Tropical Ecology, Assessment, and Monitoring Network

Zone of Human Dynamics and Ecosystem Change (ZoHDEC) Protocol Implementation Manual

– Draft –

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Acknowledgments

This protocol and all other TEAM protocols are collective works. They were developed and reviewed by numerous scientists, but in this case, especially by TO BE FILLED IN.

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1. Table of Contents

2. General Scope of this Document

The Tropical Ecology Assessment and Monitoring Network (TEAM) is designed to understand the effects of global drivers of change (climate, land use change) on biodiversity and ecosystem function by collecting standardized data through a network of sites at several spatial and temporal scales. TEAM implements standardized and detailed documented methods for data collection, data management and data/metadata distribution in order to maximize the efficiency of data collection, quality and comparability of the long-term data sets.

Biodiversity changes detected at a TEAM measurement station can be caused by local changes in the surrounding ecosystem, or by changes at regional or global scales. Local ecological, hydrological and human processes have the greatest immediate effect and are monitored according to TEAM protocols using field and remote sensing techniques. The monitoring of these processes around the TEAM measurement locations requires the delineation of the spatial area to be monitored. The monitoring area should include the most relevant and measurable processes interacting with biodiversity at the measurement station. The area to be monitored is called the Zone of Human Dynamics and Ecosystem Change (ZoHDEC). This manual describes in detail the steps and procedures necessary for delineating the ZoHDEC.

Definition of ZoHDEC (adapted from DeFries et al. 2009[1]): The Zone of Human Dynamics and Ecosystem Change is the extent of the coupled human-natural system that strongly influences biodiversity at the measurement plot.

This manual follows the reasoning and approach for delineating the ZoHDEC as described in DeFries et al. (2009). Parameters with potential effects on local biodiversity include habitat continuity and connectivity, hydrological processes such as water inflow from an upper watershed, and human activities such as deforestation, selective logging, and hunting (Figure 1).

[1] DeFries, R., F. Rovero, P. Wright, J. Ahumada, S. Andelman, K. Brandon, J. Dempewolf, A. Hansen, J. Hewson, and J. Liu, 2009. From plot to landscape scale: linking tropical biodiversity measurements across spatial scales. *Frontiers in Ecology and the Environment*. http://www.esajournals.org/doi/abs/10.1890/080104.

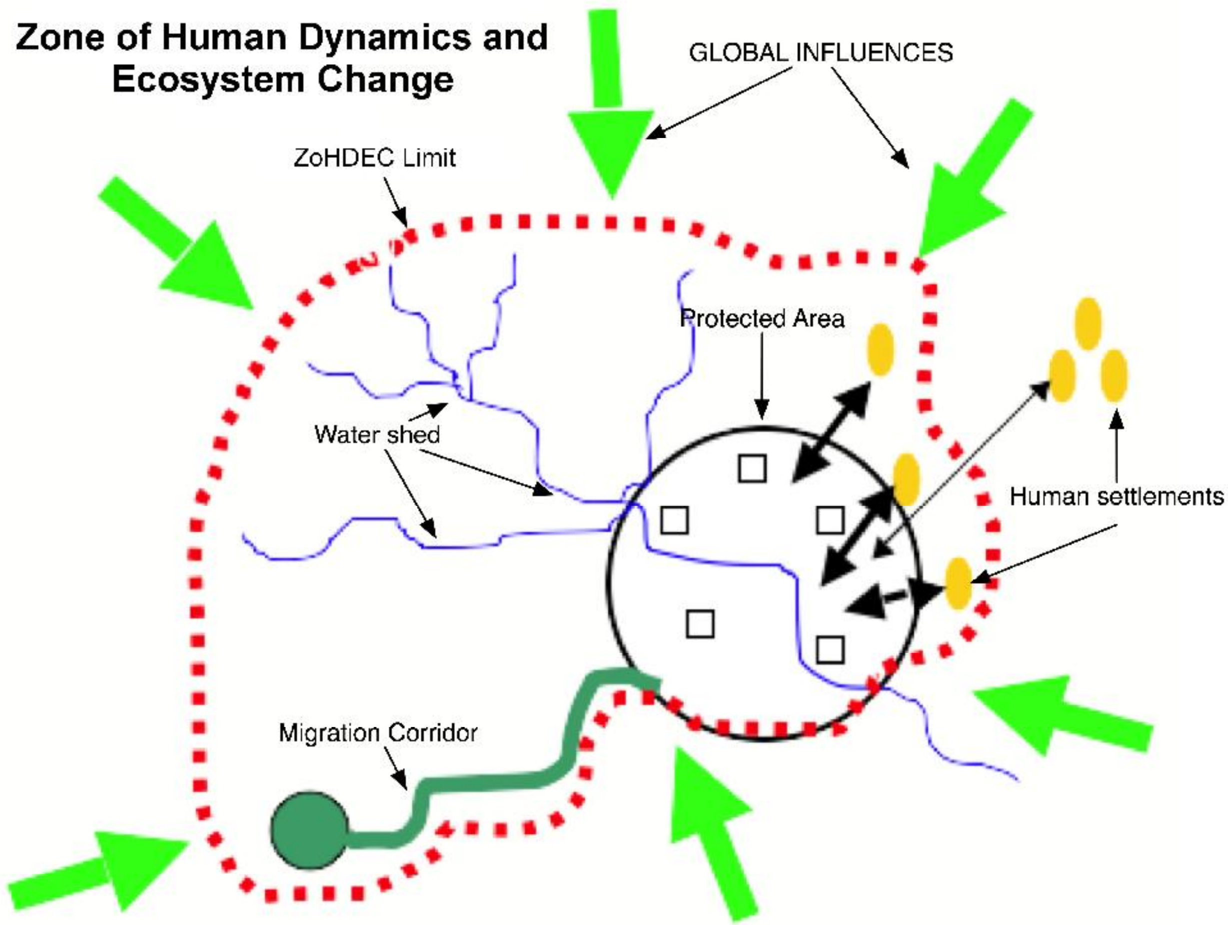

Figure 1: Hypothetical example for a ZoHDEC (dashed red line) around biodiversity measurement plots (black squares) within a managed area (black circle). Local biodiversity interacts with human processes (black arrows; human settlements: yellow), hydrologic processes (river water flow: blue lines), and biological processes (e.g. migration corridor: dark green). The ZoHDEC here encompasses the plots, watershed, migration corridor and closest human settlements. It is exposed to global influences (green arrows) such as climate change and nutrient deposition (DeFries et al. 2009[1]).

The process of identifying the ZoHDEC is based on available data and local expert opinion. The protocol uses the following four criteria:

1) Drainage basin boundaries (watersheds)
2) Contiguous habitat
3) Human activities
4) Migration corridors

This manual describes the data sets and steps necessary to incorporate each of these criteria and how to combine them to arrive at the ZoHDEC. The manual describes computational procedures to be performed in a Geographic Information System (GIS).

3. Methodology

The following sections describe the spatial data layers and steps necessary to delineate the ZoHDEC, based on local and global GIS datasets.

3.1 Acquisition and Preparation of Spatial Data Layers

The spatial data layers can be processed in any GIS software package with standard geoprocessing capabilities that include procedures to (i) union, clip and intersect polygon layers, (ii) select polygons by location and (iii) convert polygon from multi-part to single-part. This manual was developed using open source software packages. Quantum GIS (QGIS, available at www.qgis.org) provided the necessary vector-based GIS functionality. SAGA-GIS (available at www.saga-gis.org) provided raster-based GIS functionality for processing digital elevation models (DEMs) and calculating watersheds.

3.1.1 Required Spatial Data Layers

A number of polygon and raster data layers are required for calculating the ZoHDEC. We recommend to reproject all data layers to Universal Transverse Mercator (UTM) projection, datum WGS84. The UTM projection allows to directly calculate distances and areas of polygons and raster cells for deriving watersheds. UTM minimizes distortion, uses meters as units and is a commonly used projection system. Use the appropriate local north or south UTM zone by determining into which zone the larger part of the TEAM Core Area polygon (see below) falls.

i. *TEAM Core Area polygon* – defined according to the TEAM Sampling Unit Placement protocol. Reproject to the local UTM zone.
ii. *Digital Elevation Model* – A digital elevation model (DEM) is needed to delineate watersheds. The Shuttle Radar Topography Mission (SRTM) DEM at 90 m resolution is adequate and recommended for deriving watersheds in the ZoHDEC context. Download and prepare the hole-filled SRTM DEM (version 4, Jarvis et al. 2004[2]) as follows:
   a. Determine Spatial Extent – Buffer the TEAM Core Area polygon by 100,000 m (100 km). Reproject the buffered layer to Plate Caree (geographic, WGS84). Determine the minimum and maximum latitude and longitude coordinates of the new layer[3].
   b. Digital Elevation Model – The SRTM DEM tiles can be downloaded from http://srtm.csi.cgiar.org. Enter the minimum and maximum coordinates to select the appropriate tile(s) and download them in GEO-TIFF format.
   c. Prepare DEM – If more than one SRTM tile was downloaded mosaic them together into one seamless raster layer, reproject the mosaic to UTM projection using the appropriate zone and subset the mosaic layer to the minimum and maximum spatial extent of the 100 km buffer polygon derived in step ii.a[4]. Replace all SRTM no-data values (-32768) with the ESRI-Grid no-data value (-9999) and export the layer to a text file in ASCII-GRID format[5].

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[2] Jarvis, A., J. Rubiano, A. Nelson, A. Farrow, and M. Mulligan. 2004. Practical use of SRTM data in the tropics: Comparisons with digital elevation models generated from cartographic data. Working Document. Cali: International Centre for Tropical Agriculture (CIAT).

[3] Tech-Tip: The minimum and maximum extent of a georeferenced GIS layer can be determined in QGIS by opening the layer, right clicking on it, selecting *Properties* and the *Metadata* tab. The coordinates are displayed under *Extent*.

[4] Tech-Tip: Mosaicking SRTM tiles can be accomplished in standard GIS software packages, e.g. ArcGIS or GRASS or in any standard image processing software, such as ENVI, PCI or ERDAS.

[5] Tech-Tip: Replacing all -32768 values with -9999 can be accomplished in different ways depending on the software package used. In ENVI generate a mask for all values not equal to -32768, then apply the mask using a background value of -9999. Another option is to first export the mosaic to a text file and then open it in a text editor that is suitable for very large text files (e.g. UltraEdit, www.**ultraedit**.com) and use the search and replace function.

iii. *Land cover map* – The land cover map is used to derive the spatial extent of contiguous habitat (i.e. closed forest), agriculture, human settlements and infrastructure and to determine obstructed areas (e.g. large water bodies or topographic barriers). Acquire an existing high-resolution, recent land cover classification, e.g. based on Landsat or similar high resolution satellite imagery. If this is not available alternatively acquire the MODIS Vegetation Continuous Fields (VCF) tree cover layer (Hansen et al. 2003[6]) and the GlobCover v. 2.2 dataset (© ESA / ESA GlobCover Project, led by MEDIAS-France).

a. VCF – The MODIS VCF data layer can be obtained for free at https://wist.echo.nasa.gov/api/. An alternative source is the University of Maryland Global Land Cover Facility (GLCF, http://glcf.umiacs.umd.edu/). The WIST online ordering system requires registration, which is free, as are the MODIS data. On the website under *Primary Data Search* mark as data set the *Land: MODIS/Terra data set* and select *MODIS/TERRA Vegetation Continuous Fields Yearly L3 Global 500m SIN Grid V003*. Enter the minimum and maximum latitude coordinates determined in ii.a. Enter for Start date: *2005-01-01* and for End date: *2005-12-31*. In the search results select the data sets for 2005. Currently 2005 is the latest year for which VCF was produced. After ordering the MODIS tile(s) they can be downloaded via FTP in Hierarchical Data Format (HDF) format[7]. The MODIS data will be in sinusoidal projection (sphere radius 6371007.20 m). If there is more than one tile, mosaic them together. Subset the data layer to the spatial extent of the buffer layer derived in ii.a. Reproject the result to the local UTM zone (see 2 c).

b. GlobCover v2.2 – The GlobCover v. 2.2 global land cover classification is available for free after registration at http://ionia1.esrin.esa.int/. The data set is delivered in GeoTIFF format for individual continents in Plate Caree projection (datum WGS84). Download the continental data layer corresponding to the location of the TEAM site and subset it to the spatial extent of the buffer layer derived in ii.a. Reproject the result to the local UTM zone.

iv. *Water Mask* – The water mask is used to determine obstructed areas, if present. Large water bodies function as barriers to animal movements and ecological processes with potential impacts on biodiversity at the measurement locations.

a. In a GIS system extract a water mask layer from the land cover map or from other local data sources for the 100 km buffer area in UTM projection. Extract a polygon layer delineating water bodies.

b. Alternatively use the MODIS Land Water Mask, MODIS product MOD44W. For ordering and downloading the MOD44W data layer follow the instructions provided in section iii.a respectively. Under *Primary Data Search* select the dataset *MODIS/TERRA Land Water Mask Derived from MODIS and SRTM L3 Global 250m SIN Grid*. Leave the fields for start and end dates empty. Order and download the MODIS water mask in HDF[7] format, subset it to the 100 km buffer layer derived in section ii.a. and reproject it to the local UTM zone. Convert it to polygons.

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[6] Hansen, M. C, R. S DeFries, J. R.G Townshend, M. Carroll, C. Dimiceli, and R. A Sohlberg. 2003. Global percent tree cover at a spatial resolution of 500 meters: first results of the MODIS vegetation continuous fields algorithm. Earth Interactions 7, no. 10: 1-15.

[7] Tech-Tip: HDF files can be opened directly in ENVI. Alternatively they can be converted to GeoTIFF format using the HEG Tool (http://newsroom.gsfc.nasa.gov/sdptoolkit/HEG/HEGDownload.html) or the MODIS Reprojection Tool (MRT, https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool).

v. *Logged areas* – Acquire a spatial data layer with areas of forest logged within the last five years within the 100 km buffer zone derived in section ii. a. In cases where no deforestation maps are available, approximate locations of logged areas should be hand digitized using a time sequence of satellite images (visualization are available from http://www.esri.com/landsat-imagery/viewer.html or Landsat satellite imagery from http://glovis.usgs.gov/) or Google Earth (http://www.google.com/earth/index.html) and local expert knowledge.

vi. *Infrastructure layers* – Required data layers of human infrastructure are, if present, a) roads, b) human settlements, and c) industrial sites including mines. The transportation layer should include paved and unpaved roads, tracks, and railway lines. The human settlements layer should include the location and population size of the settlement. If no local data sets are available, a useful source of settlement locations is the GEOnet Names Server (GNS) of the National Geospatial-Intelligence Agency's (NGA) (http://earth-info.nga.mil/gns/html/namefiles.htm#B). Download the corresponding country file which is a comma-delimited text file containing latitude, longitude and other settlement attributes and convert it to a shape file[8]. Industrial sites should include the type of industrial activity, which could be extractive (e.g. mining) or processing (e.g. smelter). All infrastructure layers should be as recent as possible. If they are not available in-house or from local sources their approximate locations should be digitized by hand on a map, a georeferenced satellite image or on Google Earth (earth.google.com).

vii. *Key species* – Identify a single or multiple forest-dependent key species at the TEAM site. The choice of key species will be used to determine the extent of the contiguous habitat. The key species should be selected by local experts considering the following criteria:

   a. The key species should play a pivotal role in the animal community within the ecosystem of the TEAM site, maintaining community structure. A removal of the key species should likely result in significant ecological changes at the TEAM site.
   b. Indiviuals of a key species should be a typical occurrence at a TEAM site (e.g. in areas where *Panthera onca* (jaguar) is already very rare or even threatened of extinction it should not be chosen as a key species).
   c. A typical key species occupies an ecological niche in the food chain with very few or no competitors within its niche (e.g. lemur species at the TEAM site in Ranomafana, Madagascar).
   d. A key species might also control vegetation and habitat structure (e.g. elephants at the TEAM site in the Udzungwas, Tanzania).

3.1.2 Calculating Watersheds

The watersheds are calculated from the hole-filled Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) at 90 m horizontal resolution (see section *3.1.1 Required spatial data layers*). The calculation of the watersheds can be carried out in a raster-based GIS software package that provides the functionality of sink-removal, calculation of catchment areas, channel

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[8] Tech-Tip: In QGIS use the "Add Delimited Text Layer" plugin function (select the button showing three commas [,,,]). Make sure the plugin is selected in the Plugins/Manage Plugins menu. If the plugin is not listed under the Plugins menu, download it from the repository under Plugins/Fetch Python Plugins while making sure that 3rd party repositories are included.

networks and drainage basins. For the development of this manual the open-source software package SAGA-GIS version 2.0.4 was used. Carry out the following steps (Figure 2).

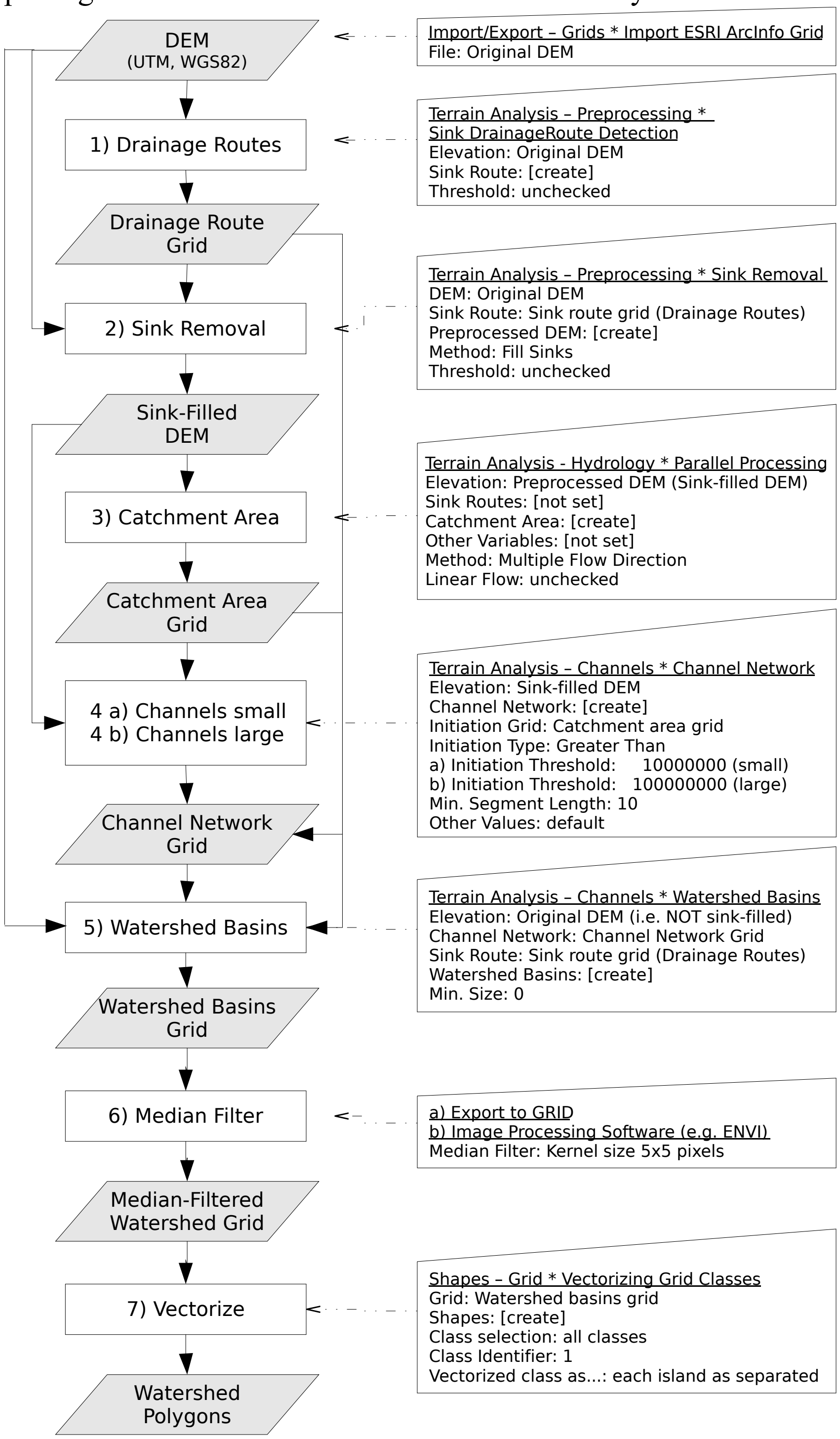

Figure 2: Flow chart for calculating watersheds from a DEM. The instructions in the right-hand column refer to SAGA-GIS software package version 2.0.4. The functions are located in the *Workspace* window on the *Modules* panel.

1) *Drainage routes* – Calculate drainage routes for the DEM. Drainage routes are needed for sink removal and for the calculation of the watershed basins. In SAGA-GIS:
    a. Select the function *Terrain Analysis – Preprocessing * Sink Drainage Route Detection* and (i) select the *Grid System*, (ii) for *Elevation* select the DEM, (iii) set *Sink Route* to [create] and (iv), under *Options*, set *Threshold* to unchecked and leave *Threshold Height* at its default value.
    b. Execute the process and save the resulting drainage route grid under a new name.
2) *Sink Removal* – Remove sinks and pits from the DEM. This is necessary because sinks and pits are problematic for hydrological analysis in general and for the calculation of watersheds in particular, since water would come to a halt at those locations and watersheds could not be calculated comprehensively. In SAGA-GIS:
    a. Select the function *Terrain Analysis - Preprocessing * Sink Removal* and (i) select the *Grid System* and DEM, (ii) for *Sink Route* select the drainage route grid created in step 1), (iii) set *Preprocessed DEM* to [create] and (iv) set *Method* to Fill Sinks.
    b. Execute the process and save the sink-filled DEM under a new name.
3) *Catchment Area* – Calculate the catchment area for each pixel. The catchment area is defined as the area of all up-slope cells which provide water flow to the cell plus the area of the cell itself. The catchment area is required as an input data layer for the calculation of watersheds. In SAGA-GIS:
    a. Select the function *Terrain Analysis - Hydrology * Parallel Processing* and (i) select the Grid System, (ii) for *Elevation* select the sink-filled DEM created in step 2), (iii) set *Catchment Area* to [create], (iv) leave all other parameters including *Sink Routes* at [not set], (v) under *Options* set *Method* to Multiple Flow Direction and leave the other values at their default (Step: 1, Linear Flow: unchecked, Linear Flow Threshold: 500, Convergence: 1.1)
    b. Execute the process and save the resulting catchment area grid under a new name.
4) *Channel Network* – Calculate the channel (water stream) network at two scales. The fine scale watersheds have a minimum area of 10 km^2 minimum upstream area, and the coarse scale watersheds 100 km^2. Watersheds at both scales are used for deriving the ZoHDEC. In SAGA-GIS:
    a. Select the function *Terrain Analysis - Channels * Channel Network* and (i) select the *Grid System*, (ii) for *Elevation* select the sink-filled DEM, (iii) for *Initiation Grid* select the catchment area grid, (iv) leave both the *Channel Network* and *Channel Direction* set to [create], (v) set *Initiation Type* to Greater Than, (vi) set *Initiation Threshold* to 10,000,000, (vii) set *Min. Segment Length* to 10, and leave all other settings at their default values. The initiation threshold determines at which point a channel or river starts. A value of 10,000,000 m^2 corresponds to 10 km^2 as the minimum upstream area for a river channel to be designated as such. This value controls the minimum size of the watershed.
    b. 4 b) Execute the process and save the resulting grid *Channel Network* under a new name. Also export the resulting channel vector layer to a shape file.
    c. 4 c) Repeat steps 4 a and b using a larger *Initiation Threshold* of 100,000,000. Make sure in the function *Terrain Analysis - Channels * Channel Network* (i) reset *Grid System – Channel Network* to [create] and (ii) reset *Shapes – Channel Network* to [create]. Save the result under a new name. This channel network with the larger

threshold will result in fewer channels. This is the layer used to calculate the watershed basins.

5) *Watershed Basins* – Calculate both small and large watershed basin grids. Individual watershed basins are distinguished in SAGA-GIS by their grid values.
   a. Select the function *Terrain Analysis - Channels * Watershed Basins*. (i) For *Elevation* select the original DEM, (ii) for *Channel Network* select the channel network grid based on the initiation threshold of 10,000,000 m^2, (iii) for *Sink Route* select drainage route grid, (iv) set *Watershed Basins* to [create] and *Min. Size* to 0.
   b. Execute the process and save the watershed basin grid under a new name.
   c. Repeat steps a. and b. with the channel network grid based on the larger initiation threshold of 100,000,000 m^2.
6) *Median Filter* – The borders in the watershed basins grid are often complex with diagonally connected single pixels or strings of pixels. This is due to the gridded nature of the dataset and to the algorithms used to calculate the watershed basins. These complex borders increase storage space and processing time unnecessarily, because the ZoHDEC is derived at a much coarser scale than the 90 m scale provided by the SRTM DEM. Simplify both the small and large watershed basin layers by applying a median filter twice to the watershed basin grids with a kernel size of 5x5 pixels. The median filter assigns to the central pixel the majority value within the square kernel. The current version 2.0.4 of SAGA-GIS does not provide this functionality. The best alternative is to transfer the grid to an image processing package, such as ENVI or ERDAS, apply the 5x5 median filter two times and transfer the result back into SAGA-GIS. Data exchange between the software packages works well via ASCII-Grid format. Save both the simplified small and large watershed basin layers under new names.
7) *Watershed Boundaries* – Create watershed boundaries from the watershed basins. In SAGA-GIS:
   a. Select the function *Shapes – Grid * Vectorizing Grid Classes* and (i) select the *Grid System*, (ii) for *Grid* select the median-filtered small watershed basins grid, (iii) leave *Shapes* set to [create] and all other values under *Options* at their defaults (*Class Selection* = all classes; *Class Identifier* = 1; *Vectorized class as...* = each island as separated polygon).
   b. 7 b) Click Okay and export the resulting polygons layers to a shape file. These are the watershed boundaries.
   c. Repeat steps a. and b. with the large watershed basins grid.

3.1.3 Contiguous Habitat and Obstructed Areas

The contiguous habitat layer corresponds to the main habitat area of the key species extending out from the TEAM Core Area. The limit of the contiguous habitat is often, but not always, the boundary of human land use or of the managed area. The managed area is a land area managed for conservation (protected area), research or other purposes. The contiguous habitat might also be restricted by topographic features, rivers or watershed boundaries.

To delineate the contiguous habitat area use the land cover map (see section *3.1.1 Required Spatial Data Layers – iii. Land Cover Map* in this manual) or use a high resolution satellite image or Google Earth (earth.google.com). Carry out the following steps:

i. Calculate the total size of the key species viable population. The effective viable population size is 50 reproducing individuals (rule of thumb commonly used in population genetics, Franklin 1980). From this number calculate the corresponding size of the real population which includes non-breeding individuals and which is usually 3 to 10 times larger than the effective population size. This requires knowledge of the population structure and reproductive behavior of the key species, which should be researched in the scientific literature.

ii. Calculate the habitat area required by the key species at the size of the total viable population. The habitat area corresponding to an individual or group of individuals of the key species should be researched in the scientific literature.

iii. If the required habitat area is smaller than the TEAM Core Area, use the TEAM Core Area as the area of contiguous habitat. In most cases the required habitat area will be larger than the TEAM Core Area. The required habitat area has to be selected as the part of the contiguous habitat polygon which is closest to the core area. This can be accomplished by using a vector or raster-based approach as outlined in the following steps:

   a. Delineate the habitat area of the key species within the wider region around the TEAM Core Area and save the delineated habitat area as a GIS polygon layer in shape file format. This should be straightforward if the key species is forest-dependent and the contiguous habitat area is unbroken.
   b. If the contiguous habitat is not continuous, e.g. encompassing areas of other land cover types, which will most often be the case, use a raster-based approach.
   c. Calculate a distance (buffer) grid at 90 m resolution around the core area with the values of each grid cell representing the distance to the core area.[9]
   d. Mask the buffer grid to only those grid cells falling within the contiguous habitat area. Set all other pixels to a no-data value.
   e. Do a statistical analysis of the buffer grid to calculate at which buffer distance the total area of pixels surpasses the required habitat area. This can be achieved by calculating how many pixels correspond to the required habitat area (n pixels), sorting the pixel values in the distance grid in increasing order and determining the value of the nth pixel. This is the maximum buffer distance corresponding to the outer limit of the required habitat area polygon.
   f. Select all pixels up to the determined maximum buffer distance and convert them to a new polygon layer.
   g. If the TEAM core area is disjunct (divided into spatially disparate polygons), repeat steps 1-3 for each individual polygon and union the results. This final polygon is the required contiguous habitat area.

Obstructed areas are all areas separated from the TEAM Core Area by barriers inhibiting animal movements and the flow of ecological processes, with potentially high impacts on biodiversity at the TEAM site. Most often these are large water bodies. Other examples are deep valleys of dry habitat, mountain ridges with distinctly different alpine climate and habitat or an escarpment. Use existing data layers of these barriers, e.g. the MODIS water mask as described in section

[9] Tech-Tip: In ENVI open the mosaicked SRTM DEM raster layer at 90 m resolution. Here the DEM layer will only be used as a template. Import the shape file with the core area polygon(s) into ENVI, overlay it onto the DEM and convert the polygons to a region of interest (ROI). Select Basic Tools / Region of Interest / Create Buffer Zone from ROIs. Select floating point as output format and confirm. This will calculate a new raster with the same dimensions as the DEM layer and each grid cell value representing the distance to the core area polygon.

3.1.1 Required Spatial Data Layers, or manually digitize the barriers based on ancillary data layers and expert knowledge.

3.1.4 Migration Corridors

Migratory corridors correspond to the migratory paths of key species at the TEAM site leading outside of the managed area or contiguous habitat layer. To derive migration corridors, follow these steps:

i. Identify migratory paths along which the animals of the key species normally migrate and their destination area, e.g. elephants migrating to a distant waterhole or dry season grazing grounds.
ii. Digitize a line along the center of the migratory path and buffer the line by 5 km on each side. This is the migratory corridor layer.

3.1.5 Human Activities and Infrastructure

Human activities can impact biodiversity measured at the TEAM sites, depending on their type, intensity and location. Logged areas and agricultural fields can be determined directly from maps or remote sensing imagery. Other activities such as hunting, grazing, extractive activities (selective logging, collection of fuel wood, fruit, honey, etc.) or industrial pollution can be determined indirectly from the distribution of infrastructure including road networks, settlements, and industrial sites. To derive the human activities layers carry out the following steps:

i. Identify the most important human activities in and around the protected area which have the highest potential to affect biodiversity at the measurement site. Include, if present, logged areas, road networks (existing data layers or digitized from satellite imagery or Google Earth), human settlements, industrial activities, and agricultural areas. Other respective human activities include but are not restricted to hunting, extractive activities (selective logging, collection of fuel wood, fruit, honey, etc.) pasturing, and industrial pollution.
ii. For each significant human activity digitize the general area within which each activity takes place, using recent remote sensing imagery (Landsat, Google Earth http://earth.google.com/) and expert knowledge. Note that the digitized areas do not have to show very fine detail. For deriving the ZoHDEC simplified boundaries encompassing the main areas of each human activity are sufficient. Buffer road layers using a 2 km buffer distance.

3.2 Derive the Zone of Human Dynamics and Ecosystem Change

The ZoHDEC is derived based on the spatial data layers generated above. Starting with the watersheds, the individual layers are overlaid step by step and four subsequent drafts of the ZoHDEC layer are generated by intersecting, combining and clipping operations within a GIS system. Carry out the steps described below to derive the first draft of the ZoHDEC (Figure 3).

3.2.1 Select Watershed Basins

The watershed polygon layers generated in section 4.1.2 contain more and larger watershed areas than appropriate for the ZoHDEC. Select the appropriate watershed basins and their subsections as follows.

i. Overlay the TEAM Core Area polygon layer over the small watershed basins layer (with minimum upstream area of 10 km^2) and select all watershed basins intersecting with the TEAM Core Area polygon. Do not select watersheds barely touching the TEAM Core Area.
ii. Overlay both the small and large channel network vector layers in order to facilitate visual interpretation of where the watershed basins are draining into. Add to the already selected watershed basins all adjacent upstream small watershed basins with channels directing water into the watershed basins selected in step i. Save all selected small watershed basins as a new layer.
iii. Overlay this new layer onto the large watershed basins layer and select all large watershed basins intersecting the new layer. Do not select any large watershed basins which are only touching, rather than overlapping, this layer. Save the selected large watershed basins as a new layer.

3.2.2 Combine Watersheds and Contiguous Habitat

The selected watersheds are restricted according to their location upstream or downstream of the TEAM Core Area and the contiguous habitat. Carry out the following steps for selecting and combining the appropriate watershed basins and subsections[10].

i. Union the contiguous habitat layer with the watershed layer generated in section 4.2.1.
ii. Convert the unioned layer from multi-part to single-part. The resulting polygon layer contains subsections of the watersheds which can be individually selected.
iii. Overlay both the large and small scale channel network vector layers in order to facilitate visual interpretation of which parts of the watersheds are upstream or downstream.
iv. Select all polygons within the contiguous habitat.
v. In addition select all sections of any watershed protruding beyond and *upstream* of the contiguous habitat. Do not select any watershed sections downstream of the contiguous habitat layer.
vi. Save all selected watershed sections to a new layer. Dissolve all polygon boundaries in the new layer into one single polygon. This is the first draft ZoHDEC.

[10] Tech-Tip: In QGIS the functionality for carrying out these steps is provided by the fTools plugin. In order to install and activate fTools open the menu function *Plugins / Fetch Python Plugins…*, select the tab *Repositories* and click the button *Add 3rd party repositories*. Then select the tab *Plugins* and in the scroll-down list highlight *fTools for QGIS*. Click the button *Install plugin* and *Close*. Open the menu function *Plugins / Manage Plugins*, check the box next to *fTools* and click *OK*. In the main menu bar now appears a new drop down menu *Tools* where the fTools are located.

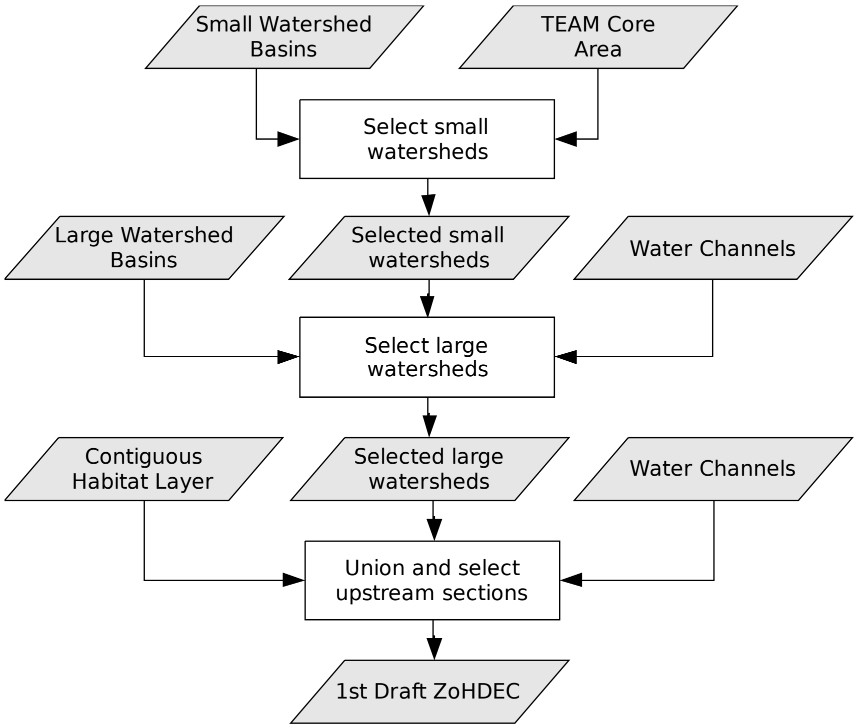

Figure 3: Flow chart illustrating how to derive the first draft of the ZoHDEC from the watersheds and contiguous habitat layers.

3.2.3 Combine with Human Activities Layers

The human activity layers usually include logging, human settlements, roads, agriculture and other layers. Combine each of the human activity layers with the first draft ZoHDEC as follows.

i. Calculate a 10 km buffer polygon around the first draft ZoHDEC[11].
ii. Overlay each human activity layer and determine if the closest locations ("frontier") of the human activity to the TEAM Core Area are included in the first draft ZoHDEC. If not, determine whether there are any locations of the human activity within the 10 km ZoHDEC buffer. If so extend the ZoHDEC to include these areas of the human activity to at least 2 km width and up to the first draft ZoHDEC 10 km buffer limit. If human activity layers are radiating out from the first draft ZoHDEC, e.g. roads, include only the areas closest to the ZoHDEC.
iii. Repeat step 2 for all human activity layers. The result is the second draft of the ZoHDEC.

3.2.4 Combine with Migratory Corridors and Barriers

In the final step the layers representing migratory corridors and barriers are incorporated to arrive at the final ZoHDEC (Figure 4).

i. Union the migratory corridor layer with the second draft ZoHDEC, extending its boundary. The resulting layer is the third draft of the ZoHDEC.

[11] Tech-Tip: If the first draft ZoHDEC polygon layer has very complicated and detailed border lines, the buffering process might take a very long time or the application might run out of memory and crash. If so, simplify the polygon before buffering, by either hand-digitizing a simplified polygon along the border of the first draft ZoHDEC, or in QGIS by using the function *Simplify Feature*.

ii. Intersect the barrier polygon with the third draft of the ZoHDEC and delete overlapping areas of the two polygons from the third draft ZoHDEC layer.
iii. If the boundary of the ZoHDEC is ragged and frayed (e.g. resulting from the conversion of raster imagery to vector layers) simplify the polygon boundary[12]. This is the final ZoHDEC.

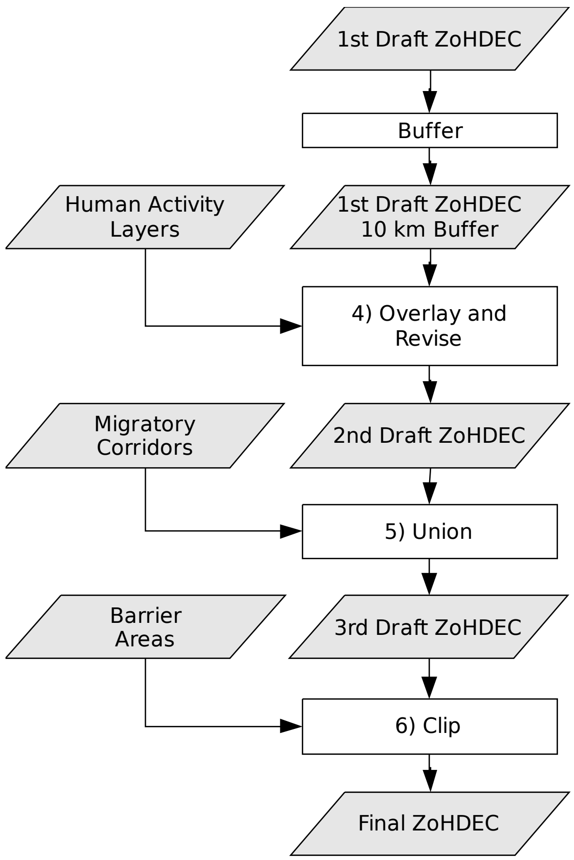

Figure 4: Flow chart illustrating how to delineate the final draft of the ZoHDEC by incorporating human activity layers, migratory corridors and barrier areas.

The final ZoHDEC should be discussed and verified with local experts and TEAM staff every 5 years to ensure the validity and usefulness of the result.

[12] Tech-Tip: A ragged polygon boundary can be simplified by manually digitizing a smoother polygon along the boundary. In QGIS the function *Simplify Feature* might be used.

4. Glossary

Core Study Area – this refers to the sub-area within the site where TEAM sampling units will be located (see TEAM Sampling Unit Placement Protocol).

DEM – Digital elevation model

ENVI – Image processing software package, produced by ITT Visual Information Solutions.

ESA – European Space Agency

GIS – Geographic information system

GlobCover – Global land cover classification product at 300 m resolution, produced by © ESA / ESA GlobCover Project, led by MEDIAS-France.

HDF – Hierarchical Data Format, a file format to store, organize and document large amounts of numerical data.

MODIS – Moderate Resolution Imaging Spectroradiometer, a multispectral satellite sensor flown on both the TERRA and AQUA satellite platforms.

QGIS – Quantum GIS open source geographic information system.

ROI – Region of Interest, term used in ENVI to designate a group of selected pixels.

SAGA-GIS – Open source geographic information system, specialized for digital elevation model and hydrological processing and raster analysis.

Site – this refers to the entire spatial area within which TEAM takes measurements and carries out monitoring activities.

SRTM – Shuttle Radar Topography Mission DEM

TEAM – Tropical Ecology Assessment and Monitoring network

UTM – Universal transverse mercator projection

VCF – Vegetation Continuous Fields, a global percent tree cover derived from MODIS data at 500 m resolution.

ZoHDEC – Zone of Human Dynamics and Ecosystem Change

5. Data Sources

5.1 Open Source GIS Software

Quantum GIS (QGIS) – www.qgis.org

SAGA-GIS – www.saga-gis.org

5.3 Satellite Imagery and Derived Datasets

USGS (Landsat, ASTER) – http://glovis.usgs.gov

Vegetation Continuous Fields (VCF) Percent Tree Cover – https://wist.echo.nasa.gov/api/, dataset *Land: MODIS/Terra data set and select MODIS/TERRA Vegetation Continuous Fields Yearly L3 Global 500m SIN Grid V004*.

GlobCover v2.2 Landcover Classification – http://ionia1.esrin.esa.int/

MODIS Land Water Mask (MOD44W) – https://wist.echo.nasa.gov/api/, dataset *MODIS/TERRA Land Water Mask Derived from MODIS and SRTM L3 Global 250m SIN Grid*

SRTM DEM (Hole-Filled) – http://srtm.csi.cgiar.org