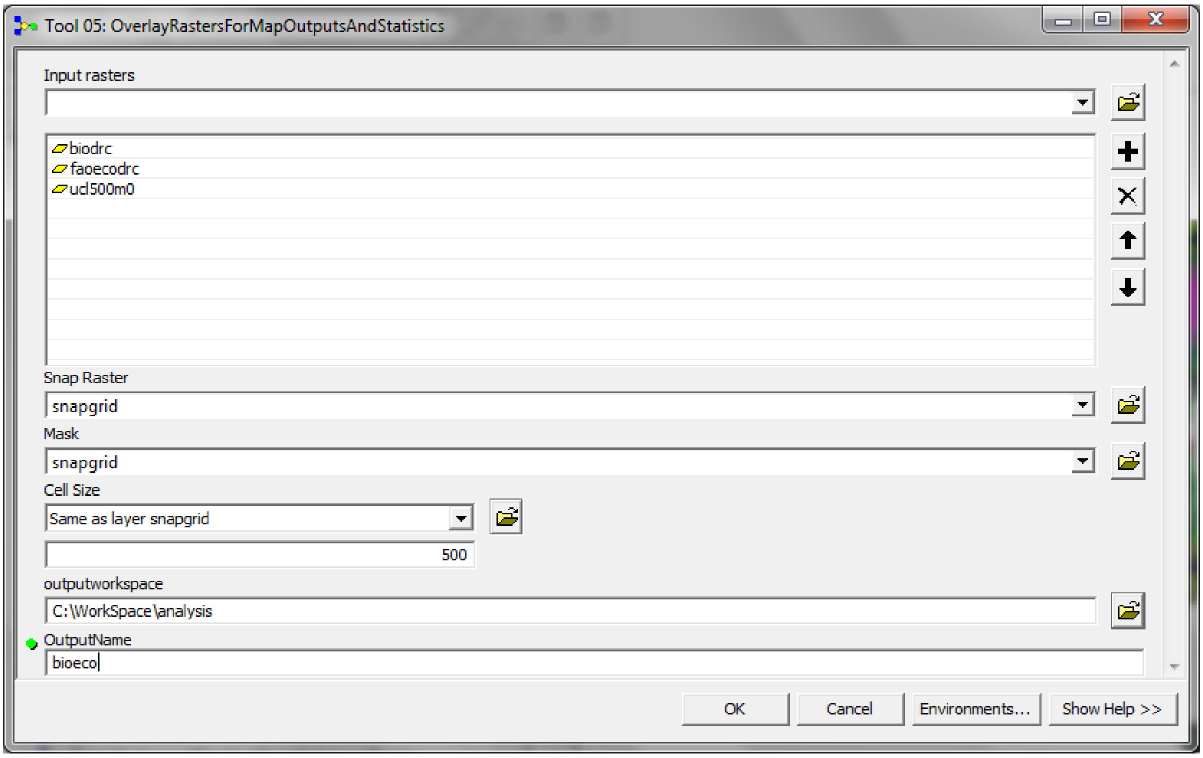
Check that the number of cells matches with the number of cells in the snapgrid (open the attribute table, right click on the count field, click on statistics and look at the value for Sum)

- **(1H) Overlay carbon, ecoregions and Landcover rasters**

Run **Tool 05: OverlayRastersForMapOutputsAndStatistics**

This combines the Biomass, FAO ecological zones and the landcover datasets.

- Input Rasters = biodrc, faoecodrc, ucl500m0
- Snap Raster = snapgrid
- Mask Raster = snapgrid
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = bioeco



Add C:\WorkSpace\analysis\ bioeco to the ArcMap session.

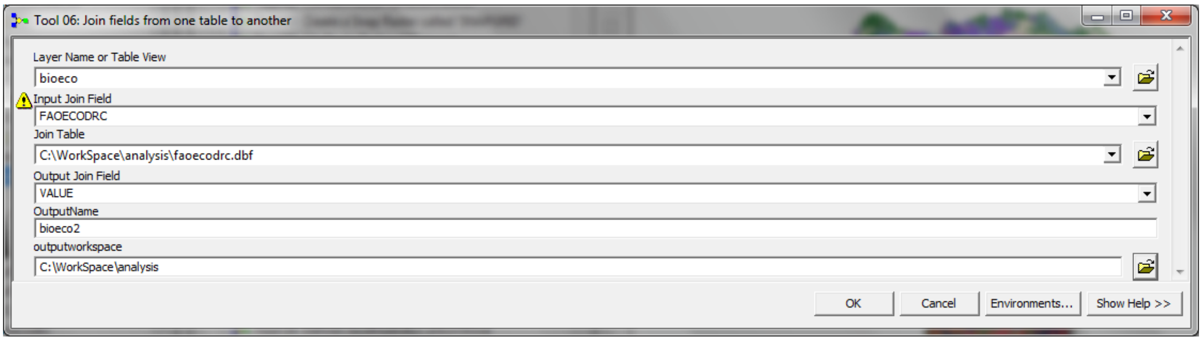
Check that the number of cells matches with the number of cells in the snapgrid (open the attribute table, right click on the count field, click on statistics and look at the value for Sum)

❖ **(1l) Join ecoregions attribute fields to the raster**

Run **Tool 06: Join fields from one table to another**

The combined output above (bioeco) contains only the 'VALUE' fields from the individual raster's that were combined. This tool can be used to join on the descriptive attributes such as the GEZ_TERM for the FAO ecological zones.

- InputTable=bioeco
- InputJoinField = FAOECODRC
- JoinTable = C:\WorkSpace\analysis\FAOECODRC.dbf
- OutputJoinField=Value
- Output workspace C:\WorkSpace\analysis
- OutputName = bioeco2



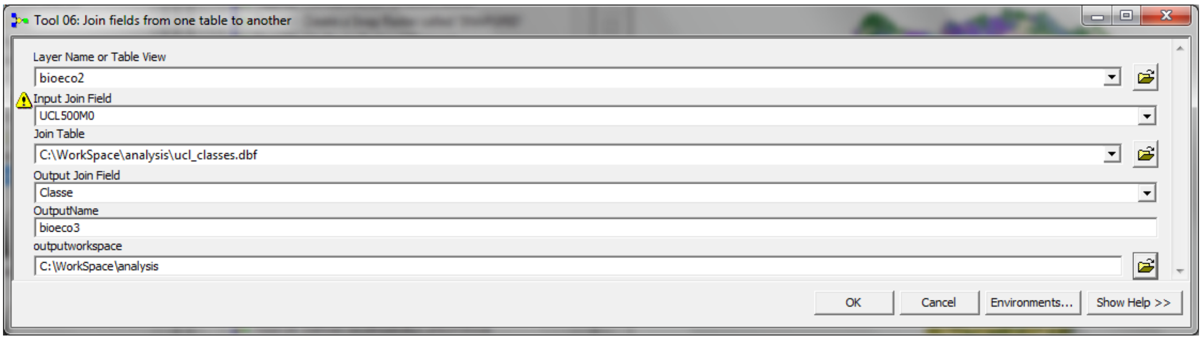
Add C:\WorkSpace\analysis\ bioeco2 to the ArcMap session. Open the attribute table to check that the GEZ_TERM field has been joined on.

❖ **(IJ) Join landcover attribute fields to the raster**

Run **Tool 06: Join fields from one table to another**

Use this tool again to this time join on the landcover attributes.

- InputTable=bioeco2
- InputJoinField = UCL500M0
- JoinTable = C:\WorkSpace\analysis\ucl_classes.dbf
- OutputJoinField= Classe
- Output workspace C:\WorkSpace\analysis
- OutputName = bioeco3



Add C:\WorkSpace\analysis and add bioeco3 to the ArcMap session. Open the attribute table to check that the GEZ_TERM field has been joined on.

❖ **(1K) Delete any unwanted attribute fields joined on in the previous steps**

Run **Tool 07: Delete fields from table**

This step deletes any unwanted joined fields such as OID_ VALUE_1 and COUNT_1.

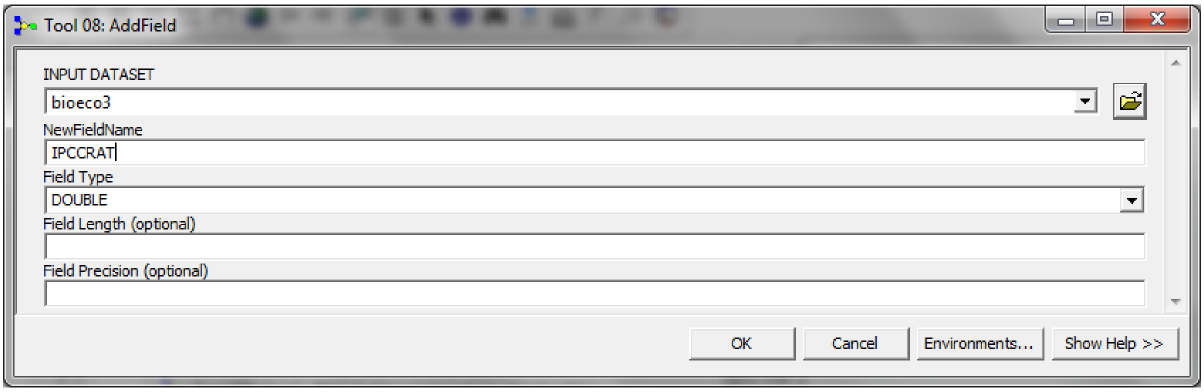
Open attribute table to check that all the unwanted attributes have been dropped.

❖ **(3A) Add a field for IPCCRAT (IPCC root-to-shoot ratio)**

Run **Tool 08: AddField**

The Inter Governmental Panel on Climate Change defines the ratio of Below-Ground Biomass to Above-Ground Biomass for different Ecological Zones. This step to add a new empty field called IPCCRAT.

- InputTable=bioeco3
- NewFieldName = IPCCRAT
- FieldType= Double
- Field Length = leave blank
- Field Precision = leave blank



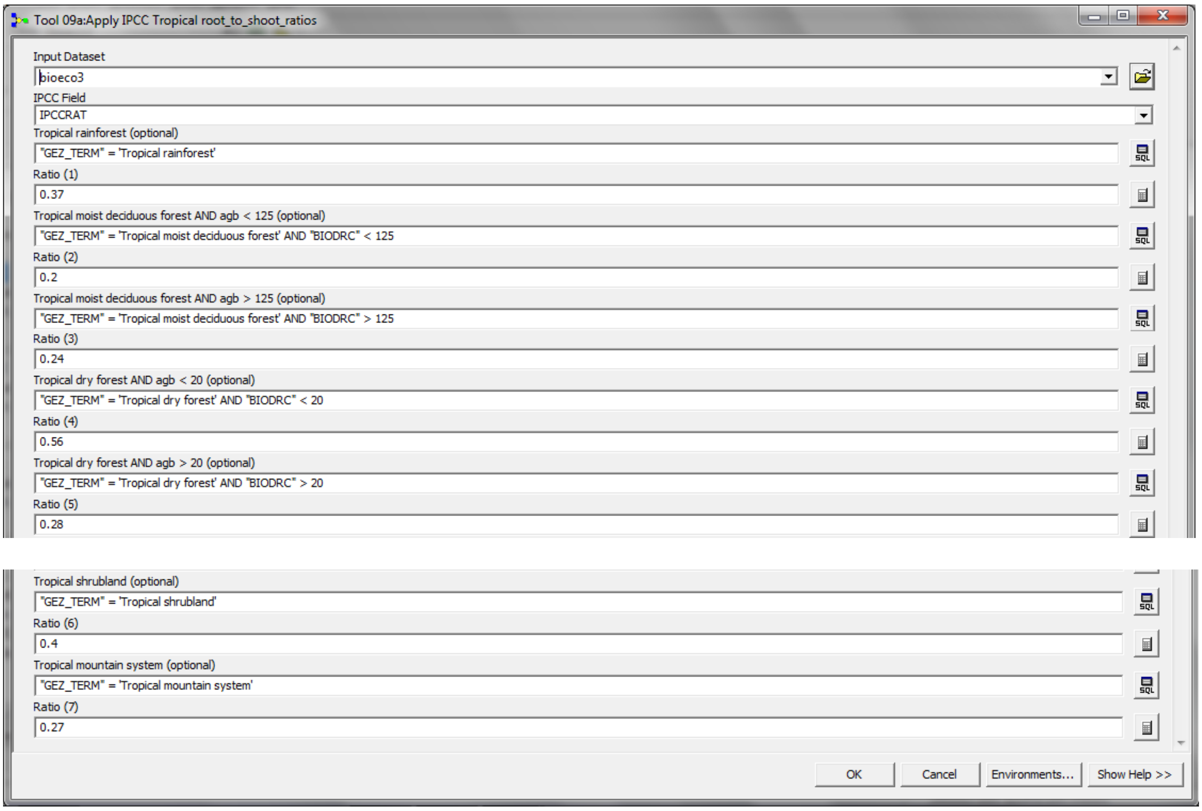
Open attribute table to check that the new field has been added.

❖ **(3B) Calculate IPCC root-to-shoot ratio's according to IPCC table**

Run **Tool 09a:Apply IPCC Tropical root_to_shoot_ratios**

This step populates the IPCCRAT field that was added in the previous step with the the root-to-shoot ratios for each ecological zone as defined by IPCC.

- InputTable=bioeco3



Open attribute table to check the IPCCRAT field is correct for each ecological zone (GEZ_TERM).

*Note: It will be necessary to also run **Tool 09b:Apply_IPCC Subtropical root_to_shoot_ratios** if the country covers more than just the tropical zone.*

Above-ground Carbon (AGC) = ***Above-ground Biomass * 0.5***

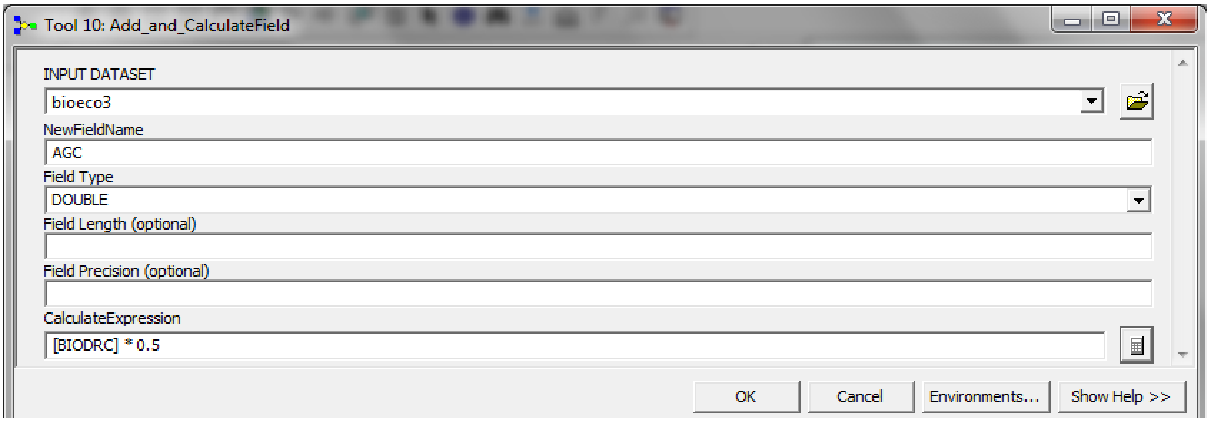
Below-ground Carbon (AGB) = ***AGC * IPCC Ratio***

So total Biomass Carbon = *AGC + BGC*

❖ **(3C) Add and calculate field for above ground carbon**

Run **Tool 10: Add_and_CalculateField (**to add a field called AGC (above ground carbon) and calculate this to be the above ground biomass values contained in the BIODRC field multiplied by 0.5 as half the biomass is carbon)

- InputTable=bioeco3
- NewFieldType = AGC
- Field Type = Double
- CalculateExpression = [BIODRC]*0.5



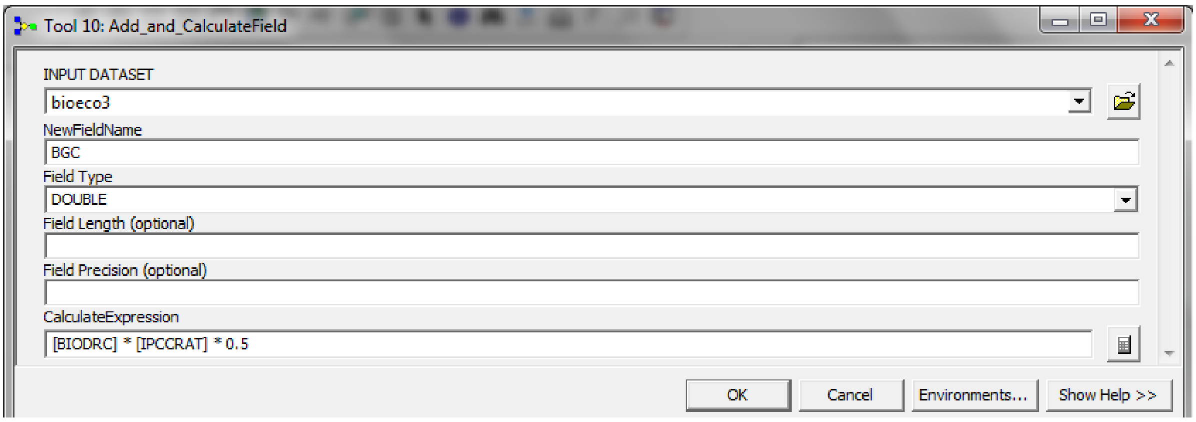
Open attribute table to check the AGCfield has been calculated correctly.

❖ **(3D) Add and calculate field for below ground carbon**

Run **Tool 10: Add_and_CalculateField**

This step adds a field called BGC (below ground carbon) and calculate this to be the Above-ground carbon multiplied by the IPCCRAT.

- InputTable=bioeco3
- NewFieldType = BGC
- Field Type = Double
- CalculateExpression = [AGC] * [IPCCRAT]



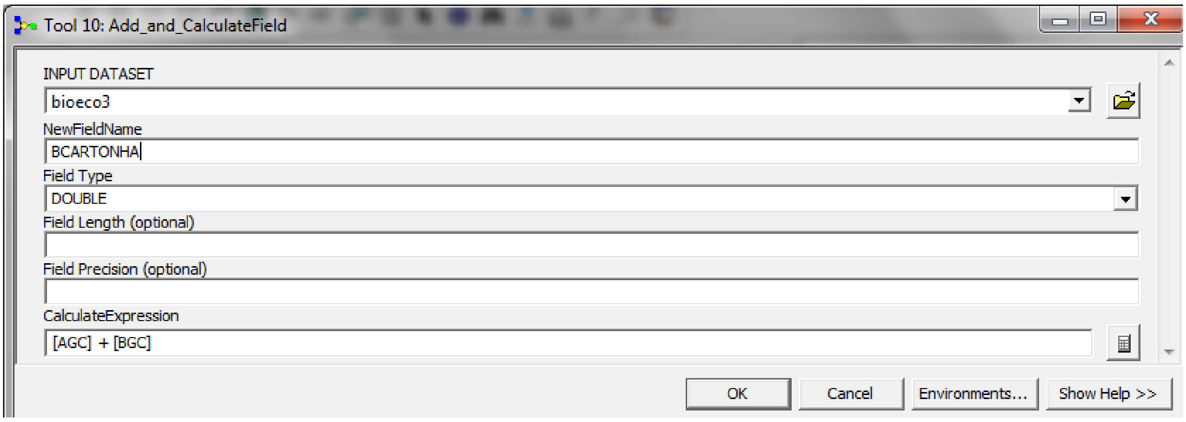
Open attribute table to check the BGC field has been calculated correctly.

❖ **(3E) Add and calculate field for above + below ground carbon**

Run **Tool 10: Add_and_CalculateField**

This step adds a field called BCARTONHA and calculate this to be AGC + BGC .

- InputTable=bioeco3
- NewFieldType = BCARTONHA
- Field Type = Double
- CalculateExpression = [AGC]+[BGC]



Open attribute table to check the BCARTONHA has been calculated correctly.

(3F) Manual Steps to deal with '0' values in the Baccini dataset

The following steps deal with the 0 values in the dataset (those representing <9 tons of biomass per hectare).

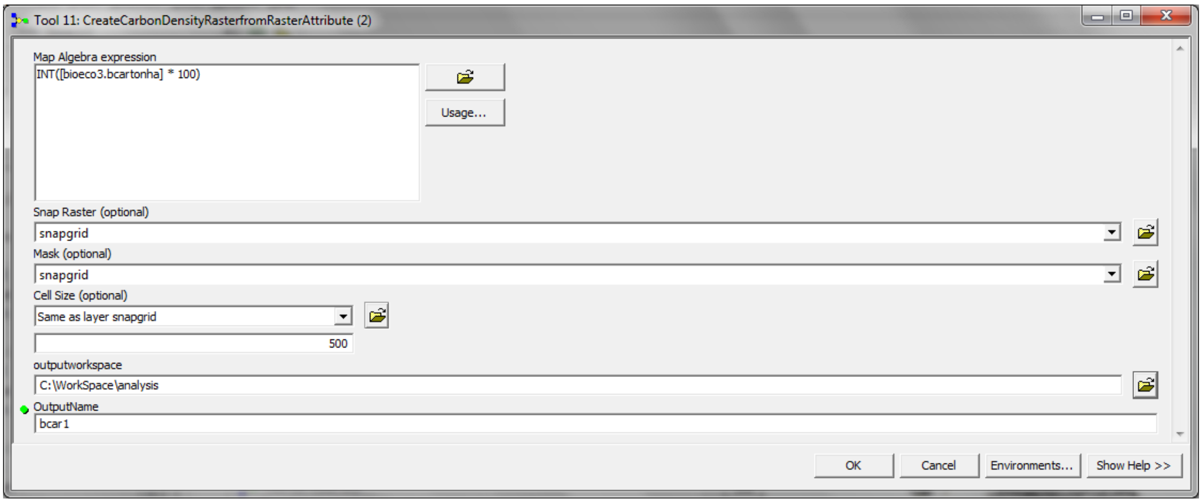
Open the attribute table and select where BCARTONHA = 0 and export the table. Experts can then look at this table and for each of the landcover types (in each ecological zone) look at the number of pixels that these represent (i.e. the COUNT Field). Where possible they will tell you what biomass carbon (above + below ground) to use for those pixels and these values can be manually calculated into the BCARTONHA field. These will be either National estimates or Global Values (Ruesch & Gibbs 2008). For the Democratic Republic of the Congo this was possible for Agriculture and Savanna classes using Ruesch & Gibbs 2008. For the Democratic Republic of the Congo this left pixels which were water and a negligible number of scattered remaining pixels with 0 values.

❖ **(3G) Create biomass carbon raster from carbon attribute field**

Run **Tool 11: CreateCarbonDensityRasterfromRasterAttribute**

This step creates a first cut of the carbon map from the BCARTONHA field.

- YOURRASTER = bioeco3
- Snap Raster = snapgrid
- Mask =snapgrid
- Cellsize = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcar1



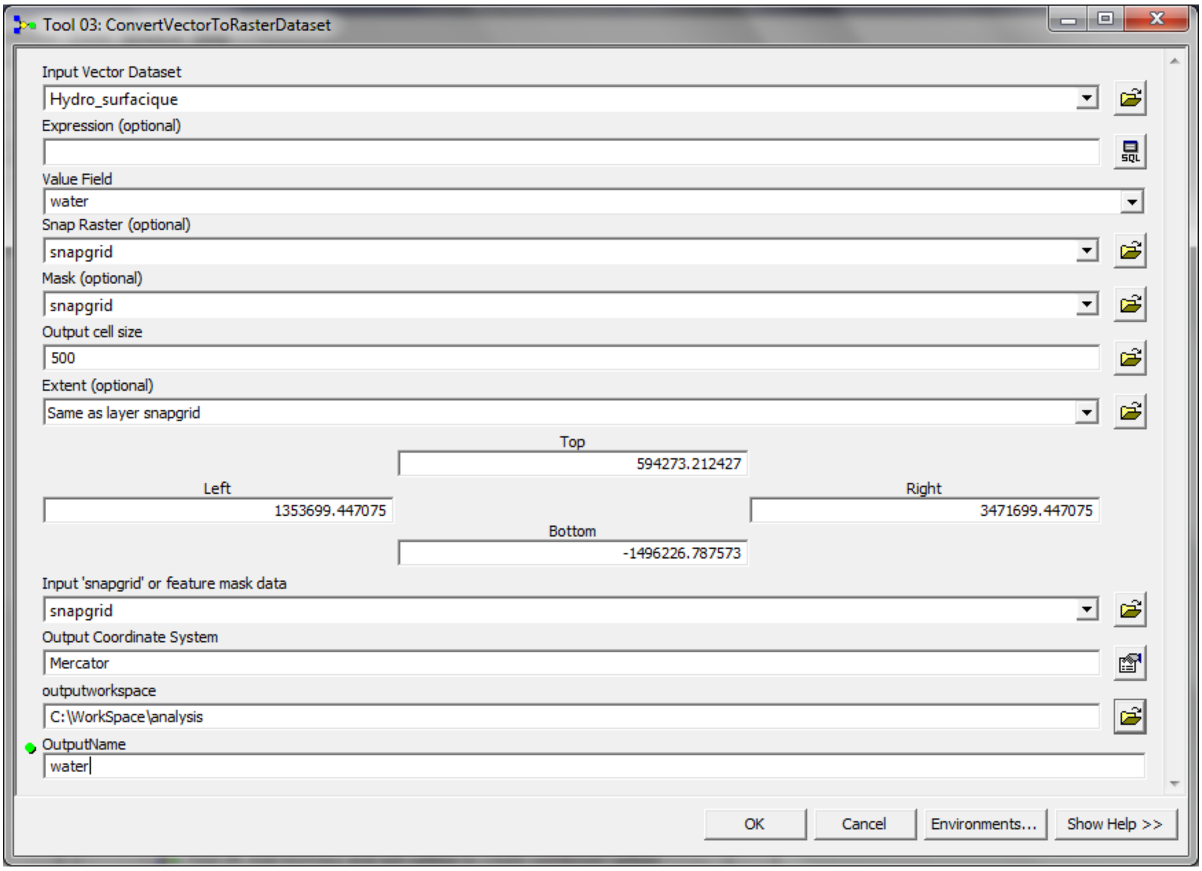
*Add C:\WorkSpace\analysis\bcar1 raster to the ArcMap session and check it's attribute table.It will only have a VALUE field and this field is in tonnes/ha * 100.*

The following steps needed to be taken to improve the Biomass Carbon dataset because the Baccini dataset only refers to forest biomass and has 0 values for biomass less than 9 tonnes/ha.

- **(3H) Convert Water Bodies to Raster**

Run **Tool 03: ConvertVectorToRasterDataset** (to convert water bodies to raster)

- The input vector dataset = Hydro_surfacique
- Value Field = water (make sure there is a field with water = 0)
- Output cell size = 500
- Snap Raster = snapgrid
- Mask =snapgrid
- Extent = Same as Layer snapgrid
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = water

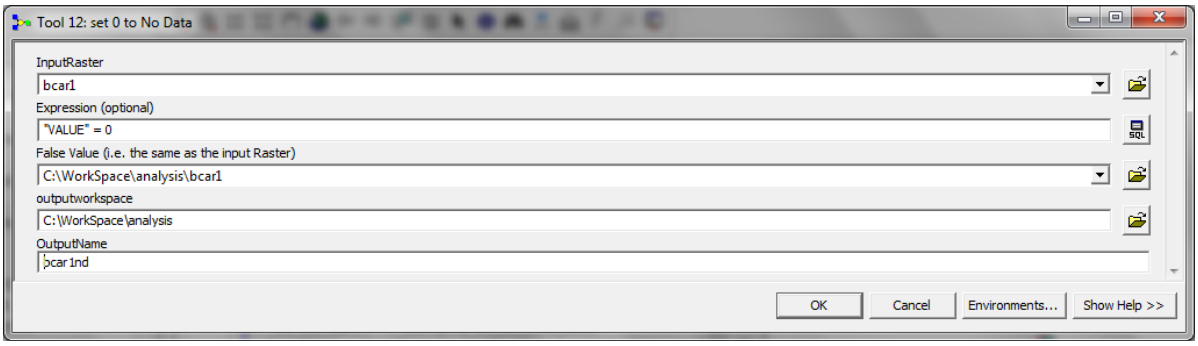


Add C:\WorkSpace\analysis\water raster to the ArcMap session

❖ **(3I) Set 0 to no data in the biomass carbon raster**

Run **Tool 12: Set 0 to No Data** (to convert 0 values to no data in the bcar1 dataset)

- InputRaster = bcar1
- Expression = "VALUE" = 0
- False Value = %InputRaster%
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcar1nd

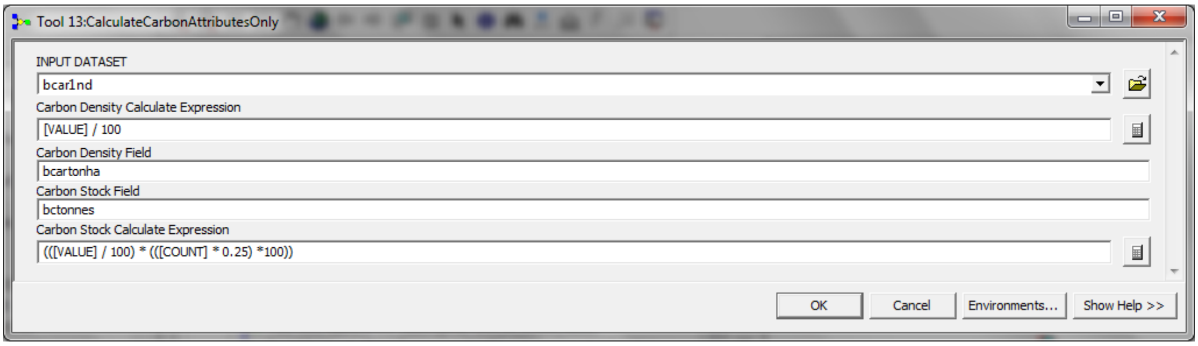


Add C:\WorkSpace\analysis\bcar1nd raster to the ArcMap session

❖ **(3J) Add Carbon Attributes to biomass carbon raster**

Run **Tool 13:CalculateCarbonAttributesOnly** (to add attributes to the bcar1nd dataset)

- InputRaster = bcar1nd
- Carbon Density Calculate Expression = [VALUE] / 100
- Carbon Density Field = bcartonha
- Carbon Stock Field = bctonnes
- Carbon Stock calculate Expression = (([VALUE] / 100) * (([COUNT] * 0.25) *100))

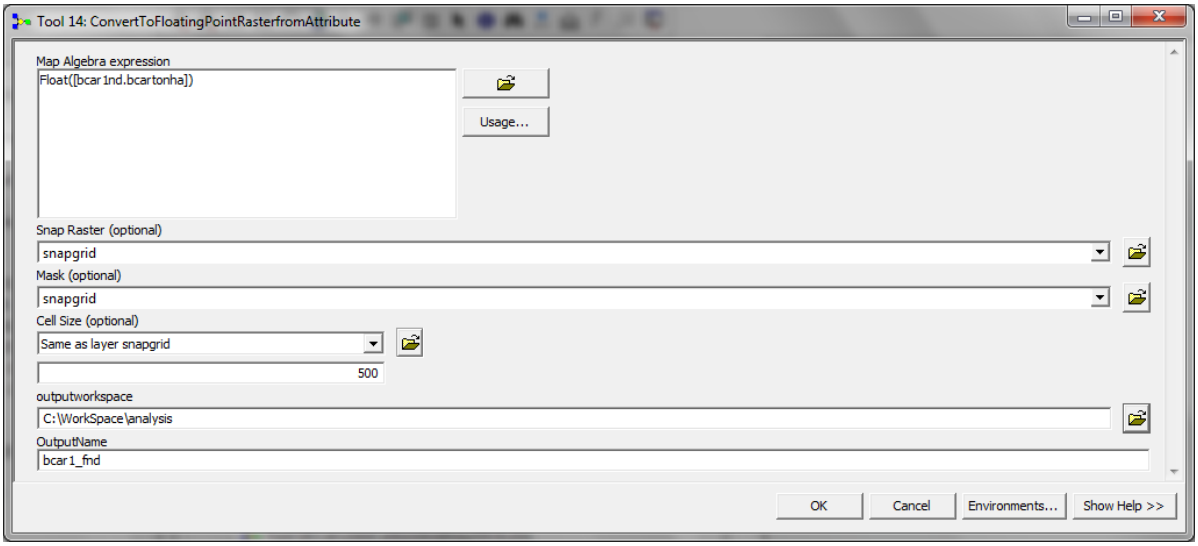


Open attribute table to check the fields have been calculated correctly.

❖ **(3K) Convert carbon raster to floating point**

Run **Tool 14: ConvertToFloatingPointRasterfromAttribute** (to convert the bcar1nd dataset to a floating point raster)

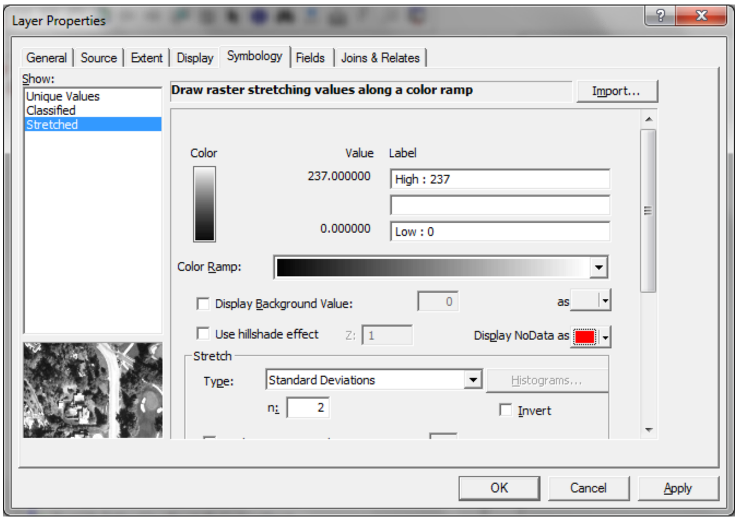
- Map Algebra Expression = Float([bcar1nd.bcartonha])
- Snap Raster = snapgrid
- Mask = snapgrid
- Cell Size = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcar1_fnd



Add C:\WorkSpace\analysis\bcar1_fnd raster to the ArcMap session

Note: To Display no data values in a floating point raster

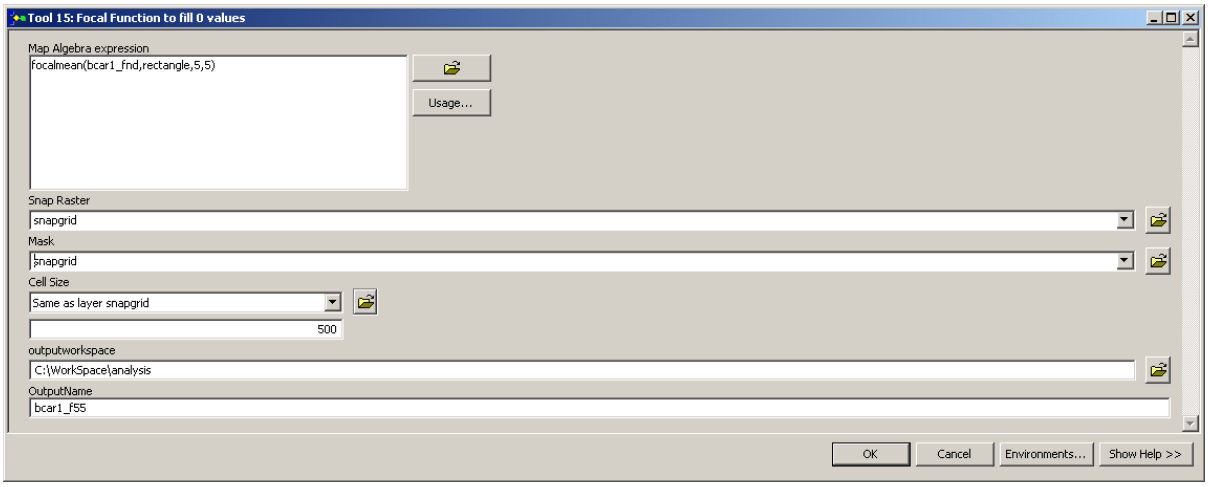
- Double click on the dataset in the table of contents
- In the Layer properties window Click on Symbology
- Change the colour where it says 'Display no data as' to a color e.g. Red



❖ **(3L) Run focal mean to fill 0 values**

Run **Tool 15: Focal Function to fill 0 values** (to fill 0 values in the bcar1_fnd dataset with the average nearest carbon value)

- Map Algebra Expression = focalmean(bcar_fnd,rectangle,5,5)
- Snap Raster = snapgrid
- Mask = snapgrid
- Cell Size = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcar1_f55

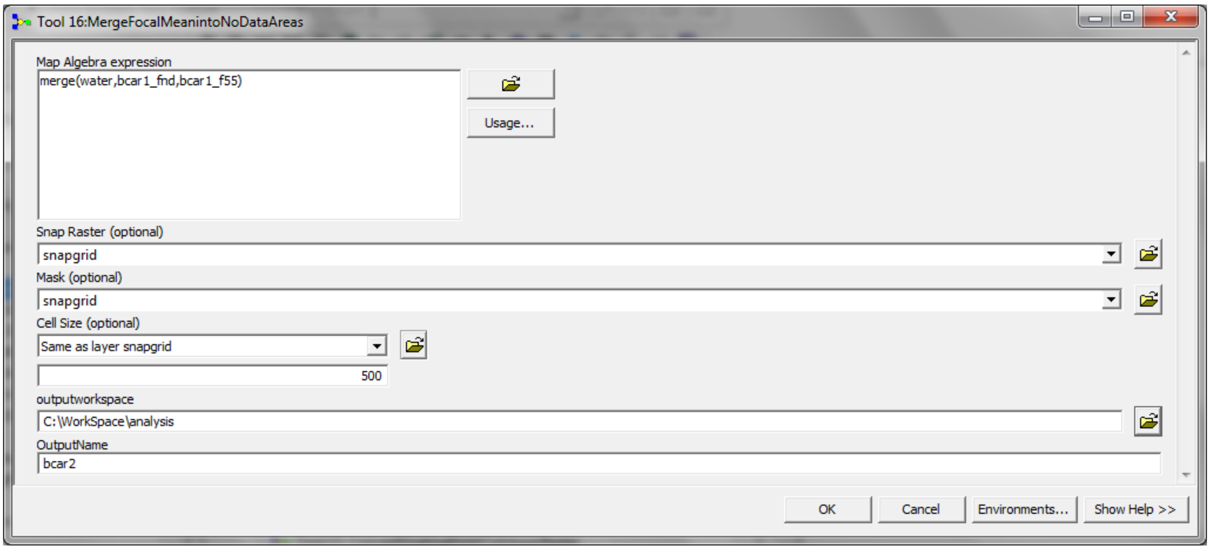


Add C:\WorkSpace\analysis\bcar1_f55 raster to the ArcMap session

❖ (3M) Merge water and focal mean into no data areas

Run **Tool 16:MergeFocalMeanintoNoDataAreas** (to fill 0 values in the bcar1_fnd dataset with the average nearest carbon value)

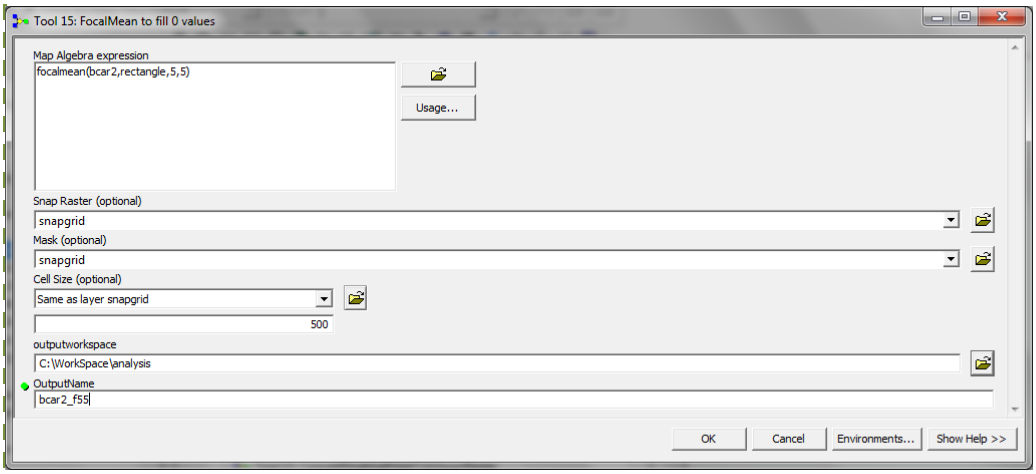
- Map Algebra Expression = merge(water,bcar1_fnd,bcar1_f55)
- Snap Raster = snapgrid
- Mask = snapgrid
- Cell Size = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcar2



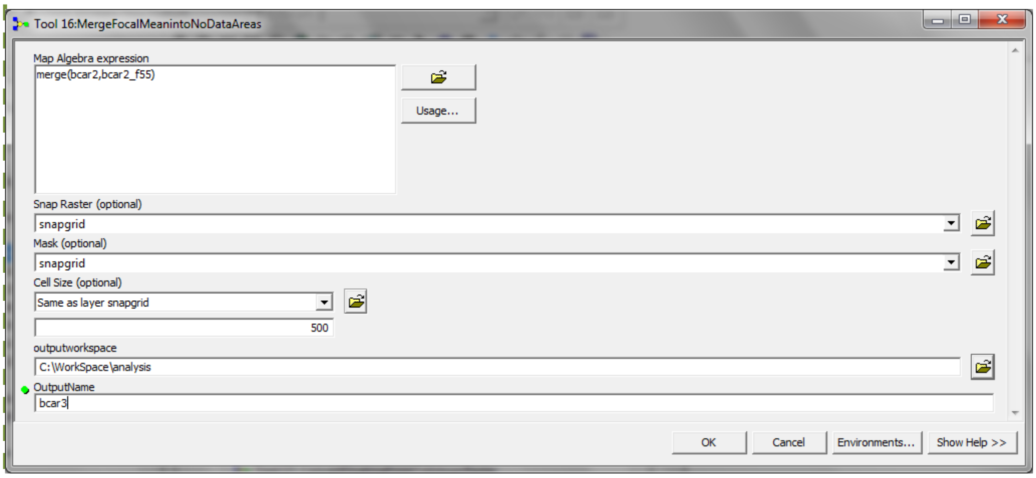
Add C:\WorkSpace\analysis\bcar2 raster to the ArcMap session

Then repeat focal mean and merge processes until no areas of 0 are left

REPEAT AS NECESSARY



Add C:\WorkSpace\analysis\bcar2_F55 raster to the ArcMap session



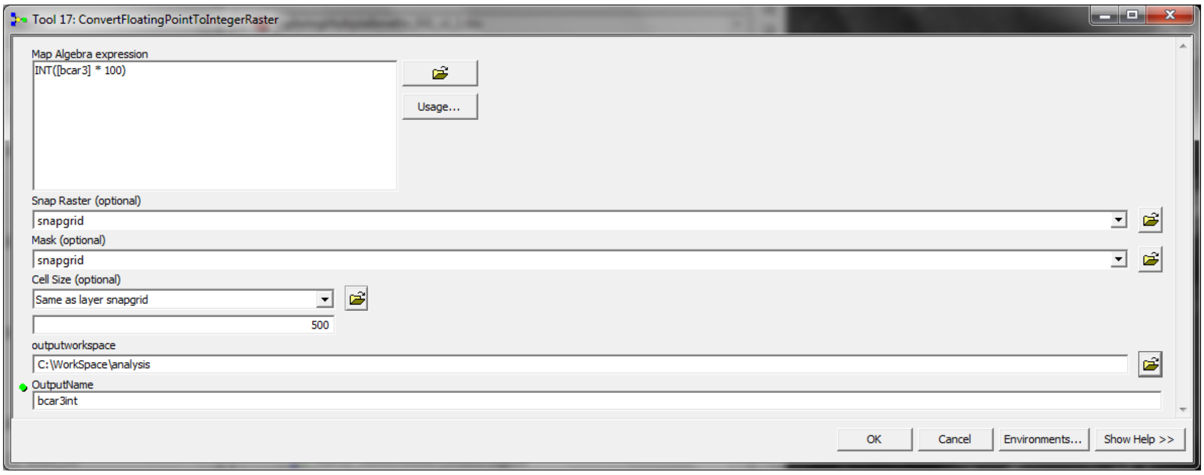
Add C:\WorkSpace\analysis\bcar3 raster to the ArcMap session

❖ **(3N) Create above and below ground biomass carbon map from carbon attribute field to give a raster dataset with units of tonnes/ha * 100**

Run **Tool 17: ConvertFloatingPointToIntegerRaster**

The tool will fill 0 values in the bcar1_fnd dataset with the average nearest carbon value.

- Map Algebra Expression = INT([bcar3] * 100)
- Snap Raster = snapgrid
- Mask = snapgrid
- Cell Size = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcar3int



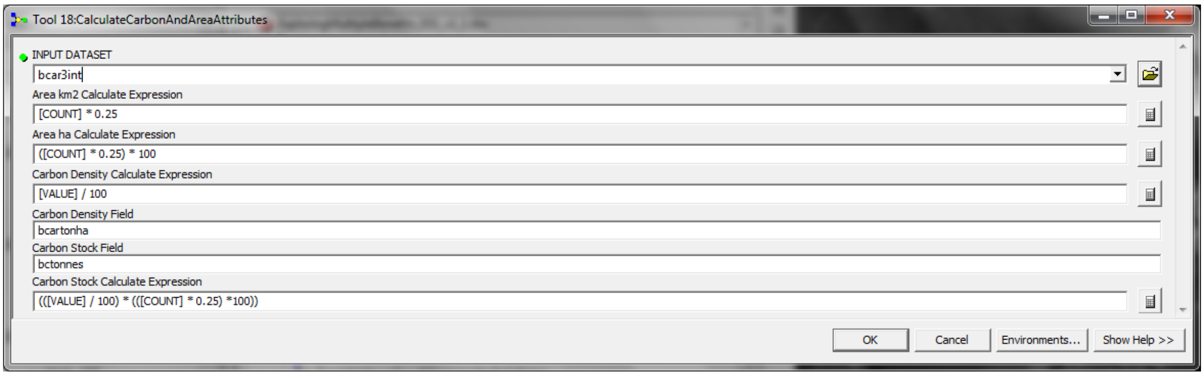
Add C:\WorkSpace\analysis\bcar3int raster to the ArcMap session

- **(30) Add area and carbon attributes to the above and below ground biomass carbon map**

  Run **Tool 18: CalculateCarbonAndAreaAttributes**

  The tool calculate the area and carbon attributes in the bcar3int raster.

    - Input Dataset = bcar3int
    - Area km2 Calculate Expression = [COUNT] * 0.25
    - Area ha Calculate Expression = ([COUNT] * 0.25) * 100
    - Carbon Density Calculate Expression = [VALUE] / 100
    - Carbon Density Field = bcartonha
    - Carbon Stock Field = bctonnes
    - Carbon Stock calculate Expression = (([VALUE] / 100) * (([COUNT] * 0.25) *100))



Open attribute table to check the fields have been calculated correctly.

At this stage the steps to create the biomass carbon dataset are complete. The biomass carbon dataset consists of above and below ground carbon.

Summary of fields in Carbon attribute table. For each row in the attribute table

Rowid	=	Internal ArcGIS unique number (starting at 0 for row 1)
VALUE	=	Biomass Carbon in tonnes / ha * 100 (to make an integer raster)
COUNT	=	Number of 500*500m cells in the dataset containing that VALUE
AREA_KM2	=	COUNT * 0.25 (as each cell is 500m * 500m)
AREA_HA	=	AREA_HA * 10000
BCARTONHA	=	Biomass Carbon in tonnes / ha (calculated from VALUE/100)
BCTONNES	=	containing that value (calculated from AREA_HA * BCARTONHA)

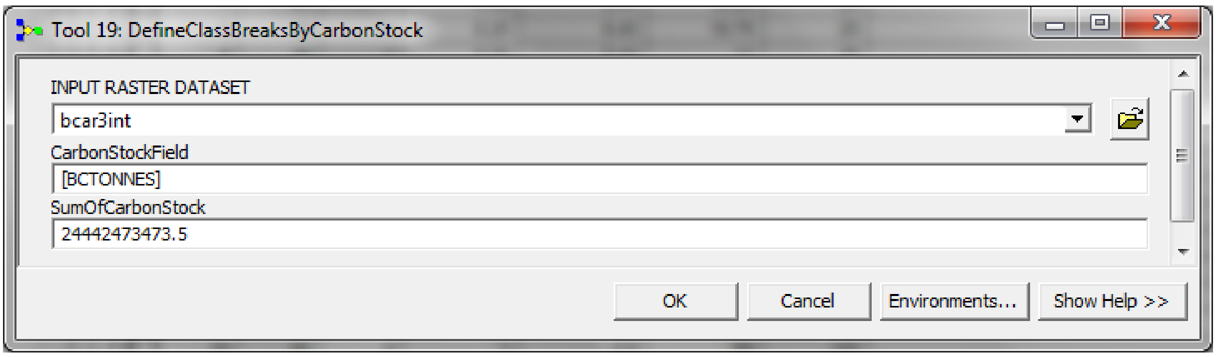
There are two different ways to display the carbon data

1) Using area-based quantiles which takes all the cells in the raster dataset and splits them into classes each containing the same number of cells i.e. For 5 classes 1/5th of the countries area
2) Using stock-based quantiles which looks at how much carbon is in the whole dataset and splits the data into equal classes containing the same amount of carbon.

❖ **(3P) To help define stockbased class breaks**

Run **Tool 19: DefineClassBreaksByCarbonStock** (for stockbased groupings)

- BEFORE running the tool, obtain sumofcarbonstock
    - Open the carbon attribute table. Make sure no records are selected.
    - Right click on the bctonnes field
    - Click Statistics
    - In the Statistics window highlight the value for Sum
    - Right Click and Copy
    - Right Click and paste the value in SumOfCarbonStock.



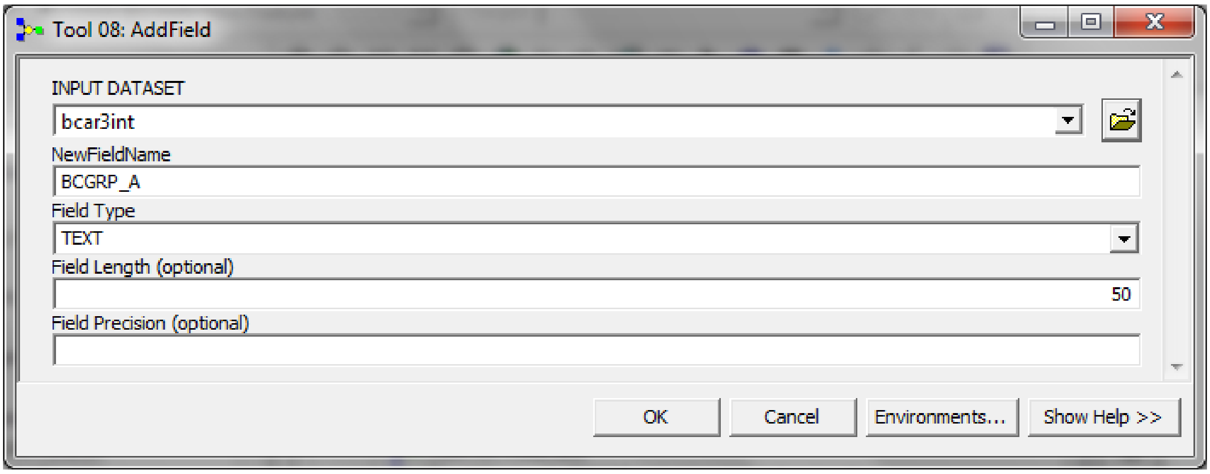
Open the bcarint3 attribute table and check that a field called cumstk and stkprop are present. Stkprop should have numbers ranging from 1 – 100 to indicate the proportion of the countries carbon in each row of the table.

❖ **(3Q) Add a field for carbon group (area based) BCGRP_A**

Run Tool 08: AddField

This step adds a new field called BCGRP_A which will be used to store the area-based classes as an attribute so that statistics can be easily generated on the same class breaks as the maps.

- InputTable=bcar3int
- NewFieldName = BCGRP_A
- FieldType= text
- Field Length = 50
- Field Precision = leave blank

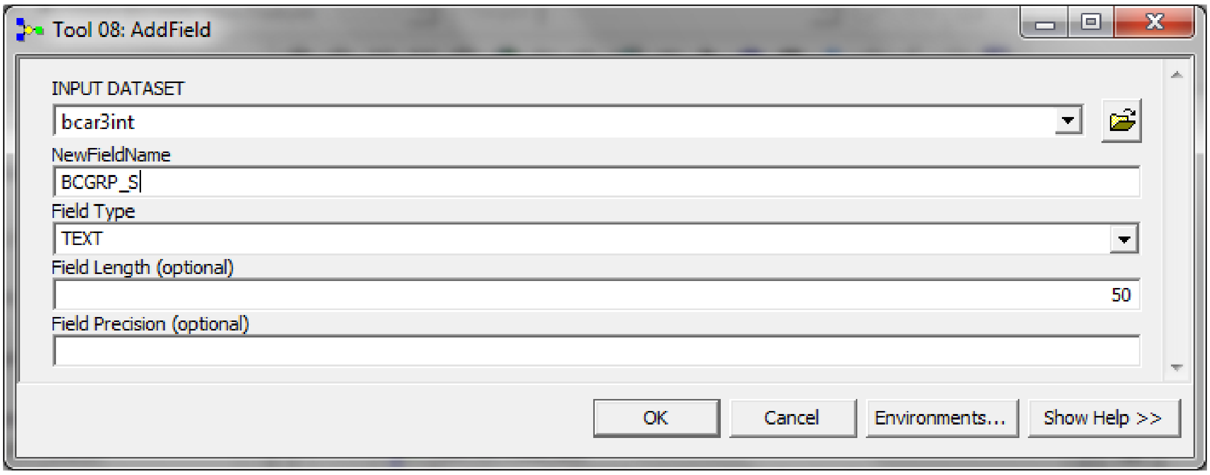


❖ **(3R) Add a field for carbon group (area based) BCGRP_S**

Run Tool 08: AddField

This step adds a new field called BCGRP_A which will be used to store the stock-based classes as an attribute so that statistics can be easily generated on the same class breaks as the maps.

- InputTable=bcar3int
- NewFieldName = BCGRP_A
- FieldType= text
- Field Length = 50
- Field Precision = leave blank

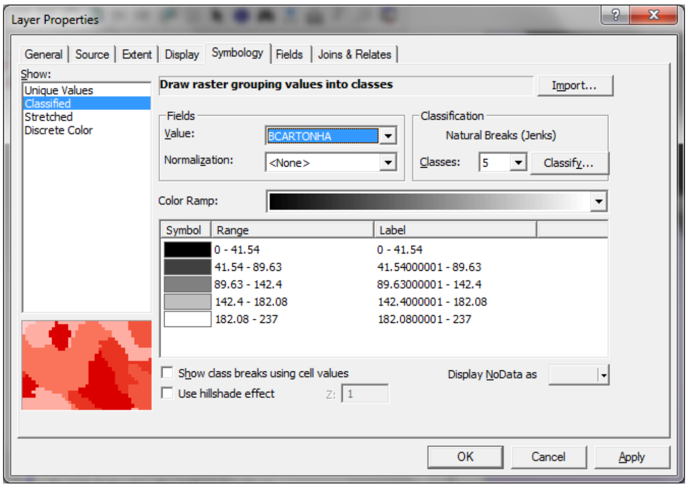

Tool 08: AddField
INPUT DATASET
bcar3int
NewFieldName
BCGRP_S
Field Type
TEXT
Field Length (optional)
50
Field Precision (optional)
OK
Cancel
Environments...
Show Help >>

(4A) Manual steps Manual Steps to add customised symbolset to ArcMap and symbolise carbon in the map layout

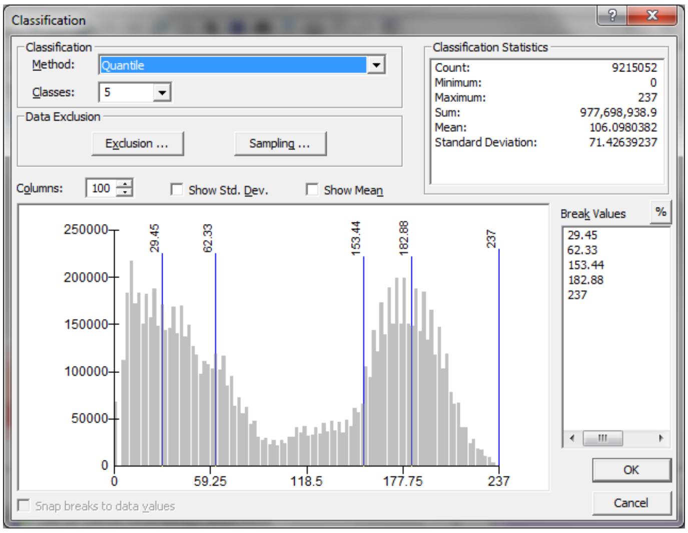
Add customised symbolset to ArcMap:-

- In ArcMAP from the main menu bar click on Tools – Styles – Style Manager . Click on the styles button on the right hand side .
- A list appears, click with the left mouse button on the small downward arrow at the bottom of the list. Keep pressing until the 'Add... ' is visible. Click Add.
- Navigate to the location where the ExploringMultipleBenefits toolbox is located chose the file carbon.style. Click Open.
- The style set will now be visible in the list in the left hand panel. Click close to close the Style Manager.

Define symbology for area-based quantiles:-

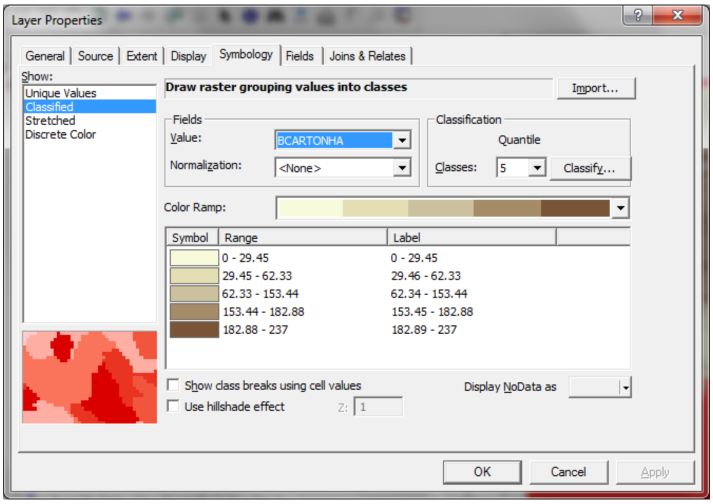


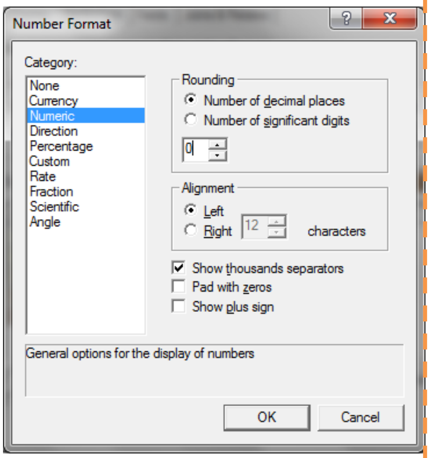
- Double-click on the carbon dataset
- In the Layer Properties window, Click on the symbology tab
- On the left panel, change from stretched to classified
- Change the 'Value' field to BCARTONHA.
- Chose number of classes (5 or 6)
- Click on the 'Classify' button on the right-hand side.



- In the Classification window change the 'Classification Methods' to Quantile.
- Click OK.

- Click Apply but do not close the Layer properties window.
- From the colour ramps pick one of the defined ramps with either 5 or 6 brown class breaks.
- Click on Lables – Format Labels and change number of decimal places to 2.



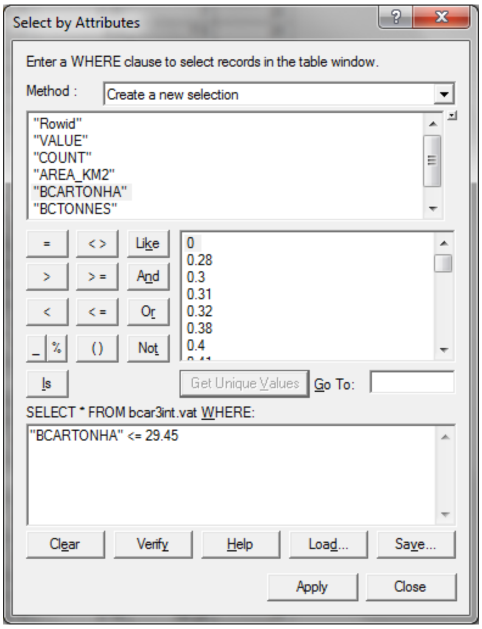


- Click ok to close the Number Format Window.
- Click Apply then OK to close the Layer Properties window

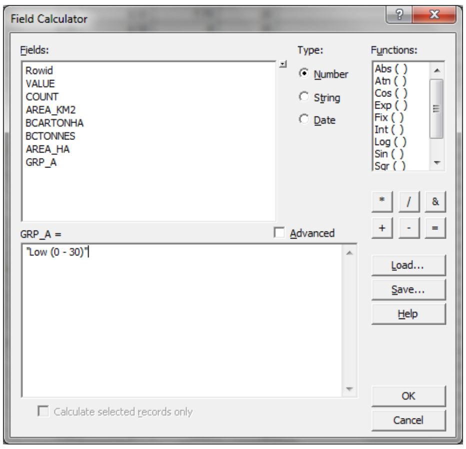
This has defined and shaded the carbon map using Area-Based Quantiles.

Populate the' BCGRP_A' attribute field with the defined class breaks.

- Open the attribute table of the carbon dataset. Click Options – Select By Attribute for the first carbon group (e.g. "BCARTONHA" <= 29.45)



- Click Apply
- Right click on the 'BCGRP_A' field
- Click Field Calculator
- Click Yes
- Calculate the first group into the field
- (e.g. "Low (0 – 29.45)"
- Click Ok.



Repeat for all the class groups (e.g.
"BCARTONHA" > 29.45 AND "BCARTONHA" <= 62.33
"BCARTONHA" > 62.33 AND "BCARTONHA" <= 153.44
"BCARTONHA" > 153.44 AND "BCARTONHA" <= 182.88
"BCARTONHA" > 182.88)

- Then for each of the class breaks click on a cell in the BCGRP_A containing the "Low (...." description. Right click – copy and paste the words into the relevant class break in the carbon layer table of contents so that when the map layout is produced those words will appear in the map legend.
- Also change BCARTONHA to "Biomass Carbon (tonnes / ha)" so that these words will also appear on the legend.
- Next to the name of the dataset add the words _AreaBased so that it can be identified easily as the AreaBased classification
- Right-click on this layer and save as layerFile calling it BiomassCarbon_AreaBased.lyr

Define symbology for stock-based quantiles:-

For 5 stock-based class breaks 20% of the carbon will be in each class break. Therefore find the BCARTONHA field values for STKPROP 20, 40, 60, 80, 100:-

- Right click on the carbon dataset
- Open the attribute table (note - the field STKPROP will automatically be sorted from 1-100)
- Scroll down the table and find the value in the STKPROP field that is closest to 20
- For this row write down the value for BCARTONHA to 2 decimal places.
- Repeat this for 40,60,80 and 100

In ArcMap make a copy of the_AreaBased layer in the table of contents

- right click on the _AreaBased carbon layer and click copy
- right click on layers in the table paste layers

2 copies of the dataset are now in the ArcMap session. Rename one of them to _StockBased.

- Double click on the _StockBased layer.
- In the Layer properties window Click on Symbology.
- Click on Classify.
- In the Classification window manually change the class breaks to the Biomass Carbon Values noted for 20,40,60,80 and 100%.
- Click Ok.
- Click Apply.
- Click Ok.

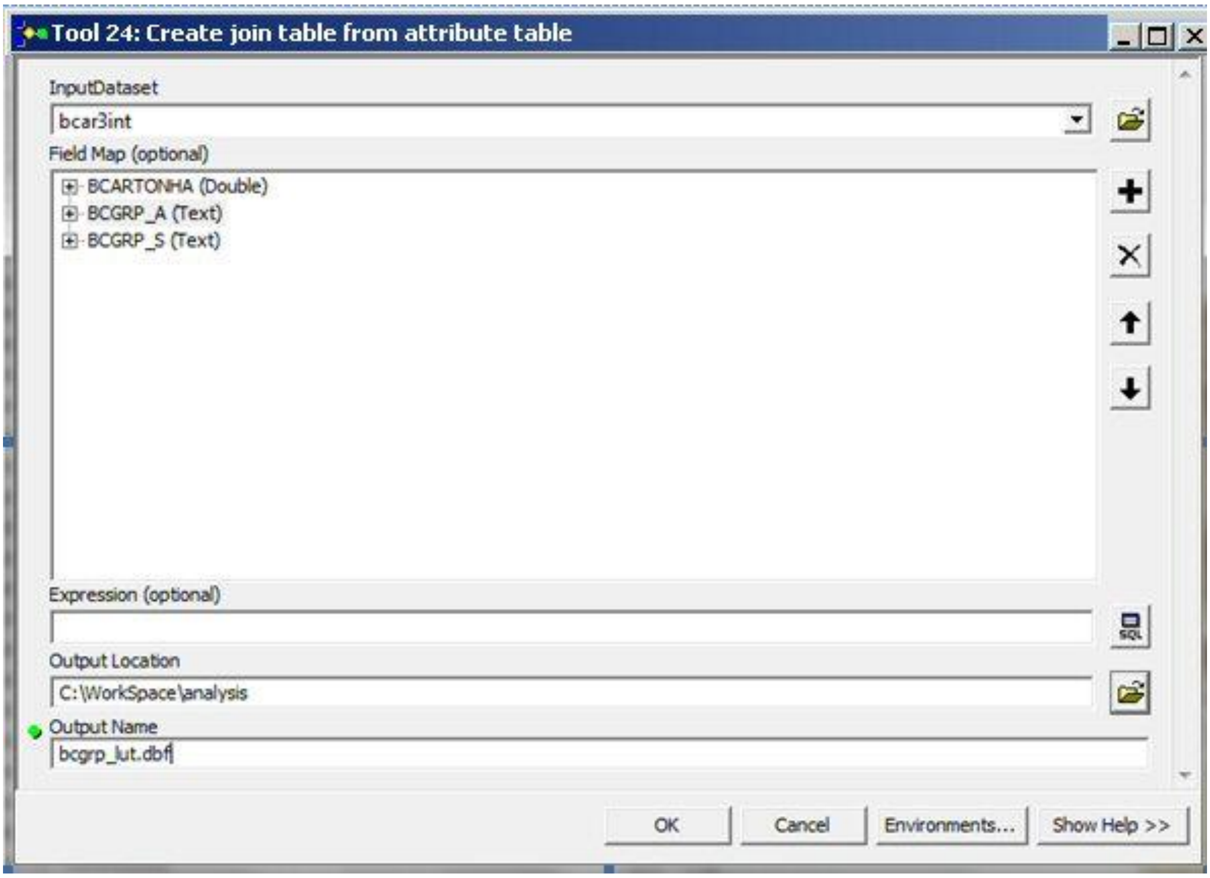
There are now two versions of the biomass carbon dataset in the ArcMap session shaded using the two methods.

(4B) Run tool 24 to create a summary dbf file of the carbon groups

Run **Tool 24: Create join table from attribute table**

This step creates a summary dbf file. This is necessary as the carbon groups will need to be joined onto the final statistics table.

- InputDataset=bcar3int
- Field Map = use the cross on the right hand side to delete any fields not required in the dbf table.
- Expression = leave blank
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcgrp_lut.dbf



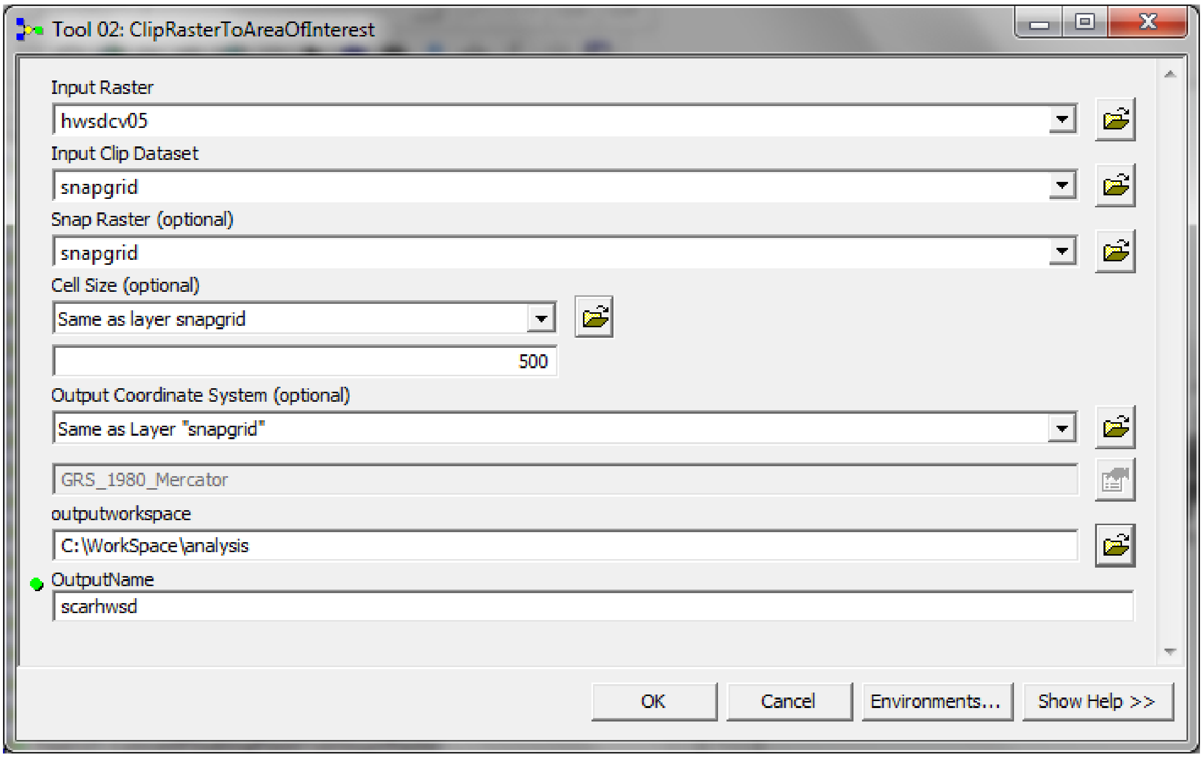
<u>Clip Soil Carbon (from the global Harmonized World Soils Database (HWSD)</u>

❖ **(5A) Clip global soil carbon dataset to 'snapgrid'**

Run **Tool 02: ClipRasterToAreaOfInterest**

This step clips the global soil carbon dataset to the country extent using the 'snapgrid'.

- Input Raster = hwsdcv05
- Input Clip Dataset = snapgrid
- Snap Raster = snapgrid
- Cellsize = 500
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = scarhwsd

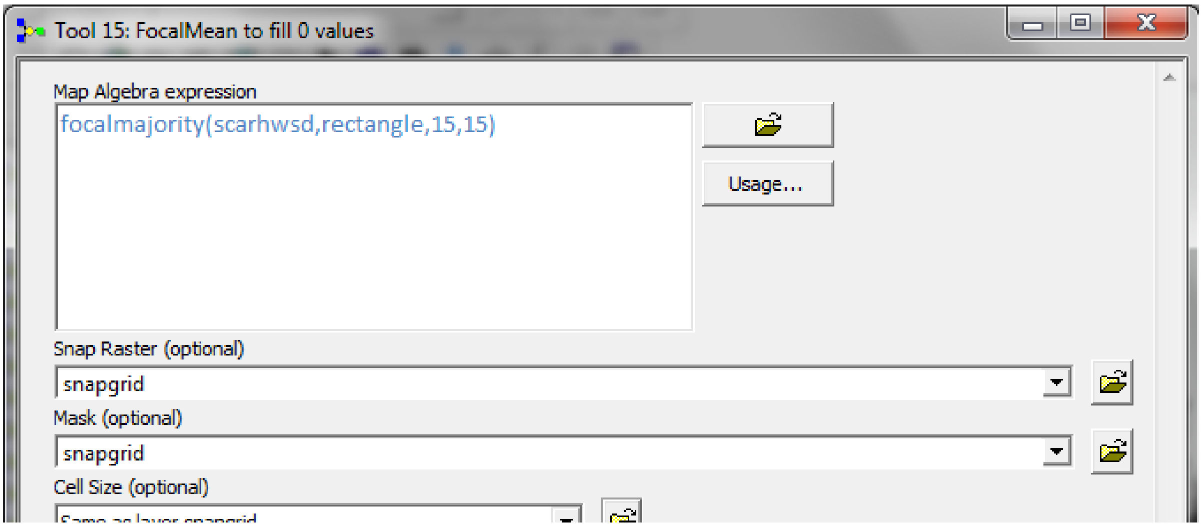


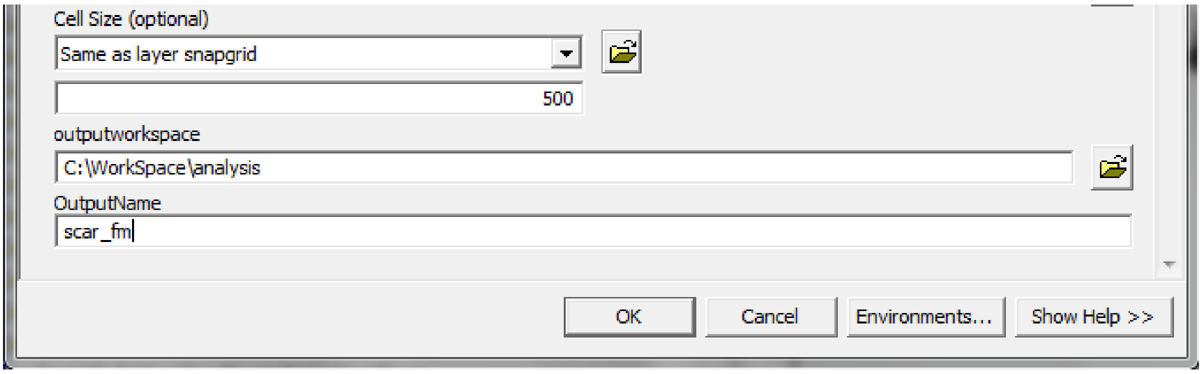
Add C:\WorkSpace\analysis\scarhwsd raster to the ArcMap session

❖ **(5B) Run a Focal majority to fill any missing pixels**

Run **Tool 15: Focal Function to fill 0 values** (to fill 0 values in the bcar1_fnd dataset with the average nearest carbon value)

- Map Algebra Expression = focal**majority**(scarhwsd,rectangle,15,15)
- Snap Raster = snapgrid
- Mask = snapgrid
- Cell Size = 500
- Output workspace = C:\WorkSpace\analysis
- OutputName = scar_fm



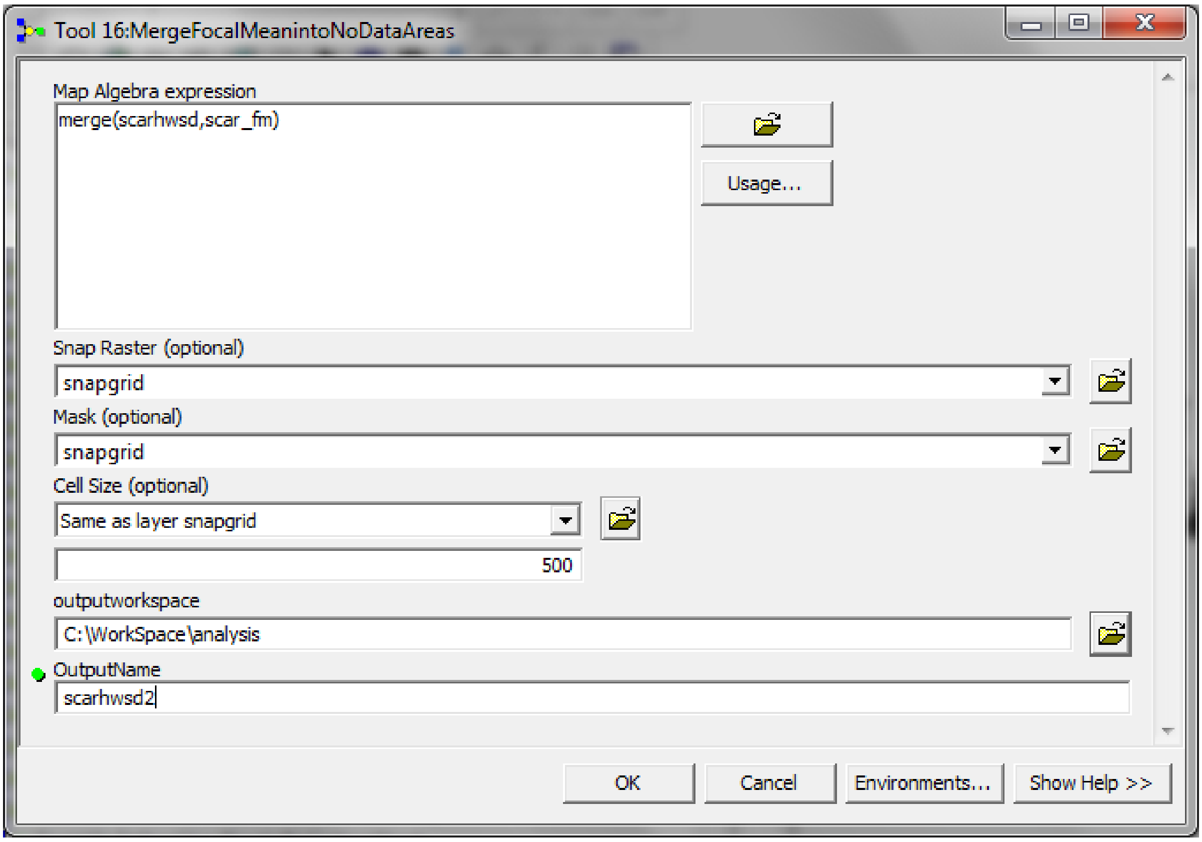


Add C:\WorkSpace\analysis\scar_fm raster to the ArcMap session

- **(5C) Merge soil carbon and the result of the focal majority to include missing pixels in soil carbon**

  Run **Tool 16: MergeFunctionValuesintoNoDataAreas** (to fill 0 values in the bcar1_fnd dataset with the average nearest carbon value)

  - Map Algebra Expression = merge(scarhwsd,scar_fm)
  - Snap Raster = snapgrid
  - Mask = snapgrid
  - Cell Size = 500
  - Output workspace = C:\WorkSpace\analysis
  - OutputName = scarhwsd2

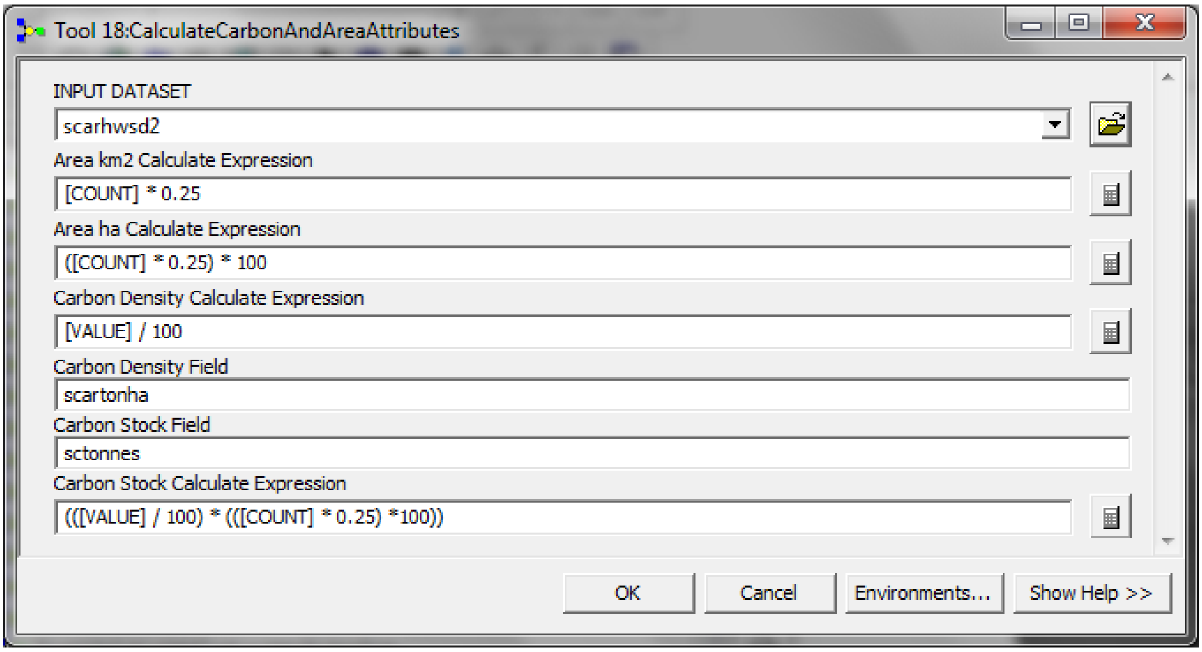


Add C:\WorkSpace\analysis\scarhwsd2 raster to the ArcMap session

- **(5D) Add area and carbon attributes to the soil carbon map**

Run **Tool 18:CalculateCarbonAndAreaAttributes**

- Input Dataset = scarhwsd2
- Area km2 Calculate Expression = [COUNT] * 0.25
- Area ha Calculate Expression = ([COUNT] * 0.25) * 100
- Carbon Density Calculate Expression = [VALUE] / 100
- Carbon Density Field = scartonha ***(NOTE the change to s instead of b)***
- Carbon Stock Field = sctonnes ***(NOTE the change to s instead of b)***
- Carbon Stock calculate Expression = (([VALUE] / 100) * (([COUNT] * 0.25) *100))



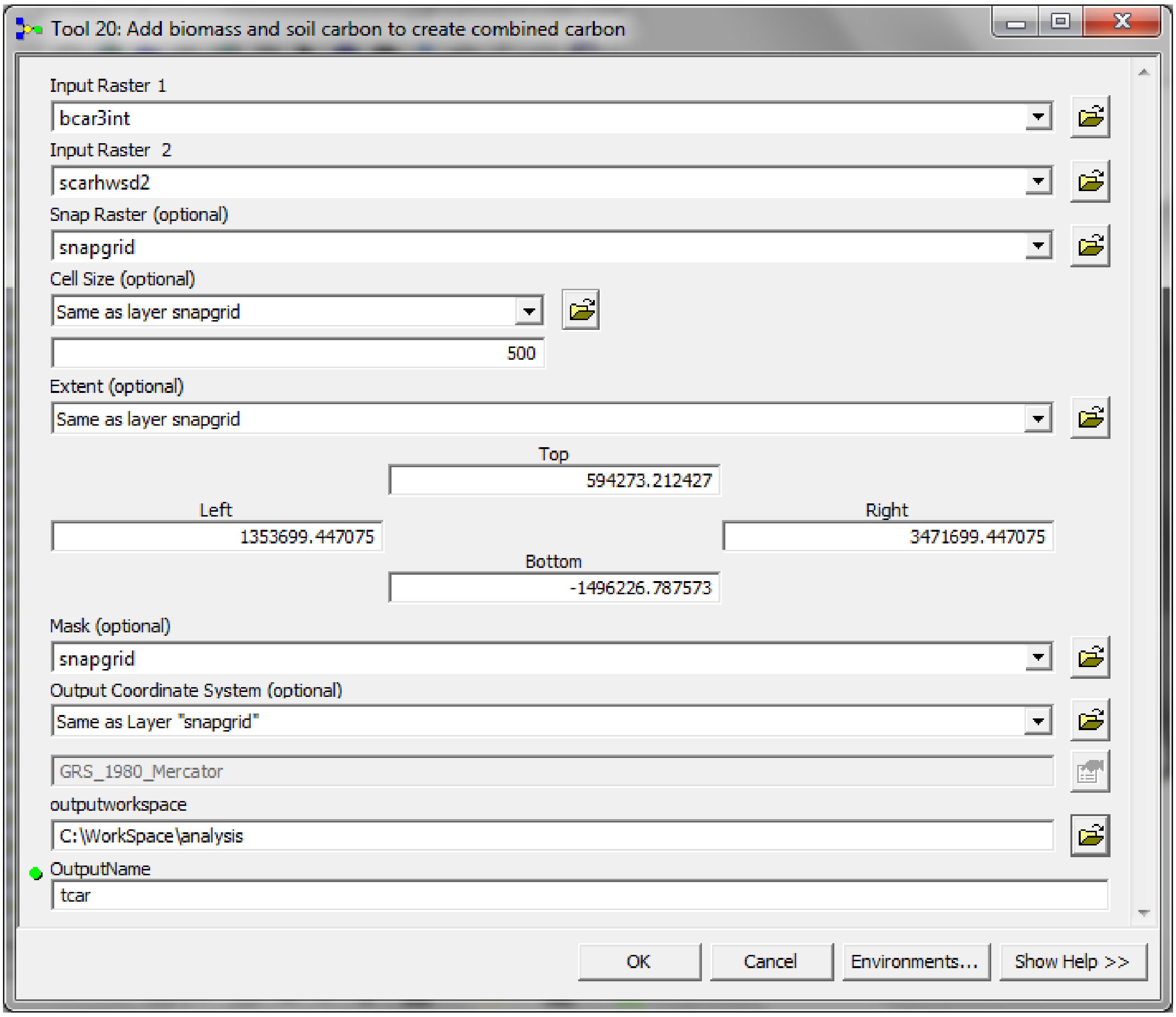
Open attribute table to check the fields have been calculated correctly.

<u>Combine the biomass and soil carbon datasets to create a total carbon dataset</u>

- **(6A) Add the above and below ground biomass carbon and the soil carbon to create a combined carbon map**

Run **Tool 20: Add biomass and soil carbon to create combined carbon**

- Input Raster 1 = bcar3int
- Input Raster 2 = scarhwsd2
- Snap Raster = snapgrid
- Cell Size = 500
- Extent = Same as Layer snapgrid
- Mask =snapgrid
- Output coordinate system = same as snapgrid
- Output workspace = C:\WorkSpace\analysis
- OutputName = tcar

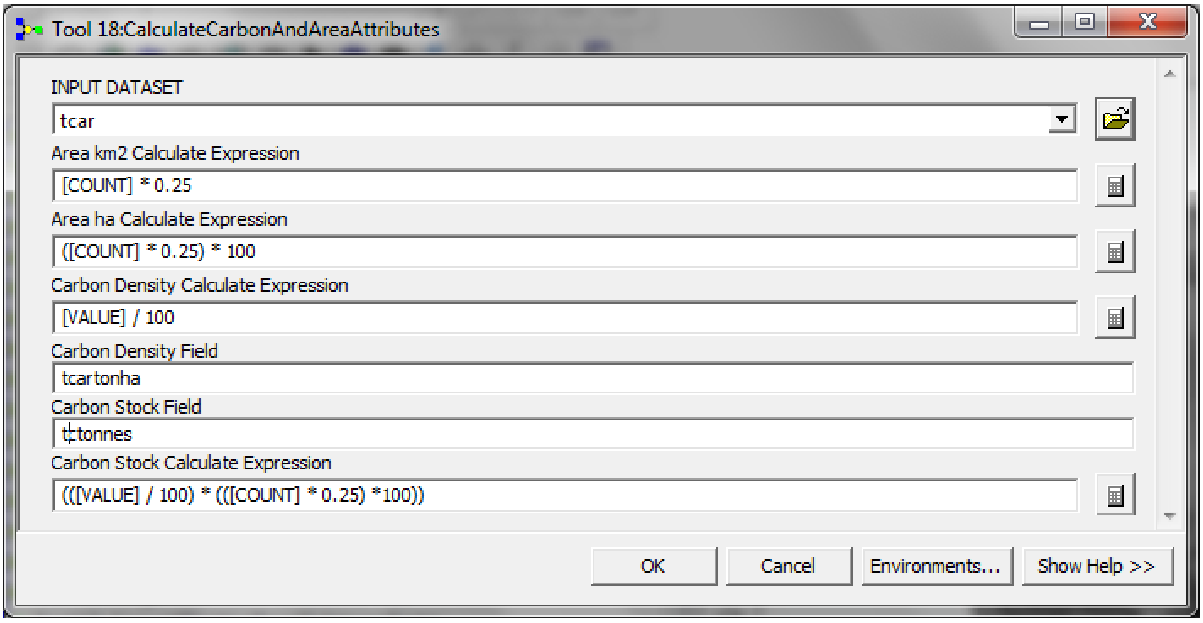


Add C:\WorkSpace\analysis\tcar raster to the ArcMap session

❖ **(6B) Add area and carbon attributes to the combined carbon (total carbon) map**

Run **Tool 18: CalculateCarbonAndAreaAttributes**

- Input Dataset = tcar
- Area km2 Calculate Expression = [COUNT] * 0.25
- Area ha Calculate Expression = ([COUNT] * 0.25) * 100
- Carbon Density Calculate Expression = [VALUE] / 100
- Carbon Density Field = tcartonha ***(NOTE the change to t instead of b)***
- Carbon Stock Field = tctonnes ***(NOTE the change to t instead of b)***
- Carbon Stock calculate Expression = (([VALUE] / 100) * (([COUNT] * 0.25) *100))



Open attribute table to check the fields have been calculated correctly.

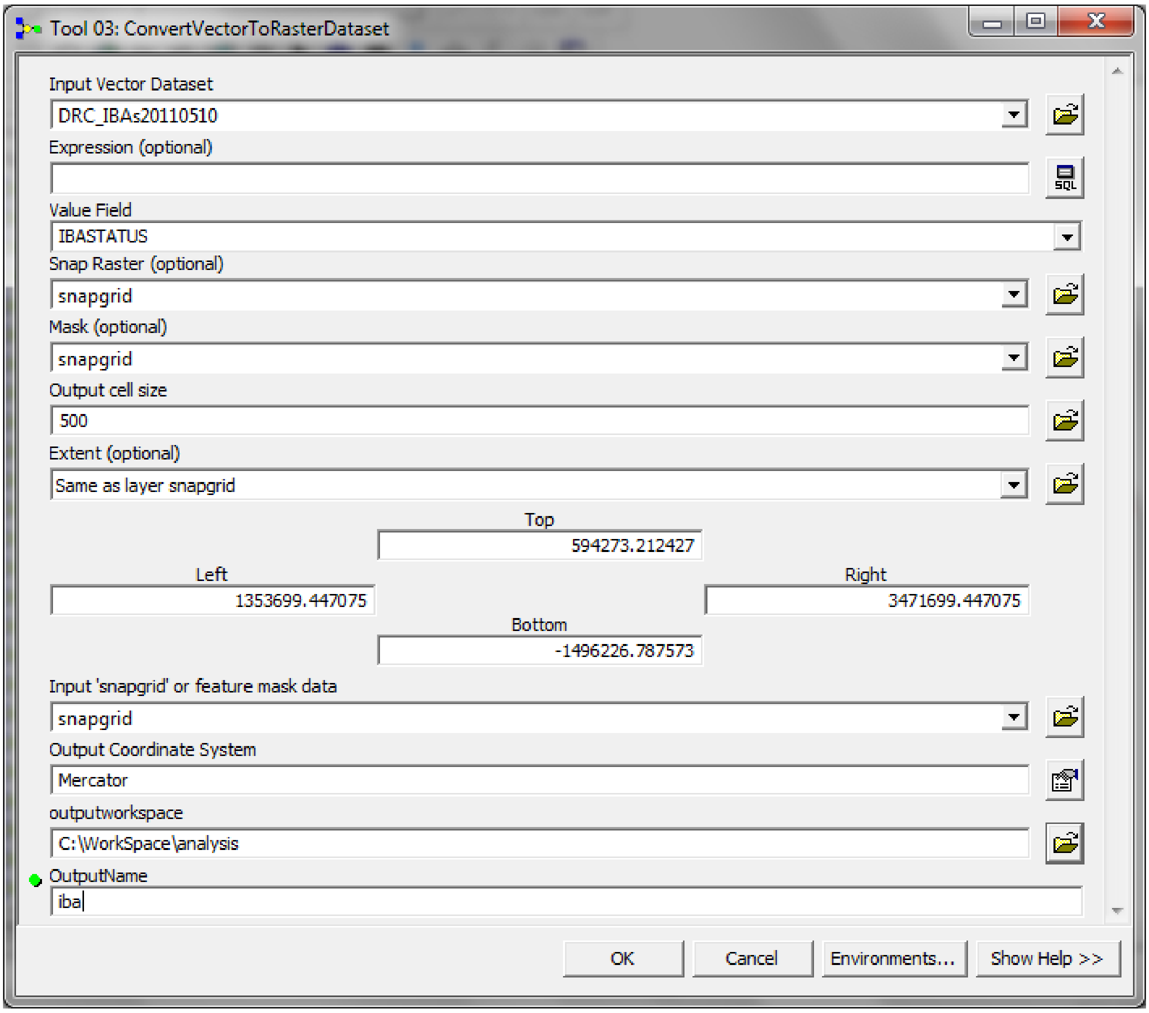
Producing Overlays with thematic datasets

- **(7A) Convert thematic dataset to raster**

REPEAT FOR EACH THEMATIC DATASET

Run **Tool 03: ConvertVectorToRasterDataset**

- The input vector dataset = DRC_IBAs20110510
- Value Field = IBASTATUS)
- Output cell size = 500
- Snap Raster = snapgrid
- Mask =snapgrid
- Extent = Same as Layer snapgrid
- Output coordinate system = Same as Layer snapgrid e.g.Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = iba



Add C:\WorkSpace\analysis\iba raster to the ArcMap session

FOR CARTOGRAPHY

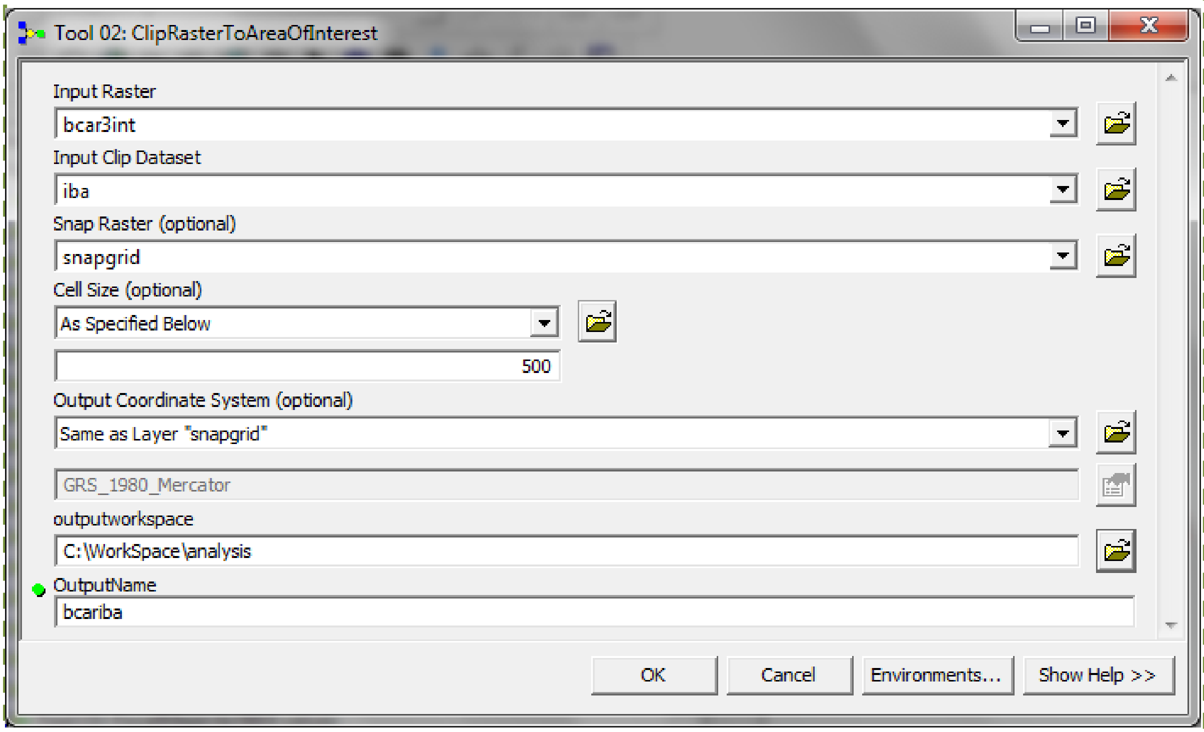
❖ (8A) Clip carbon map with thematic raster

Run **Tool 02: ClipRasterToAreaOfInterest**

REPEAT FOR EACH THEMATIC DATASET

This step clips the biomass carbon dataset to the thematic raster

- Input Raster = bcar3int
- Input Clip Dataset = iba
- Snap Raster = snapgrid
- Cellsize = 500
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = bcariba

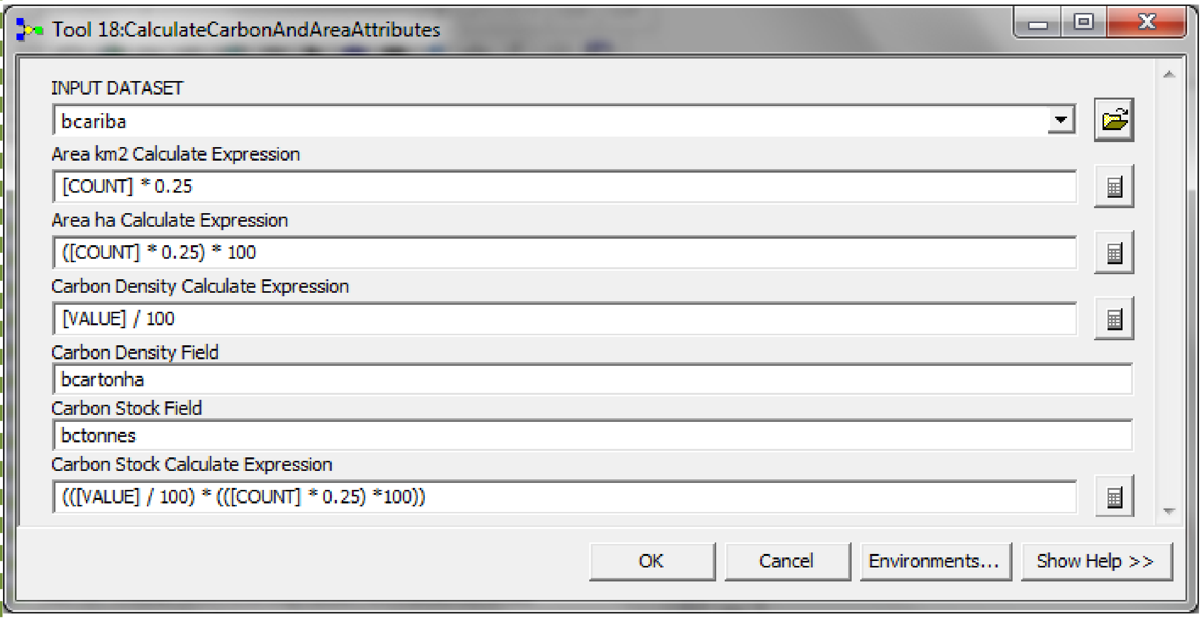


Add C:\WorkSpace\analysis\bcariba raster to the ArcMap session

❖ (8B) Add area and carbon attributes to the clipped biomass carbon map

Run **Tool 18:CalculateCarbonAndAreaAttributes** (add attributes to the bcar3int raster)

- Input Dataset = bcariba
- Area km2 Calculate Expression = [COUNT] * 0.25
- Area ha Calculate Expression = ([COUNT] * 0.25) * 100
- Carbon Density Calculate Expression = [VALUE] / 100
- Carbon Density Field = bcartonha
- Carbon Stock Field = bctonnes
- Carbon Stock calculate Expression = (([VALUE] / 100) * (([COUNT] * 0.25) *100))



Open attribute table to check the fields have been calculated correctly.

Shade the thematic dataset clipped carbon in the same classbreaks as the full carbon dataset

- Double click on bcariba
- In the Layer Properties window click on Symbology
- Click on Classified
- Click on import and pick from the dropdown (Chose to shade by either the _Areabased or _Stockbased carbon)
- Click Ok
- Pull down the ColorRamp dropdown and pick a different 5 class ramp(e.g. greens)
- Draw the outlines of the thematic datasets from the Shapefile with line thickness 1.

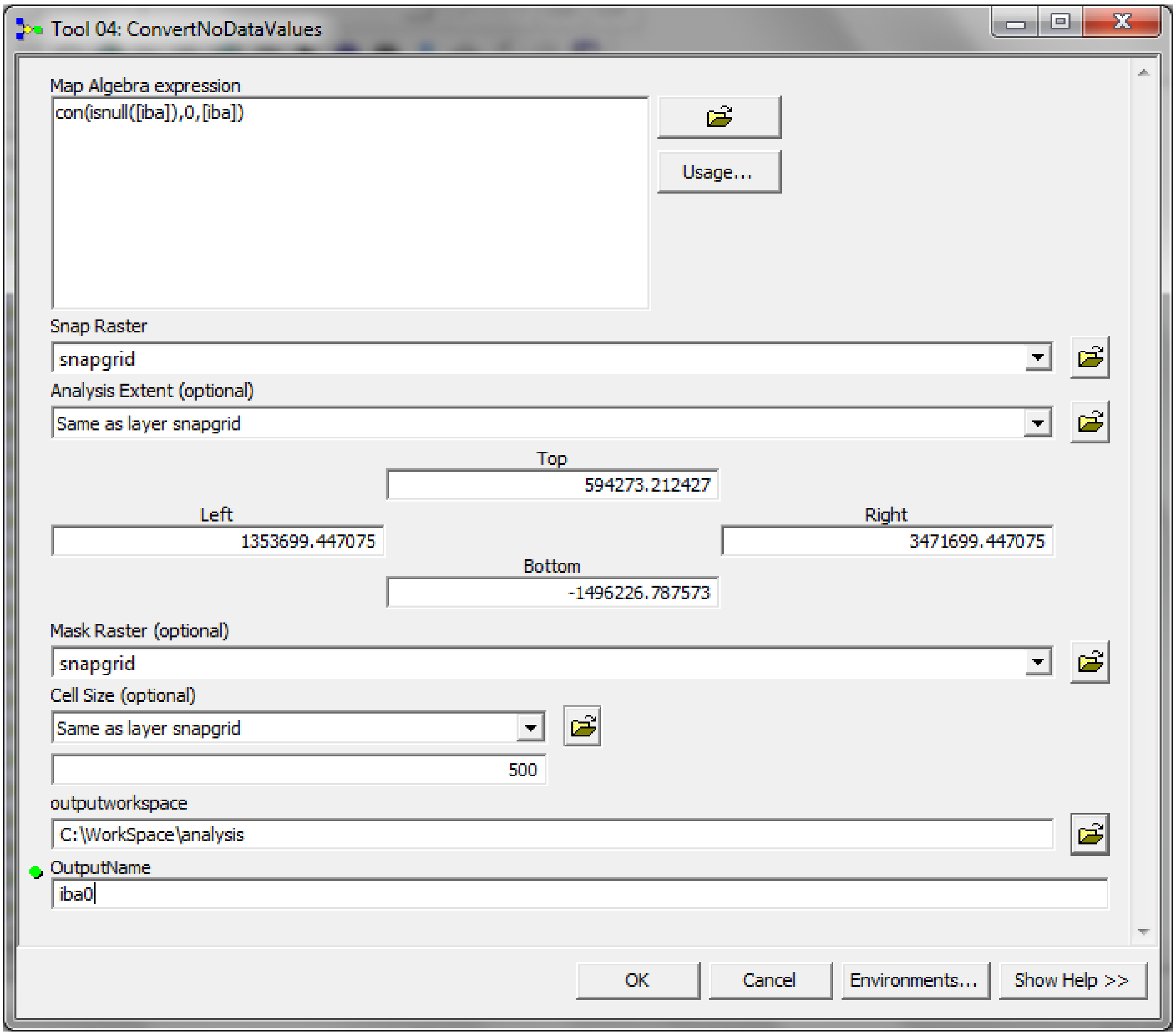
FOR ANALYSIS

❖ **(9A) Convert nodata to 0 in thematic raster**

Repeat for Each Thematic Dataset

Run **Tool 04: ConvertNoDataValues**

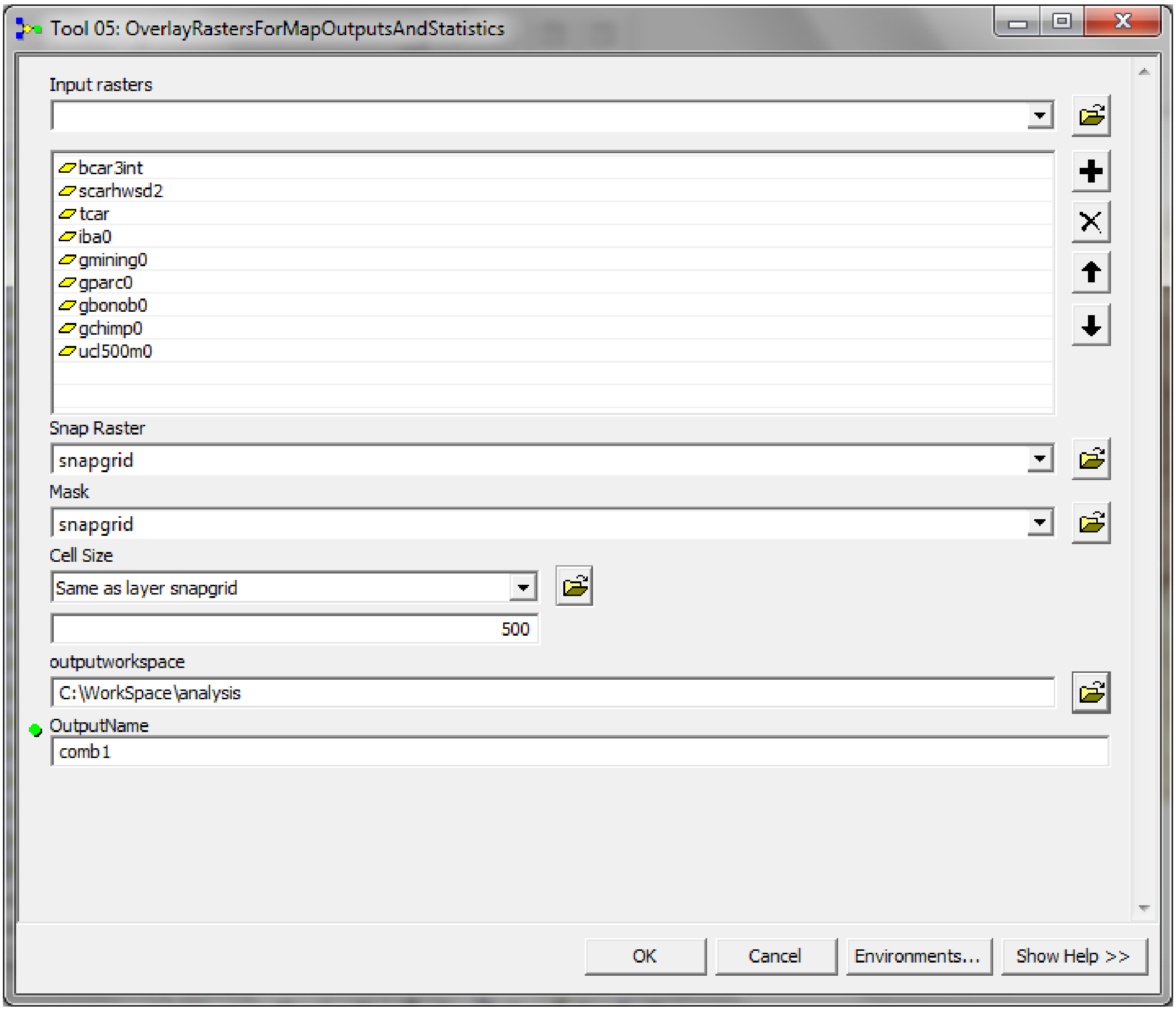
- Map Algeba = con(isnull([iba]),0,[iba])
- Snap Raster = snapgrid
- Analysis Extent = Same as layer snapgrid
- Mask Raster = snapgrid
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output Raster = C:\WorkSpace\analysis\iba0



❖ **(9B) Overlay carbon and thematic datasets**

Run **Tool 05: OverlayRastersForMapOutputsAndStatistics** (This combines the Biomass, FAO ecological zones and the landcover datasets)

- Input Rasters =navigate to the folder and pick up all the dataset with a '0' bcar3int, iba0, pa0
- Snap Raster = snapgrid
- Mask Raster = snapgrid
- Output coordinate system = Same as Layer snapgrid e.g. Mercator
- Output workspace = C:\WorkSpace\analysis
- OutputName = bioeco

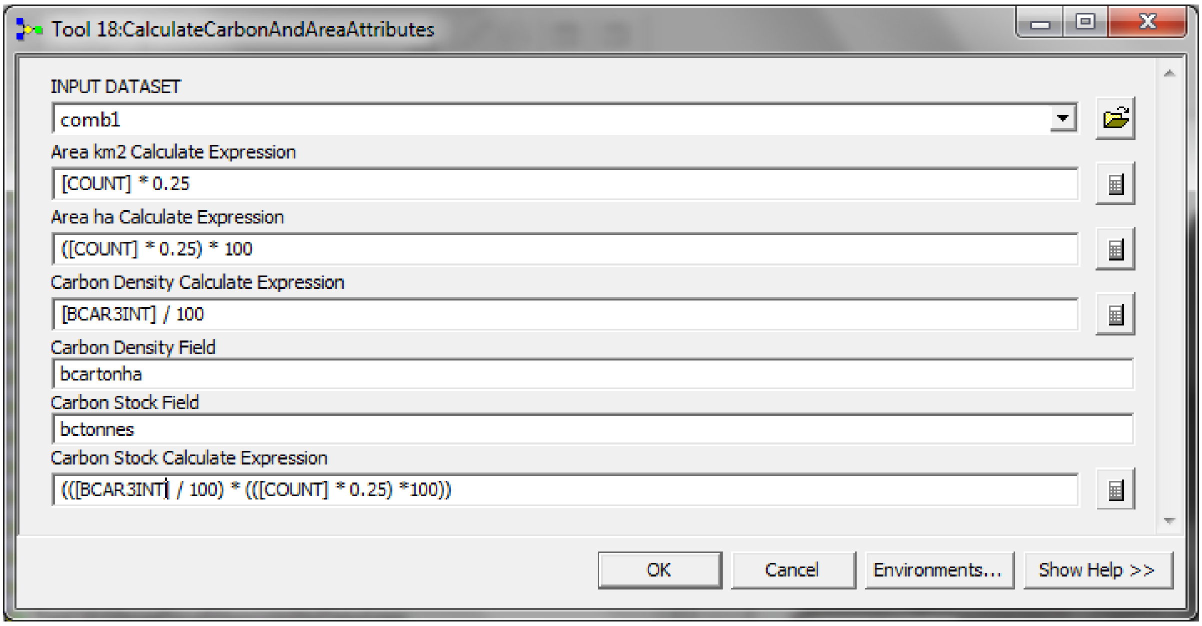


Add C:\WorkSpace\analysis\comb1 raster to the ArcMap session

❖ **(9C) Add area and biomass carbon attributes to combined dataset**

Run **Tool 18:CalculateCarbonAndAreaAttributes**

- Input Dataset = comb1
- Area km2 Calculate Expression = [COUNT] * 0.25
- Area ha Calculate Expression = ([COUNT] * 0.25) * 100
- Carbon Density Calculate Expression = [BCAR3INT] / 100
- Carbon Density Field = bcartonha
- Carbon Stock Field = bctonnes
- Carbon Stock calculate Expression = (([BCAR3INT] / 100) * (([COUNT] * 0.25) *100))

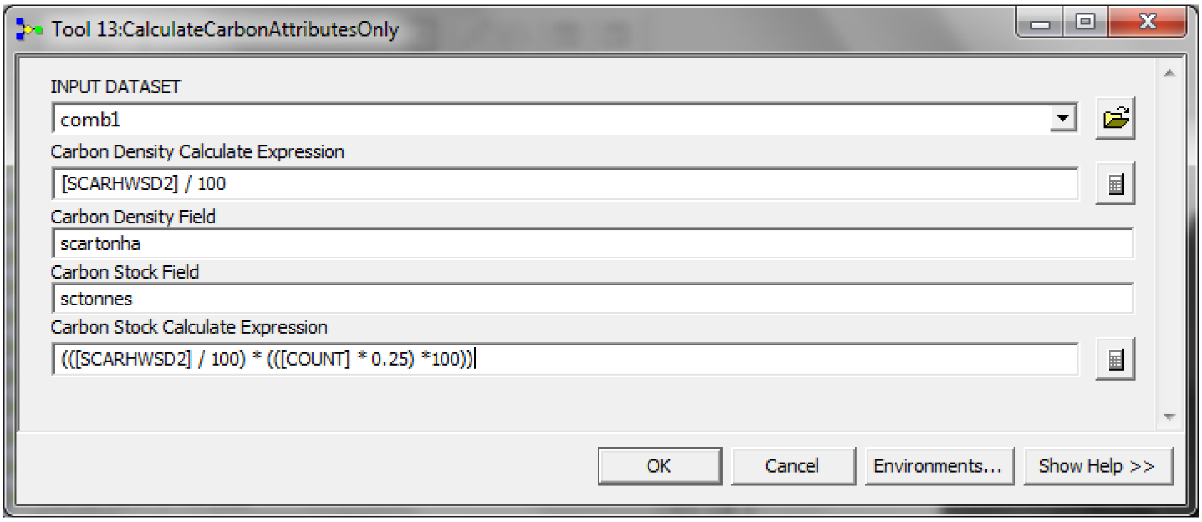


Open attribute table to check the fields have been calculated correctly.

❖ ***(9D) Add on soil carbon attributes to the combined dataset***

Run **Tool 13:CalculateCarbonAttributesOnly**

- InputRaster = comb1
- Carbon Density Calculate Expression = [**SCARHWSD2**] / 100
- Carbon Density Field = **scartonha**
- Carbon Stock Field = **sctonnes**
- Carbon Stock calculate Expression = (([**SCARHWSD2**] / 100) * (([COUNT] * 0.25) *100))

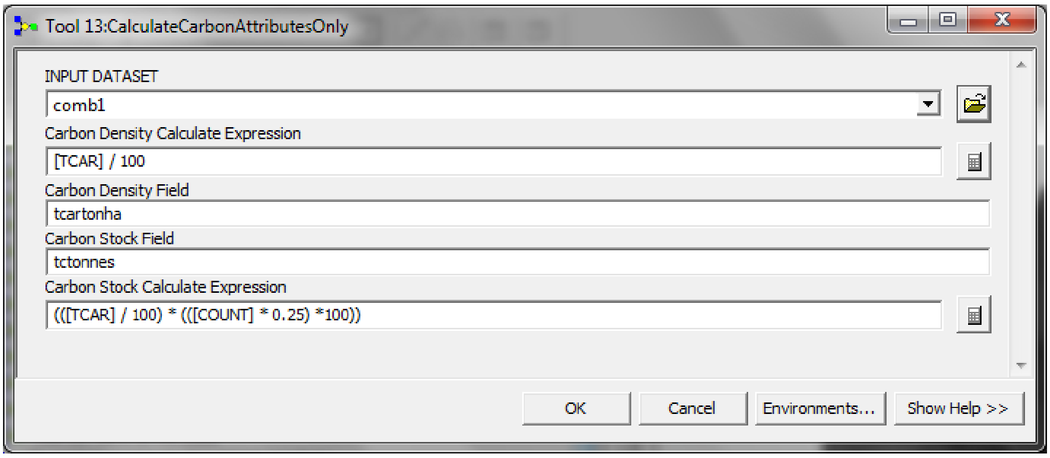


Open attribute table to check the fields have been calculated correctly.

❖ **(9E) Add on combined (total) carbon attributes to the combined dataset**

Run **Tool 13:CalculateCarbonAttributesOnly**

- InputRaster = comb1
- Carbon Density Calculate Expression = [**TCAR**] / 100
- Carbon Density Field = **tcartonha**
- Carbon Stock Field = **tctonnes**
- Carbon Stock calculate Expression = (([**TCAR**] / 100) * (([COUNT] * 0.25) *100))



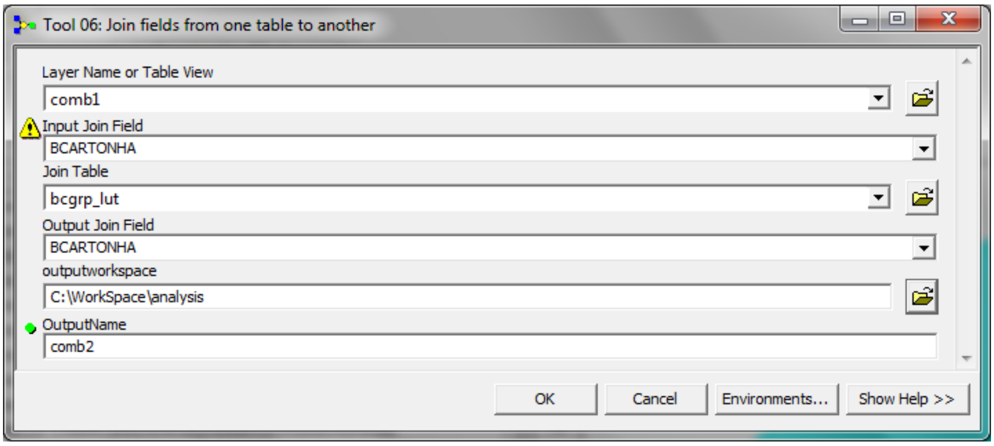
(9F) Join attribute fields to the raster

Run **Tool 06: Join fields from one table to another**

REPEAT FOR EACH ATTRIBUTE THAT NEEDS DESCRIPTIONS JOINING ON

This tool can be used to join on the descriptive attributes such as the bcgrp_lut.dbf.

- InputTable=comb1
- InputJoinField = BCARTONHA
- JoinTable = C:\WorkSpace\analysis\bcgrp_lut.dbf
- OutputJoinField=BCARTONHA
- Output workspace C:\WorkSpace\analysis
- OutputName = comb2



The combined output above (comb1) contains only the 'VALUE' fields from the individual raster's that were combined so this step may be need to be repeated many times. Note that a new raster dataset is created each time.

Add C:\WorkSpace\analysis\ comb2 to the ArcMap session. Open the attribute table to check that the BCGRP_A and BCGRP_S fields have been joined on.

REPEAT AS NECESSARY AFTER EACH JOIN

❖ **(9G) Delete any unwanted attribute fields joined on in the previous steps**

Run **Tool 07: Delete fields from table**

This step deletes any unwanted joined fields such as OID_ VALUE_1 and COUNT_1.

Open attribute table to check that all the unwanted attributes have been dropped.

❖ **(9H) export the final attribute to dbf for use in excel**

Run **Tool 24: Create join table from attribute table**

This step creates a summary dbf file. This is necessary as the carbon groups will need to be joined onto the final statistics table.

- InputDataset=bcar3int
- Field Map = keep all fields
- Expression = leave blank
- Output workspace = C:\WorkSpace\analysis
- OutputName = comb_out.dbf

2.4 Processing the results in Excel

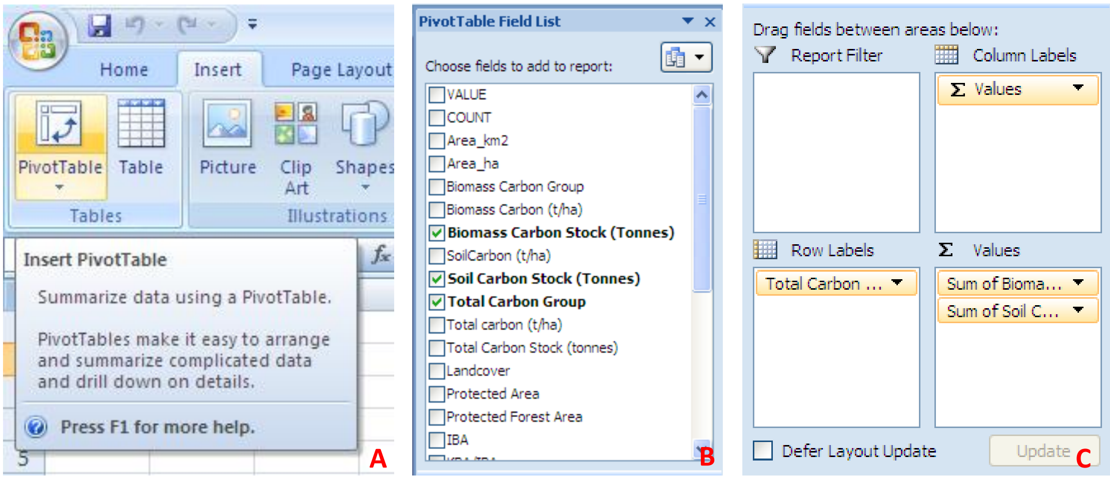
The table output from the GIS analysis summarising the overlap between all existing information used - was then analysed using Microsoft® Office Excel® 2007. This involved the following steps:

Step 1: Insert a pivot table

Insert a new pivot table (A) and select all the data from the summary table to go into the pivot table.

Step 2: Select features for calculation

Those features that are needed for a statistical calculation can now be selected from the Pivot Table Field List that automatically appears on the right side of the excel sheet (B). Features can be made to appear in rows or columns by grabbing and pulling them into the corresponding window as shown in C. The resulting table is shown in D. It includes the total sum of the values of each feature in each column.



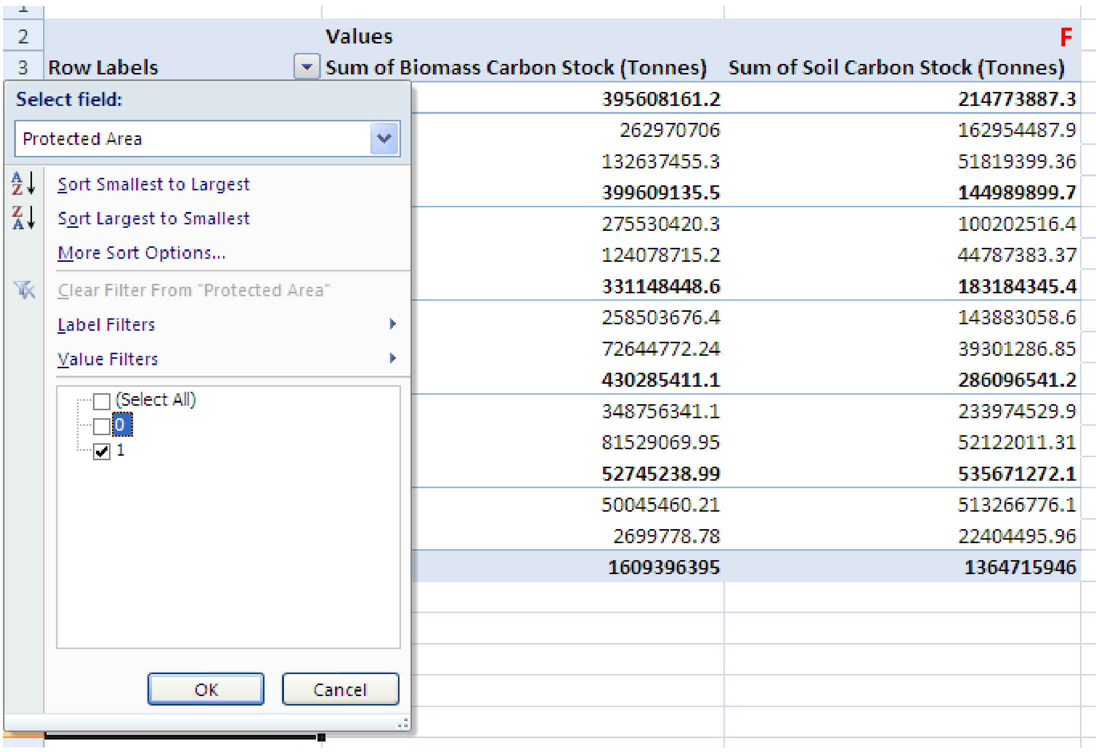
D

2		Values	
3	Row Labels	Sum of Biomass Carbon Stock (Tonnes)	Sum of Soil Carbon Stock (Tonnes)
4	High (274 - 497)	395608161.2	214773887.3
5	Medium High (244 - 273)	399609135.5	144989899.7
6	Medium (192 - 243)	331148448.6	183184345.4
7	Medium Low (112 - 191)	430285411.1	286096541.2
8	Low (0 - 111)	52745238.99	535671272.1
9	Grand Total	1609396395	1364715946

By selecting a different set of features or increasing the criteria in the first column, different and more specific calculations can be done. For instance, if the question was 'How much carbon is in protected areas in Cambodia', the feature 'Protected Area' would have to be selected in the Pivot Table Field List (B) and dragged into the Row Labels box (under 'Total Carbon' as in C). In the table, for each carbon density class the amount of carbon inside and outside protected areas is now shown (0 = outside,1 = inside, see E).

2		Values	E
3	Row Labels	Sum of Biomass Carbon Stock (Tonnes)	Sum of Soil Carbon Stock (Tonnes)
4	**High (274 - 497)**	**395608161.2**	**214773887.3**
5	0	262970706	162954487.9
6	1	132637455.3	51819399.36
7	**Medium High (244 - 273)**	**399609135.5**	**144989899.7**
8	0	275530420.3	100202516.4
9	1	124078715.2	44787383.37
10	**Medium (192 - 243)**	**331148448.6**	**183184345.4**
11	0	258503676.4	143883058.6
12	1	72644772.24	39301286.85
13	**Medium Low (112 - 191)**	**430285411.1**	**286096541.2**
14	0	348756341.1	233974529.9
15	1	81529069.95	52122011.31
16	**Low (0 - 111)**	**52745238.99**	**535671272.1**
17	0	50045460.21	513266776.1
18	1	2699778.78	22404495.96
19	**Grand Total**	**1609396395**	**1364715946**

By clicking on the little arrow at the right end of the 'Row Labels' box, categories in each of the features can be selected and unselected. For instance, in order to only show carbon in protected areas, click on this arrow, select the field 'Protected Area' and unselect the category '0' (F). The table will then only show carbon in protected areas split up by carbon density group.



It is recommended to generate a separate table for each calculation. The quickest way to do so is by selecting the entire pivot table, selecting the copy function and inserting it into an empty cell. The features can then be adapted to suit the next calculation.

Microsoft Office provides the following online training courses:

- How to filter Pivot Table report data in Excel 2007: http://office.microsoft.com/en-us/training/pivottable-ii-filter-pivottable-report-data-in-excel-2007-RZ010208048.aspx
- How to calculate data in Pivot Table reports in Excel 2007: http://office.microsoft.com/en-us/training/pivottable-iii-calculate-data-in-pivottable-reports-in-excel-2007-RZ010210288.aspx.

4. Review of maps and interpretation of results (task 3)

Carefully reviewing the maps and interpreting the results is a central task to this work. Preferably, this should be carried out by or with colleagues who are very familiar with the geographical area in focus and will notice if anything is clearly misrepresented in any of the maps generated.

Maps should be reviewed from two critical perspectives, assessing their appropriateness and meaning. Reviewing the appropriateness of maps for the task in hand will involve identifying and understanding the limitations of the underlying data, which will be necessary for the interpretation of results and the preparation of text to describe them. Reviewing the meaning of maps is part of the interpretation of results, as the latter depends on clarity about what the maps do and do not show, why it is interesting to show this, and what conclusions can and cannot be drawn.

The carbon maps that can be generated applying approaches described here provide a first picture on carbon distribution but cannot be used for Measuring, Reporting and Verification (MRV). They are produced to demonstrate spatial relationships between carbon and other values of land as well as management units, socio-economic factors and pressures. The aims are (a) to raise awareness about multiple benefits that can be gained from REDD+ and issues that countries may want to take into consideration in the REDD+ planning phase and (b) to provide a first visual tool that can be used in this effort. Producing carbon maps that can be used for MRV requires significantly more time and more field data. It may be important to highlight this when writing a summary report on this work as a means to manage expectations and avoid misinterpretation and misuse of results.

Despite the above limitation in the use of the carbon dataset, it is desirable to generate the most accurate carbon map possible with the available data and resources. Therefore, a careful review of any carbon map used and discussion on how well it reflects the situation in the area in focus is considered essential.

Box 5 summarises some questions you may wish to consider when reviewing a map showing the distribution of biomass carbon for its appropriateness. Different issues will need to be considered for different maps, depending on the data used in their generation. For example, most of the considerations in Box 5 would not be appropriate for reviewing a map showing the spatial distribution of a combination of biomass and soil carbon, as carbon can then be high in areas that have little or no vegetation due to large amounts of carbon stored in soil.

Box 5: Considerations for reviewing a map showing the distribution of biomass carbon

- Do areas of highest biomass carbon occur in places where the vegetation is densest and highest?
- Is the biomass carbon lower where vegetation is known to be disturbed or degraded?
- If expected biomass carbon patterns differ from the ones shown by the map, could this be because some land use changes are more recent than the underlying data?
- Urban areas, barren land and water bodies should have no or very low biomass carbon – is that the case?
- How does biomass carbon in high altitude areas compare to biomass carbon in lower altitudes? If the higher altitude areas tend to have more biomass carbon, could this be due to a problem with remotely sensed underlying data?
- Is biomass carbon appropriately reflected in areas that are known to often be covered by clouds?

Another potentially important consideration in reviewing maps for their appropriateness is whether the presented data is approved or accepted by the government of the area in focus. This consideration is of particular importance if the aim is for the outputs to feed into policy planning and implementation, as this is closely dependent on political acceptance.

Reviewing maps for their appropriateness can result in decisions to amend or correct them. Consequently, it may make sense to complete this review and resulting amendments and corrections before starting to review maps for their meaning. Box 6 summarises considerations that may be relevant at this stage of the review process, using three examples.

Box 6: What do the maps mean?

a) Carbon and biodiversity

Datasets prioritising areas for their biodiversity often only capture certain (groups of) species, such as Important Bird Areas, which are identified using criteria that apply specifically to birds. While birds are sometimes considered to also be representative for other groups of species, criteria developed for other species groups may well deliver a different set of sites of importance for biodiversity. In general, as there is no one unit to measure biodiversity, existing data on biodiversity do not capture biodiversity in all its facets. This means that there may well be important biodiversity around the areas for which data exists. This is important to note in order to avoid drawing conclusions from the map that may disadvantage biodiversity that is not captured in the available data.

b) Carbon and oil and gas related activities

Datasets on activities related to oil and gas often differentiate between "contract blocks" and "open areas". Both categories can cover large areas. For the interpretation of results it is important to clarify what is happening in these areas and what these activities mean in the context of planning for multiple benefits from REDD+. For example, in the case of Ecuador, contract blocks and open areas jointly cover the largest part of the Ecuadorian Amazon region, which is very high in carbon (Bertzky *et al.* 2010). However, oil drilling activities are not happening throughout these areas, but instead somewhere within them, potentially accompanied by infrastructural projects to improve access to the drilling sites. Hence the fact that large areas of land are included in such polygons does not mean that all carbon and multiple benefits within are under pressure. In order to discuss potential pressures on carbon and multiple benefits, it is therefore important to understand how oil and gas related activities affect the areas within (and around) current contract blocks and may affect areas within (and around) open areas in the future.

c) Carbon and poverty

Overlaying carbon and poverty can be interesting for a number of reasons. Where poverty is high, people often depend more directly on access to natural resources, including on fuel wood and non-timber forest products, such as medicinal plants and nuts. Visualising where poverty coincides with high carbon can help thinking about where REDD+ can, if appropriately designed, actively support the improvement of local livelihoods. It may also help start thinking about how REDD+ measures could be designed to comply with the objectives of REDD+ without compromising the basic needs of the people. In some cases, the coincidence of poverty and high carbon could also be regarded as a potential pressure on carbon and multiple benefits from REDD+. For example, where charcoal production has been discovered as a promising source of income and is increasing, it may be important to incorporate the development of alternative sources of income into the design of REDD+ measures in the area. Combining carbon and poverty data can thus help thinking about how REDD+ measures can influence poverty, and vice versa, and how REDD+ design can support livelihoods while achieving its conservation and climate change mitigation objectives.

In addition to the in-depth review of the maps it is important to carefully select statistical calculations that will deliver relevant results, referring back to the defined priorities, questions and scope, and to think about what conclusions can and cannot be drawn from them. Whether or not certain calculations are of interest or relevant to a specific context remains a subjective decision. However, keeping in mind what the target audience may really want to get from the outputs can help in this decision-making process.

Once it has been decided what calculations may be of interest to the readers, it will also be important to think about how to present the results of the calculations. There are different ways for doing this, and some may be easier to understand or considered more meaningful than others. For example, it may make sense to present carbon stored in certain areas as percentage of total carbon rather than as mega- or gigatonnes. This will help readers understand the figures in the context of the overall picture.

When interpreting results of calculations, it is again important to remember the meaning of the maps. For example, if a calculation reveals that one quarter of a country's carbon falls within open areas for oil and gas related activities, this may not mean that all this carbon will be lost due to exploitative activities in the future. The considerations that might be relevant when interpreting the results of calculations are thus very similar to the ones for reviewing the maps for their meaning (see Box 6), with the difference that the calculations actually add figures to the overall picture. Box 7 provides examples for considerations that may help interpret the maps together with the results from calculations and draw conclusions that might be of interest to policy-makers.

Box 7: Considerations for interpreting the results of maps and calculations

Example 1: Half of the area that is high in carbon and important for biodiversity is outside protected areas.

- Could this mean there should be more protected areas or would other approaches to sustainable natural resource use be more suitable?
- Who is responsible for and interested in these areas, i.e. do they fall within other management units, such as forest concessions, or do they overlap with indigenous territories? Would an additional calculation make sense to determine how responsibility for and interest in these areas spread among different stakeholders?
- From the available data, do these areas seem under pressure? If so, would an additional calculation make sense to specify what part of these areas may be under pressure?
- Is protected area designation and management a successful route to protection of ecosystem carbon stocks in this area?

Example 2: Sixty percent of the country's biomass carbon is within 5km of areas of recent forest cover loss.

- Can it be assumed that forest cover loss will continue from where it has happened already, and so, is it likely that all this biomass carbon may get lost from continuing deforestation in the years to come? If not, what is a more realistic figure for the biomass carbon that might be under pressure from future deforestation?
- How might areas that are important for biodiversity and other multiple benefits be affected from future deforestation?
- What is the assumed impact of this pressure on the opportunity cost of REDD+?

The examples included in Box 7 illustrate how the outputs of this mapping and spatial analyses exercise can help one to think further about the context for REDD+. This can be helpful, especially in the planning phase for multiple benefits from REDD+, even if some of the data used in this work is will need improvement over time. Another important aspect to remember is that it will never be possible to map all values of land. Ecosystem service mapping is still a great challenge and for many ecosystem services, such as provision of non-timber forest products, a lot of locally gathered data is necessary in order to generate an informative map.

In summary, review and interpretation of the maps and results of this work can help to

- Understand data limitations;
- Highlight needs for improvement of data;
- Clarify what can and cannot be concluded from this work;
- Identify further questions and data needed to address those;

The outcomes of this task should facilitate the finalisation of the products of this work, although it is likely that discussions about the meaning of maps and calculation results continue into the finalisation of outputs. We look forward to seeing the results of your work!

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Annex 1: Effective map presentation

These guidelines provide some tips and helpful hints on effective map presentation for Carbon mapping.

General advice:-

- For a map series define your extent (continue with this for the rest of your maps). Try to account for the most complicated map i.e. in terms of the amount of space needed for text, legends etc.
- Add scalebar, north arrow, legend – ***do not*** convert these to graphics. There are options to help you manipulate the layout of these. *Once converted to graphics they are no longer linked to the map data so if colours change the legend will be wrong. If the position of the map changes the graphic will be wrong*
- Overlay of thematic data with carbon
    - place as open boundaries or hatched boundaries – allows user to see carbon underneath (if polygons are not too small or hatching too dense)
    - Use a transparency of a solid colour overlay – the carbon colours underneath are altered and it is difficult to distinguish which areas are in which class
    - Clip the carbon data to the boundaries and display with same carbon class breaks but with different colour ramp.
- If many themes on single map try to simplify as much as possible. E.g. if displaying Protected Areas and Key Biodiversity Areas maybe just use 1 colour for each theme.
- Chose colours appropriate for application – screen presentation, publishing, both.
- Colour combinations – which themes are most important. What should be standing out most on the map.
- Think about colour-blindness – e.g red/green colour combination not good
- Background layers – what should be labelled.
- Fonts and text sizes
- Scale bars and scale text
- Graticule intervals
- Saving colour ramps – importing colour ramps
- Saving colours
- Publishing and saving map packages.
- Creating layer packages
- Output formats:
    - Interactive PDFs
    - Publication quality tif files