

# Tools for Carbon Emissions Estimation and Mapping in East Africa Guide

The following information was adapted from Ned Horning's *Workshop on Tools for Carbon Emissions Estimation and Mapping in East Africa, d*eveloped as a part of a NASA-SERVIR funded project "Forest carbon assessment for REDD+ in the East Africa SERVIR region" – a collaboration of the Woods Hole Research Center, the American Museum of Natural History, and the Regional Centre for Mapping of Resources for Development.

# **Objectives of the training:**

The main purpose of the training is to learn how to use open source software to estimate carbon emissions from deforestation using reference geospatial datasets, such as multi year land cover land use maps, and above ground biomass data.

Main analyses to be learned using R:

- Perform geospatial analyses, including vector and image processing
- Create land cover map classifications using Random Forest method
- Perform land cover land use change analysis and identify deforestation
- Calculate accuracy assessments and validation of land cover maps
- Calculate carbon emissions from deforestation based on temporally comparable biomass and deforestation maps

This guide explains how to navigate and use the training materials, including R scripts, presentations and sample datasets.

#### I. Preparing the Software

These materials utilize the open source software R, RStudio and QGIS. You can download these programs directly from their websites. They are available for Mac OS X, Windows, and Linux:

- a. QGIS: <u>http://www.qgis.org/en/site/</u>
- b. R: https://www.r-project.org/
- c. RStudio: https://www.rstudio.com/products/rstudio/download/

Udemy hosts a free overview of R Basics that is very helpful for new R users. https://www.udemy.com/r-basics/

There are several packages you will need to install in RStudio in order to run the analyses. Not all of these packages are necessary for every step but they will be used in order to run through all the exercises, They can be installed directly through the RStudio install feature by searching for the package name (Figure 1). These packages are:

- car
   caret
   chron
   colorspace
   data.table
   dichromat
   digest
   doParallel
   e1071
   foreach
   gdalUtils
   geosphere
   ggplot2
   gtable
   iterators
- 17. lme418. magrittr19. maptools

16. labeling

- 20. MatrixModels
- 21. minqa
- 22. munsell
- 23. nloptr
- 24. pbkrtest
- 25. plyr
- 26. quantreg
- 27. R.methodsS3
- 27. R.methouss 28. R.oo
- 28. K.00
- 29. R.utils
- 30. randomForest

31. raster
32. RColorBrewer
33. Rcpp
34. RcppArmadillo
35. RcpEigen
36. reshape2
37. rgdal
38. rgeos
39. RStoolbox
40. scales
41. sp
42. SparseM
43. stringi
44. stringr
45. XML

Addims     Ad	•••		RStudi	0								
Permissions_v3.R * * DutaProcessingScript.R**         Permissions_v1.2000         Permissions_v3.R * * * * * * * * * * * * * * * * * * *	<b>0</b> .•   <del>(</del>	💇 🔹 🔜 📄 🇪 Go to file/function 🔰 🔯 📲 Addins 🗸							۱	Project: (	(None) -	
<pre>     Source on Save</pre>	🖭 em	issions_v3.R × 💽 DataProcessingScript.R* ×				Envi	ronment	History			_	
1       11brary(raster)         2       setwd(*/Users/ecadams/Desktop/CarbonEmissionMapping/Data*)         #       Read reference land cover image from 2010.         6       ClippedLC.Image < "Zambia_Mops_June2014/ZambiaMaps/Zambia20105cheme_i_landCoverClip.tif"	40	🔊 🔒 🗌 Source on Save 🔍 🧪 📃		Run 🐤 🕞 Source	• 2	1		mport Datase	et + 🥑	List	- @	
<pre>setwd("/Users/ecadams/Desktop/CarbonEmissionMapping/Data") # Read reference land cover image from 2019. ClippedLC.Name &lt; "Zambia_Maps_June2014/ZambiaMaps/Zambia2005Cheme_i_landCoverClip.tif" ClippedLC.Name &lt;- "Zambia_Maps_June2014/ZambiaMaps/Zambia20005Cheme_i_landCoverClip.tif" ClippedLC.Name &lt;- "Zambia_Maps_June2014/ZambiaMaps/Zambia20005Cheme_i_landCoverClip.tif" LC2000_Image &lt;- raster(LC2000_Image to match the extent of # Resample the 2000 land cover image to match the extent of # Geostarp Lette From the 2010 land cover image to match the extent of # Geostarp Lette Sample (LC2000_Image Aligned + CitppedLC.Image Tester(LC2000_Image Aligned + CitppedLC.ImageTester(LC2000_ImageAligned + CitppedLC.ImageTester(LC2000_ImageAligned, filename-outL2200Nkme, for 21 22.2 # Nun crosstab to see the number of pixels in each of the citpped LC2000_ImageAligned, filename-outL2200Nkme, for 22.3 # fun crosstab to see the number of pixels in each of the citpped LC2000_ImageAligned, filename-outL2200Nkme, for LINAME Description LC2000_ImageAligned, filename-outL2200Nkme, for LINAME Description to Applied Regression 2.1-2 Install dependencies LC2000_ImageAligned, filename-outL2200Nkme, for LINAME Description to Amplied Regression 2.1-2 Install dependencies LC2000_ImageAligned, filename-outL2200Nkme, for LINAME Description detain and Regression 6.2-0 Console -/ @ R is free software and comes with ABSOLUTELY NO MARRANTY. You are welcome to redistribute it under certain conditions. Type 'license()' or 'licence()' for distribution details. Natural language support but running in an English locale Licedeame and the redistribute in entribute on Locadet Distribute in entribute on Locadet Distribute in entribute on Locadet Distribute in entribute on</pre>	1	library(raster)				Global Environment *			Q			
<pre>setwd("/Users/acadams/Desktop/CarbonEmissionMapping/Data")  # Read reference land cover image from 2010. CitypedLC.Image &lt;- raster(clippedLC.Mame) # Read in land cover image for 2000 # Read in land cover i</pre>	2					-						
# Read reference land cover image from 2010.       Environment is empty         6 clippedLC.Image < "Zambia_Maps_June2014/ZambiaMaps/Zambia20105cheme_i_landCoverClip.tif"	3	<pre>setwd("/Users/ecadams/Desktop/CarbonEmissionMapping/Data")</pre>										
<pre>5 # Read reference land cover image from 2010. C clippedLC.Name &lt;- "Zambia_Mops_June2014/Zambia&amp;ps/Zambia2010Scheme_i_landCoverClip.tif" ClippedLC.Mame &lt;- "Zambia_Mops_June2014/Zambia&amp;ps/Zambia2000Scheme_i_landCoverClip.tif" ILC2000_Image &lt;- raster(ClippedLC.Mame) # Read in land cover image for 2000 ILC2000_Name &lt;- "Zambia_Mops_June2014/Zambia&amp;ps/Zambia2000Scheme_i_landCoverClip.tif" ILC2000_Image &lt;- raster(IC2000_Name) Install Packages # Resomple the 2000 land cover image to match the extent of 5 cott("Resomple the 2000 land cover image to match the extent of 16 LC2000_Image &lt;- rasemple(LC2000_Image, ClippedLC.Image 19 cott("Writing resompled 2000 land cover image \n") 16 LC2000_ImageAligned, filename-outLC2000Name, for 19 cot("Writing resompled 2000 land cover image to disk\n") 20 writeRoster(LC2000_ImageAligned, filename-outLC2000Name, for 21 22.4 fluon crosstab to see the number of pixels in each of the c 28.24 (Toplevel : R is free software and comes with ABSOLUTELY NO MARRANTY. You are welcome to redistribute it under certain conditions. Type 'license()' or 'licence()' for distribution details. Natural language support but running in an English locale Natural language support but running in an English locale A is fore software and code with advision for R 0.2- A is codetools code Analysis Tools for R 0.</pre>	4							Er	vironment is empty			
b       clippedL_Name       - Yamid_Naps_June2014/20001040p5/20001020105cheme_1_lond.over(lip.tif"         clippedL_Name       - roster(clippedL_Name)       #         #       # Read in land cover image for 2000       Install Packages         10       LC2000_Name << "Zambid_Nops_June2014/ZambidApp5/Zambid20005cheme_i_landCoverClip.tif"	5	5 # Read reference land cover image from 2010.										
ctrppearc_ingge < roster(ctrppearc_ingge <	6 cltppedLC_Name <- "Zambia_Maps_June2014/ZambiaMaps/Zambia2010Scheme_i_landCoverClip.tif"											
# Read in land cover image for 2000 # Read in land cover image for 2000 ILC2000_Nome < "Zambia_Mops_June2014/Zambiadops/Zambia2000Scheme_i_landCoverClip.tif" Install Packages outLC2000_Image <- ransin_Kaps_June2014/Zambiadops/Zambia2000Scheme_i_landCoverClip.tif" Install Packages Install I LC2000_ImageAligned Install I CL2000_ImageAligned Install I LC2000_ImageAligned Install I LC2000_ImageAligned, filenome-outLC2000Nnme, for Install I Cl2000_ImageAligned, filenome-outLC2000Nnme, for Install I dependencies Install dependencies Install I dependencies Install I dependencies Install I dependencies Install I careet Install I dependencies Install I careet Install I dependencies Install I careet Install I dependencies Install I dependenci		clippedLC_image <- raster(clippedLC_Name)										
Finded With Text Text Text Text Text Text Text Text	å	# Read in land cover image for 2000										
1 LC2000_Image <- roster(LC2000,Name)	10	5 # Redu in Land Cover image for 2000 10 LC2000 Name ← "Zambia Mass lun2014/ZambiaMans/Zambia2000Scheme i landfavorflin tif"										
12       outl.22009/ame <- "Zanbia_Maps_June2014/Zanbia200	11	LC2000_Image <- raster(LC2000_Name)	Install Packages									
13       Resample the 2000 land cover image to match the extent of scale ("Resample the 2000 land cover image to match the extent of scale ("Resample the 2000 land cover image to match the extent of scale ("Resample the 2000 land cover image to match the extent of scale ("Resample the 2000 land cover image to match the extent of scale ("Resample the 2000 land cover image to the clippedL_Image (clippedL_Image (clippedL_	12	outLC2000Name <- "Zambia_Maps_June2014/ZambiaMaps/Zambia2004	instant actuages		5 H							
14 # Resample the 2000 land cover image to match the extent of 15 cact (Resample the 2000 land cover image (Lipped) Linace, clipped(Linace)       Packages (separate multiple with space or comma):         16 LC2000_ImageAligned resample(LC2000_ImageAligned, clipped(Linace)       Packages (separate multiple with space or comma):       Install to Library:         17 # Compacting down and cover image (Arrow or the 2010 image cover (A	13		Install from:	Configuring Repositories								
15       cct("Resample the 2000 land cover image'n")         16       LC2000_ImageAligned < - resample(LC2000_Image, clippedLC.Image	14	# Resample the 2000 land cover image to match the extent of	Repository (CRAN)			Files	Plots	Packages	Help Viewer			
16       LC2000_ImageAligned <- resomple(LC2000_Image, clippedLC_Image)	15	<pre>cat("Resample the 2000 land cover image\n")</pre>				Thes	riots	rackayes	Theip Viewei			
17 # Copy the color polette from the 2010 image to the clipped. 18 LC2000_ImageAlignedHegend - clipped. 19 cat("Writing resampled 2000 land cover image to disk'n") 20 writeRaster(LC2000_ImageAligned, filename-outLC2000Name, for 22.4 flor constato to see the number of pixels in each of the clipped. 22.4 flor constato to see the number of pixels in each of the clipped. 22.4 flor constato to see the number of pixels in each of the clipped. 23.4 flor constato to see the number of pixels in each of the clipped. 24.4 flor betwel :       Install to Library: Library/Framework/Versions/3.3/Resources/lE install dependencies       System Library boot Bootstrap Functions (Originally by 1.3- Angelo Canty for S) is install dependencies         Console ~/ r>       Console ~/ r>       R is free software and comes with ABSOLUTELY NO MARRANTY. You are welcome to redistribute it under certain conditions. Type 'license()' or 'licence()' for distribution details. Natural language support but running in an English locale       Install cole       Install Cancel       Install Cancel       Install clipped. Codetools       Code Analysis Extended Rousseuw et al.       Codetools       Code Analysis Tools for R       0.2- 0.2-	16	<pre>LC2000_ImageAligned &lt;- resample(LC2000_Image, clippedLC_Image)</pre>	Packages (separate multiple with	space or comma):		OL I	nstall	Update	Q,		G	
18       LC2000_ImageAlignedHegend <- ClippedL_ImageFlegend	17	# Copy the color palette from the 2010 image to the clipped					Name	Descri	ption	Versi		
19       Cdc("Writing resompted 2000 lond cover image to diskin)         20       mittalkoster(L2000_LangeAligned, filename.outL2000Name, for         21       Library/Framework/Rifamework/Versions/3.3/Resources/IE         22.2       # Run crosstab to see the number of pixels in each of the c         28.24 (Top Level) :       Install dependencies         Console -/        Careet         R is free software and comes with ABSOLUTELY NO WARRANTY.       Install dependencies         You are welcome to redistribute it under certain conditions.       7.3 - 0         Type 'license()' or 'licence()' for distribution details.       Analysis Extended Rousseeuw et al.         Natural language support but running in an English locale       0.4 - 0.2 - 0.4	18	LC2000_ImageAligned@legend <- clippedLC_Image@legend	-			Syste	em Librar	y				
20       mritekaster(riczwor.ling/exityrieu, riter/ame.out/22000kame; rot       18         21       22       # Run crosstab to see the number of pixels in each of the classification and Regression 2.1-2       Companion to Applied Regression 2.1-2         28.24       (fubrest):       install dependencies       Caret       Classification and Regression 6.0         Console ~/        Caret       Classification and Regression 6.2       Caret       Classification and Regression 6.2         Console ~/        Console ~/        Chronological Objects which can 2.3-       Chronological Objects which can 2.3-       Chronological Objects which can 2.3-         R is free software and comes with ABSOLUTELY NO WARRANTY.       Install       Cancel       Chronological Objects which can 2.3-         You are welcome to redistribute it under certain conditions.       Type 'license()' or 'licence()' for distribution details.       7.3-         Natural language support but running in an English locale       Codetools       Code Analysis Tools for R       0.2-         Codetools       Code Analysis Tools for R       0.2-       0.2-	19	cat("Writing resampled 2000 land cover image to diskin")	Install to Library:			0	boot	Bootst	tran Functions (Originally by	1.3-		
22       # Run crosstob to see the number of pixels in each of the c       Install dependencies       Caret       Companion to Applied Regression       2.1-2       Caret       Classification and Regression       66<	20	writeRaster(LC2000_ImageAligned, filename=outLC2000Name, for	/Library/Frameworks/R.framework/	/ersions/3.3/Resources/lib 📀				Angel	o Canty for S)	18	Ŭ	
28.24 (Top Level) ::       Careet       Classification and Regression       6.0-         Console ~/ >       Careet       Classification and Regression       6.0-         R is free software and comes with ABSOLUTELY NO WARRANTY.       Install       Cancel       Chron       Chronological Objects which can       2.3-         Type 'license()' or 'licence()' for distribution details.       Natural language support but running in an English locale       2.0.4         O classification and Regression       6.0-       Chron       Chronological Objects which can       2.3-         Natural language support but running in an English locale       0.0-       Calestor       'Finding Groups in Data': Cluster       2.0.4         O closel for Colssification       0.2-       0.2-       0.2-       0.2-	22	# Run crosstab to see the number of pixels in each of the cl					car	Comp	anion to Applied Regression	2.1-2	0	
Console -/ > Console -/ > R is free software and comes with ABSOLUTELY NO WARRANTY. You are welcome to redistribute it under certain conditions. Type 'license()' or 'licence()' for distribution details. Natural language support but running in an English locale	28:24	(Top Level) ‡	Install dependencies		Script ¢		caret	Classi	fication and Regression	6.0-	0	
Console -/ @       Install       Cancel       chron Objects which can 2.3- Haidle Dates and Times 47         R is free software and comes with ABSOLUTELY NO WARRANTY. You are welcome to redistribute it under certain conditions. Type 'license()' or 'license()' or distribution details. Natural language support but running in an English locale       7.3- 14       14         O cluster       'Finding Groups in Data': Cluster al.       2.0.4       Analysis Extended Rousseeuw et al.         O cluster       'Codetools       Code Analysis Tools for R       0.2- 0.2-	Console ~/ 🔗							Traini	Training			
R is free software and comes with ABSOLUTELY NO WARRANTY.       Install       Cancel       Handle Dates and Times       47         You are welcome to redistribute it under certain conditions.       Cass       Functions for distribution details.       14         Cluster       'Finding Groups in Data': Cluster       2.0.4       14         Cluster       Analysis Extended Rousseeuw et al.       0.02         D is a clubration statistication in English locale       0.2-       0.2-							chron	Chron	Chronological Objects which can		8	
Class       Functions for Classification       7.3-         You are welcome to redistribute it under certain conditions.       14         Class       Functions for Classification       14         Class       Extended Rousseeuw et al.       0         Codetools       Code Analysis Tools for R       0.2-         14       14       14				Install Cancel				Handl	e Dates and Times	47		
Type 'license()' or 'licence()' for distribution details.         Natural language support but running in an English locale         Dia of elicense         Code Analysis Tools for R         0.2-	You a	ree software and comes with Absolutelt no warkawit.					class	Functi	ons for Classification	7.3-	8	
Natural language support but running in an English locale          Custer Analysis Tools for R         0.2         0	Type	license()' or 'licence()' for distribution details					ductor	"Cindu	na Crouns in Data": Cluster	204		
Natural language support but running in an English locale     al.       codetools     Code Analysis Tools for R     0.2-       14     14	1,700						cluster	Analys	sis Extended Rousseeuw et	2.0.4	0	
Codetools Code Analysis Tools for R 0.2-	Natu	ural language support but running in an English locale						al.				
B is a self-shareful many sentral between 14							codetools	Code	Analysis Tools for R	0.2-	0	
R is a collaborative project with many contributors.	Risc	a collaborative project with many contributors.								14		
Type 'contributors()' for more information and	Type 'contributors()' for more information and						colorspac	e Color	Space Manipulation	1.2-6	3	
'citation()' on how to cite R or R packages in publications.	'citation()' on how to cite R or R packages in publications.						compiler	The R	Compiler Package	3.3.0	8	
data.table Extension of Data.frame 1.9.6 💿							data.table	Extens	sion of Data.frame	1.9.6	8	
Ippe 'aemo()' for some aemos, 'nelp()' for on-line nelp, or datasets The R Datasets Package 3.3.0 0	type demoty for some demots, hetp() for on-time hetp() 0P						datasets	The R	Datasets Package	3.3.0	8	
dichromat Color Schemes for Dichromats 2.0-0. @	Type	a()' to auit R					dichroma	t Color	Schemes for Dichromats	2.0-0	8	
- Specify to year the second s	-ype	q() co quee ni					digest	Create	Compact Hash Digests of	0.6.9	0	
> Ugest Create Compact Hash Digests 01 0.0.9	<b>N</b>						uigest	R Obie	ects	0.0.9	0	
	<u> </u>						d - B U -	. P	-I. Banallal Adamson Kanala	1 0 10	_	

Figure 1. R studio platform screenshot - showing how to install packages.

## II. Review of R

This folder contains 4 folders, 1. Vector Processing In R Demo, 2. Image Processing In R, 3. Recent Geospatial Updates In R, and Data.

Each of these folders contain information relevant to utilizing R for vector and raster processing in general. If you are a novice user of R for geospatial analysis the material in these folders will serve as a good review with examples of some of the core capabilities of R. It is recommended to go through the materials in each of these folders in order to gain an understanding of some of the processing behind estimating carbon emissions. Each of the folders have presentations that contain reference information as well as R code. The Data folder contains all of the referenced files for each of the R scripts in each folder except for the Landsat data. In order to download the Landsat data, go to earthexplorer.usgs.gov. Enter search criteria as: Path 174 and row 69 for Landsat 8, January 2, 2016. Save this scene in the Landsat8 folder. Navigate to Landsat 5 and download the scenes for November 20, 2010 and October 20, 2000 for the same path and row. Save them in the LT5 folder. You will need a USGS account in order to download the scenes.

Opening the scripts within RStudio allows for easy manipulation, visualization, and execution of the codes. You will need to set your working directory to the ReviewOfR/Data folder. The codes are commented to indicate what is occurring at each step. Below are helpful suggestions for each of the scripts in the folders

- 1. Vector Processing in R
  - a. VectorOperationsInR.R Run the code line by line to see examples of various vector data functions using the example data
    - i. Line 4 Change the working directory
    - ii. Line 105 & 106 This function is to get coordinates from the plot, which are user defined. When you run this line, it will activate the plots window for you to click the location you would like to identify the coordinates for. Press finish in the plot window after you have clicked to complete the analysis. You will repeat this process again for the following lines.
- 2. Image Processing in R
  - a. ImageOperationsInR.R- Run the code line by line to see examples of various raster processing capabilities
    - i. Line 2 Change the working directory
    - ii. *Line 48 & 49* This function is similar to lines 105 and 106 in the Vector Operations In R script. You can click and interact with the plot window. Clicking finish completes the analysis
- 3. Recent Geospatial Updates in R
  - a. testRStoolbox\_demo.R Run the code line by line to illustrate some of the capabilities of the RStoolbox, including supervised (random forest) and unsupervised classifications. Land cover classifications will be needed to for the carbon emissions calculations later in this demonstration. Make

sure your working directory is pointed to the Data folder in the ReviewOfR folder.

- b. Accuracy Assessment
  - i. accuracyAssessment.R serves as a general example on how to perform accuracy assessments on user generated land cover classification maps, example data is provided in the Data folder and the script is currently written to use this example data. Should the user wish to apply this method to their own data, they will need to update more than the working directory as indicated in the comments of the script
  - ii. validateMapExample.R uses external data to validate an example map, similar to the accuracy assessment example, you will have to update the fields with information relevant to your particular study area to work outside the example given.

## **III.** Carbon Emissions

The Carbon Emissions folder contains a presentation, which serves as an overview to some of the concepts regarding carbon emissions mapping, 2 R scripts, emissions\_v3.R and DataProcessingScript.R, and a Data folder. The DataProcessingScript.R script is useful for preprocessing the necessary data to calculate carbon emissions using the "emissions\_v3.R" script. Example data has been provided in the Data folder. The details below will outline the data requirements and steps to calculate carbon emissions.

Data Preparation: Collect the following data to calculate carbon emissions using the emissions\_v3.R script:

- A biomass map for your region in .tiff format. Woods Hole Research Center has produced a national dataset for the pantropical region of aboveground live woody biomass derived from field/LiDAR(GLAS) and MODIS at 500 m spatial resolution in tons per hectare. The dataset and more information can be found at: <u>http://whrc.org/publications-data/datasets/pantropical-national-level-carbon-stock/</u>
  - For demonstration purposes the ZambiaBiomass500m.tif file will be used
- A land use land cover change map highlighting the areas of forest loss also in .tiff format. This can be created using 2 land cover maps from different years and the script DataProcessing.R included with these materials.
  - The land use land cover maps used in this example are available at apps.rcmrd.org/landcoverviewer
  - Alternatively, you can use the capabilities highlighted in the testRStoolbox\_demo.R, the accuracyAssessment.R, and the validateMapExample.R scripts to create land cover classification maps for your region.
  - For demonstration purposes the Zambia2000scheme\_i\_landCoverClip.tif file and the Zambia2010Scheme\_i\_landCoverClip.tif file in the ZambiaMaps

folder can be used. The accuracy assessment information is also included for reference. These maps used the 6 IPCC, the International Panel on Climate Change, top-level land categories for greenhouse gas (GHG) inventory reporting.

- You will also need to determine the land cover class values that represent deforestation. If you used the DataProcessingScript.R those values were combined in the legend of the land use change image. For example: the legend from the RCMRD land cover viewer is: 1. Forestland, 2. Grassland, 3. Cropland, 4. Wetland, 5. Settlement, 6. Otherland. A value of 12 in the land cover change image would indicate the previous image was forestland but is now grassland; a value of 43 would indicate that area was wetland and is now cropland. Thus the values of 12, 13, 14, 15, and 16 would represent deforestation using these data.
- The emissions v3.R script performs a number of processing steps. After the • biomass and land cover change image are input they are compared and then both are cropped to the common area covered by both images. Next the biomass image is resampled so it is the same resolution as the land cover change image. The biomass per pixel is then calculated since the original biomass units are biomass per hectare. The biomass map should reflect predeforestation conditions. The last analysis step is to use zonal statistics to calculate the sum of the biomass per pixel values for each of the deforestation classes and then convert that number to emitted CO<sub>2</sub> by multiplying by 0.5 (convert weight of dry biomass to carbon)\* and multiply the result by 3.66 (convert weight of carbon to  $CO_2$ ). The emitted  $CO_2$  values are output in tons in the terminal window along with the total CO<sub>2</sub> for all classes. If an output image was defined in the variables section then the last processing step is to output an image with biomass per pixels values. The R script has comments to help you understand each processing step.

\*The 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4, page 48 provides conversion factors to calculate carbon from biomass depending on your region and land cover class.

Guide for using the example data:

- 1. Create the land use land cover change map following the DataProcessingScript.R and using the Zambia Maps for 2000 and 2010. The only step involved here is to make sure you set your working directory. The following outlines the steps occurring in the script
  - a. The script outputs the LC\_Change2000Times10Plus2010.tif file in the working directory, which is the land cover land use image file for the carbon emissions calculations
- 2. In the emissions\_v3.R script you set the variables as follows
  - i. Setwd(your own working directory)
  - ii. The biomassImageName is ZambiaBiomass500m.tif
  - iii. Nodata value is 0

- iv. The name and path of the land cover change image is the file we generated in the previous step LC\_Change2000Times10Plus2010.tif
- v. The pixel values for deforestation are 12, 13, 14, 15, 16
- vi. The land cover change image nodata value is 0
- vii. targetImage is lcc
- viii. You can name the out image whatever you would like, as well as change the destination path. For this example it is set to write the BiomassPerPixel.tif into the data folder.
  - ix. Run the entire script at once, not line by line
  - The script will print the total CO<sub>2</sub> emissions for each of the deforestation classes followed by the total emissions and the output image, ZambiaBiomass500m.tif, in tons of biomass per pixel instead of tons of biomass per hectare