

# THE SAVANNA ECOSYSTEMS MAP OF BELIZE 2010: TECHNICAL REPORT

VERSION 1 (DRAFT)

SEPTEMBER 2010

DARWIN INITIATIVE PROJECT 17022  
SAVANNA ECOSYSTEM ASSESSMENT: BELIZE

IAIN D. CAMERON

NEIL STUART

ZOE GOODWIN



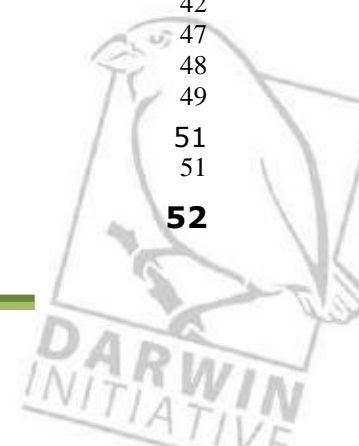
Royal  
Botanic Garden  
Edinburgh

GeoEye  
Foundation



## Table of Contents

<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.1	Project Overview	1
1.2	The need for a national savanna conservation strategy	1
1.3	Previous savanna mapping and classification in Belize	4
<b>2</b>	<b>THE 2010 SAVANNA ECOSYSTEM MAP</b>	<b>6</b>
2.1	Objectives	6
2.2	Requirements	6
2.3	Specifications	6
2.3.1	Vegetation mapping scales	6
2.3.2	Planimetric accuracy	7
2.3.3	Mapping scale	7
2.3.4	Temporal currency	7
2.3.5	Geographic coverage	7
<b>3</b>	<b>THE DARWIN INITIATIVE SAVANNA CLASSIFICATION FOR BELIZE</b>	<b>8</b>
3.1	Classification principles	8
3.1.1	Lowland savanna definition	8
3.1.2	Savanna landscapes	8
3.1.3	The class hierarchy	9
3.2	Landscape level vegetation classes	11
3.2.1	Lowland savanna	11
3.2.2	Forest	11
3.2.3	Wetland	11
3.3	Patch-level vegetation classes (IDC & ZG)	12
3.3.1	Forest and wetland Inclusions	12
3.3.2	Open savanna	12
3.3.3	Dense tree savanna	13
3.3.4	Seasonally waterlogged	14
3.4	Summary Statistics	19
3.4.1	Landscape level analysis	19
3.4.2	Patch-level analysis	21
<b>4</b>	<b>METHODOLOGY</b>	<b>24</b>
4.1	Remote Sensing Datasets	25
4.1.1	SPOT -5	25
4.1.2	ALOS PALSAR	27
4.1.3	IKONOS	29
4.1.4	ASTER	31
4.1.5	Landsat	32
4.1.6	Google Earth	33
4.2	Ground-Truth Data	34
4.2.1	Training data	34
4.2.2	Validation data	37
4.3	Land-Cover Classification	37
4.3.1	Object-oriented classification	37
4.3.2	Image segmentation in Ecognition	38
4.3.3	Rule-based classification	42
4.3.4	Manual classification of savanna in Cayo district	47
4.3.5	Manual classification of problem classes	48
4.3.6	Output generalisation	49
4.4	Map Validation	51
4.4.1	Comparison against validation points	51
<b>5</b>	<b>REFERENCES</b>	<b>52</b>



## List of Figures

Figure 1: Estimated area of lowland savanna converted to other uses.	2
Figure 2: Comparison of protected areas against the lowland savanna	3
Figure 3: The Belize Ecosystem Map: 2004 (Meerman & Sabido, 2001).	5
Figure 4: The savanna landscape class hierarchy.	9
Figure 5: Landscape level and patch level polygons on the right.	10
Figure 6: Examples of broadleaf forest and wetland ecosystems.	11
Figure 7: Examples of open savanna.	12
Figure 8: Examples of dense tree savanna.	13
Figure 9: Examples of seasonally waterlogged savanna.	14
Figure 10: The Savanna Ecosystems Map 2010 landscape level (northern Belize).	15
Figure 11: The Savanna Ecosystems Map 2010 landscape level (southern Belize).	16
Figure 12: The Savanna Ecosystems Map 2010 patch level (northern Belize).	17
Figure 13: The Savanna Ecosystems Map 2010 patch level (southern Belize).	18
Figure 14: The savanna landscape is comprised of lowland savanna.	22
Figure 15: Comparison of lowland savanna estimates from the 2004 and 2010.	23
Figure 16: Summary of the Savanna Ecosystems Map of Belize 2010.	24
Figure 17: Footprints of SPOT images and dates shown over administrative districts.	26
Figure 18: Footprints of ALOS images and dates shown over administrative districts .	29
Figure 19: Footprints of IKONOS images and dates shown over administrative districts.	30
Figure 20: Footprints of ASTER images and dates shown over administrative districts.	31
Figure 21: Footprints of Landsat images and dates shown over administrative districts.	33
Figure 22: Distribution of training polygons.	35
Figure 23: Distribution of validation points from ground survey conducted in 2010	36
Figure 24: An example of the image-object hierarchy.	38
Figure 25: Multiresolution concept flow diagram.	39
Figure 26: The Ecognition segmentation and classification workflow.	40
Figure 27: Segmentation of an image into landscape and patch level objects.	41
Figure 28: Example of a rule-based classification for a wetland in the RBCMA.	41
Figure 29: Box and whiskers plot showing the distribution of NDVI.	43
Figure 30: Box and whiskers plot showing the distribution of mean HV.	44
Figure 31: Box and whiskers plot showing the distribution of mean SWIR.	45
Figure 32: Box and whiskers plot showing the distribution of GLCM red homogeneity.	45
Figure 33: Identification of lowland savanna from ASTER image.	47
Figure 34: Summary of processing steps used in output generalisation.	50



## List of Tables

Table 1: Areas of landscape level vegetation classes and percentage of total per class	19
Table 2: Areas and percentage of patch level classes under protection	19
Table 3: Area of lowland savanna ecosystem with respect to national protected area	20
Table 4: Areas of patch level classes and percentage of total per class	21
Table 5: SPOT-5 sensor characteristics	25
Table 6: Details of SPOT-5 images used	25
Table 7: RMSE values in pixels estimated for each SPOT image	27
Table 8: IKONOS sensor characteristics	30
Table 9: Landsat sensor characteristics	31
Table 10: Landsat sensor characteristics	32
Table 11: Ground-truth land cover polygons and points according to class and data source	34
Table 12: Classification ruleset and specific attribute thresholds	46
Table 13: Classification error matrix for patch-level classes	51
Table 14: Classification accuracy per patch-level class	51



## **1 Introduction**

### **1.1 Project Overview**

In 2009 the “Savanna Ecosystem Assessment: Belize”, or “SEA: Belize”, project was initiated with the purpose of increasing available data and enhancing the capacity of local institutions to undertake taxonomic research and mapping required to identify priority areas for conservation within savannas. This three year project is funded by the UK DEFRA Darwin-Initiative, and brings together a consortium of partners from the UK and Belize to address these problems. These are: The University of Edinburgh (UoE), The Royal Botanic Garden Edinburgh (RBGE), The University of Belize (UB), The Belizean Forestry Department (FD), The Belize Botanical Garden (BBG), Programme for Belize (PfB) and Belize Tropical Forest Studies (BTFS).

The specific aims of the project are to:

1. Provide improved and more current savanna vegetation mapping for Belize to support conservation and management;
2. Conduct baseline taxonomic research and botanical survey of savanna areas;
3. Enhance the capacity of local institutions to continue providing and interpreting biological data for conservation management.

This report explains how the first objective, the generation of the new savanna map and vegetation classification system, was achieved during the first year of the project. While it marks the end of concentrated effort to produce a baseline savanna vegetation map, the map and vegetation classification should continue to be validated and updated during, and hopefully beyond, the lifetime of the project. During the second year of the project we are working with our in country partners (particularly BTFS) to undertake assessment of the mapping prior to its release.

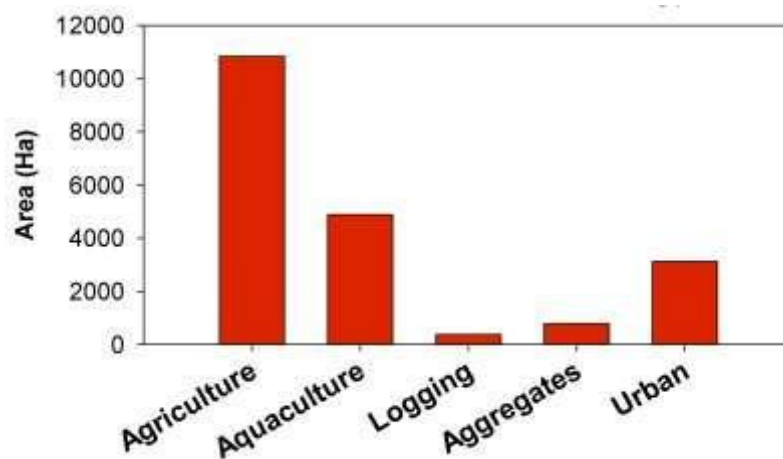
### **1.2 The need for a national savanna conservation strategy**

The savannas of Belize occupy almost 10% of the land area, furnishing distinctive landscapes of ecological and economic value. They are the most northerly example of lowland savannas in the Americas. Whereas upland savannas of Central America have been the subject of numerous studies of plant diversity, the lowland savannas have received little attention until now. Lowland savannas in Belize are threatened by a combination of human pressures and by climate change. Yet preliminary investigations show that these savannas and associated wetlands are diverse ecosystems providing important habitats for plants and wildlife.

Gap analysis in 2005 revealed that, compared to other ecosystems, savannas are under-represented in the National Protected Areas System (see Figure 2), with about 23% of national savanna areas at that time assigned some form of protected status. This needs to be urgently addressed because savannas are experiencing an increasing variety and severity of threats. Since they occur on relatively accessible level ground there is pressure to clear savanna for settlement and for infrastructure. New data from this project shows that the development of large scale aquaculture and agriculture is having dramatic impacts upon lowland savannas nationwide and are responsible for altering the drainage, nutrient cycling and fire regimes of this ecosystem, resulting in ecosystem degradation. By comparing the Savanna



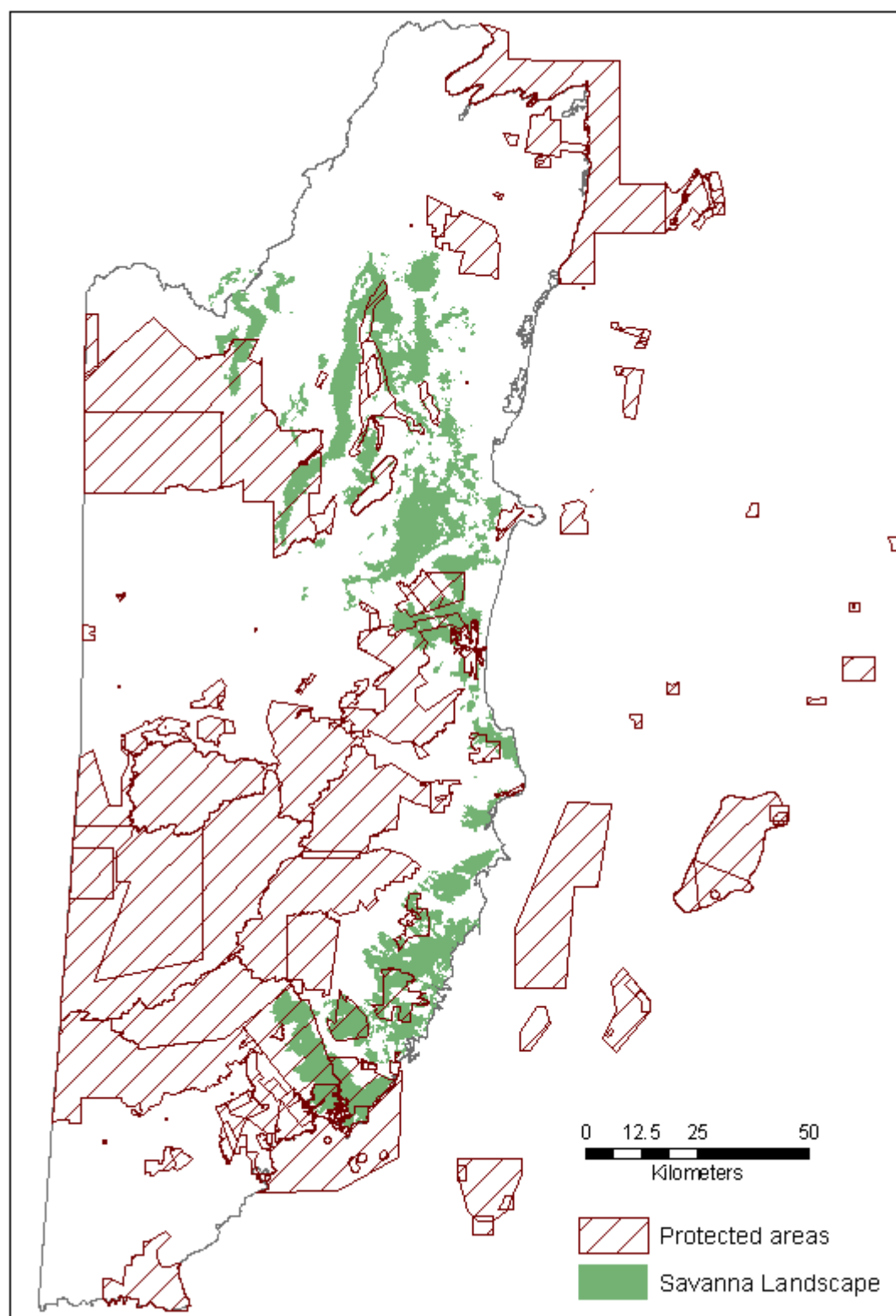
Ecosystem Map 2010 against archived Landsat imagery dating from 1980 and topographic mapping we estimate that from an original total area of 168,000 ha, approximately 20,000 ha has been converted to other uses, i.e. roughly 12% of lowland savanna has already been lost to development. Figure 1 shows that the two largest sources of development are agriculture and aquaculture, together making up for almost 80% of the area lost from savanna. Aquaculture in particular has dramatically increased in scale from the first experimental pond in 1980, to generating revenues of Bz\$ 84.28 million by 2004. However, lowland savannas are in themselves a potentially significant economic resource. For example the FD seeks to harvest pine, palms and other plant resources and to promote ecotourism in a sustainable manner that protects biodiversity hotspots within savanna areas, but presently lacks the taxonomic or geographic information needed to ensure that harvesting does not inadvertently affect areas of high conservation value. These shortcomings, together with the pressure for wholesale conversion of lowland savannas to other uses, make the formulation of a national conservation strategy for savannas a top priority.



*Figure 1: Estimated area of lowland savanna converted to other uses.*

One key problem that this Darwin project seeks to resolve is the insufficient information for developing a national conservation strategy for this ecosystem. Specifically:

1. There is no comprehensive checklist of savanna species. Geographic and botanical information on species distribution is incomplete, with little known about patterns or frequency of endemism.
2. Many savanna areas, particularly in the south, were unexplored botanically and there is therefore little basis for making informed conservation decisions.
3. Efforts to map the biogeography of savannas nationally have, until now, been limited. Only an approximate extent of savannas was delimited in the Ecosystems Map of Belize of 2001. This mapping lacked habitat and species-specific detail that would be required to allow priority areas for conservation or economic use to be identified within savanna areas.



*Figure 2: Comparison of protected areas against the lowland savanna ecosystem as identified from the Savanna Ecosystems Map 2010. Note that roughly 73% of this ecosystem has no protected status.*



### 1.3 Previous savanna mapping and classification in Belize

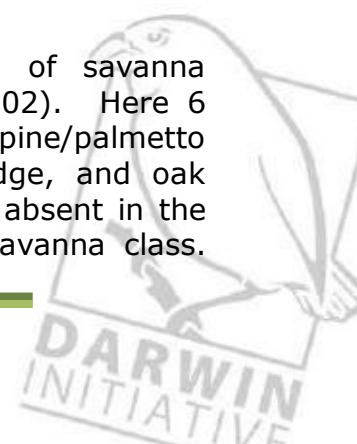
In this section we review some previous vegetation classification applied to savannas in Belize. For comprehensive reviews of more general vegetation classification applied to Belize and Central America, see Vreugdenhil *et al* (2001) and Meerman & Sabido (2001).

The Belize Ecosystem Map: 2004 version is the most recent update of the Central American Ecosystems Map by Meerman & Sabido (2001). This classifies the plant formations of Belize according to the UNESCO vegetation classification system and was based upon interpretation of Landsat imagery and the Brokaw & Iremonger map (1995). The UNESCO system is a physiognomic vegetation classification system which classifies vegetation primarily according to structure, and is designed to be globally applicable. Formations are described according to the dominant above ground woody or herbaceous elements, together with biological (e.g. seasonality) and ecological (e.g. climate, elevation) criteria. As it is an extendable classification system, Meerman & Sabido (2001) also included biogeographic distribution and species associations where appropriate. These formations were identified at a scale of 1:250,000, to coincide with existing topographic. While Meerman & Sabido have introduced a scale-related parameter with the Ecosystem descriptor, whereby UNESCO classes are grouped into more general ecosystems, the UNESCO system itself does not recognise the fact that an ecosystem may contain formations with very different physiognomic structure. This is a clear for classifying heterogeneous systems such as savannas which may be predominantly open grassland at a coarse scale, and yet is found to include patches of wetland, low density woodland and forest when viewed at at finer scales. Rather than separating these into different ecosystems according to physiognomy, it would be useful to recognise them as functional savanna associates.

Meerman & Sabido (2001) identified two distinct savanna ecosystems within Belize ;short-grass savanna with needle-leaf trees (V.A.2.a (1).(2)) and short-grass savanna with shrubs (V.A.2.b (2)). Short-grass savanna with shrubs is considered the typical lowland savanna, with a fairly depauperate set of species and few trees due to the frequent fire regime and poor drainage. Short-grass savanna with needle-leaf trees is described as a pine-dominated open forest form that is transitional between short-grass savanna with shrubs and tropical evergreen seasonal needle-leaf lowland dense forest (I.A.2.a.(2).(b)), which is a mixed *Pinus caribaea*-broadleaf assemblage. Importantly, neither of these classes make any reference to the presence of dense tree savannas.

The two UNESCO savanna classes were defined for use at a scale of 1:250,000, and were interpreted from moderate resolution Landsat images. However, using the higher resolution SPOT images available in this project, and comparing against ground observations, we were unable to reliably distinguishbetween areas according to these two class descriptions. Instead smaller savanna components such as woodlands, forest and wetland formations, that are not visible in the Landsat images previously used, could be identified.

At the other end of the scale-spectrum, a detailed classification of savanna assemblage was conducted for the RBCMA by Bridgewater *et al* (2002). Here 6 savanna sub-types were identified: Grassland and scrub grassland, pine/palmetto savanna, palmetto thicket, savanna orchard, woodland and pine ridge, and oak thicket. This scale of classification identifies the dense tree savannas absent in the UNESCO system, and embeds these classes within a smaller-scale savanna class.





However, it is a primarily botanical classification that was not designed with vegetation mapping in mind. Thus many of these formations are either difficult to differentiate from remotely sensed images (e.g. pine/palmetto savanna, and grassland and scrub grassland) or are at too small to be accurately delimited using the imagery available in this project (e.g. palmetto thicket).

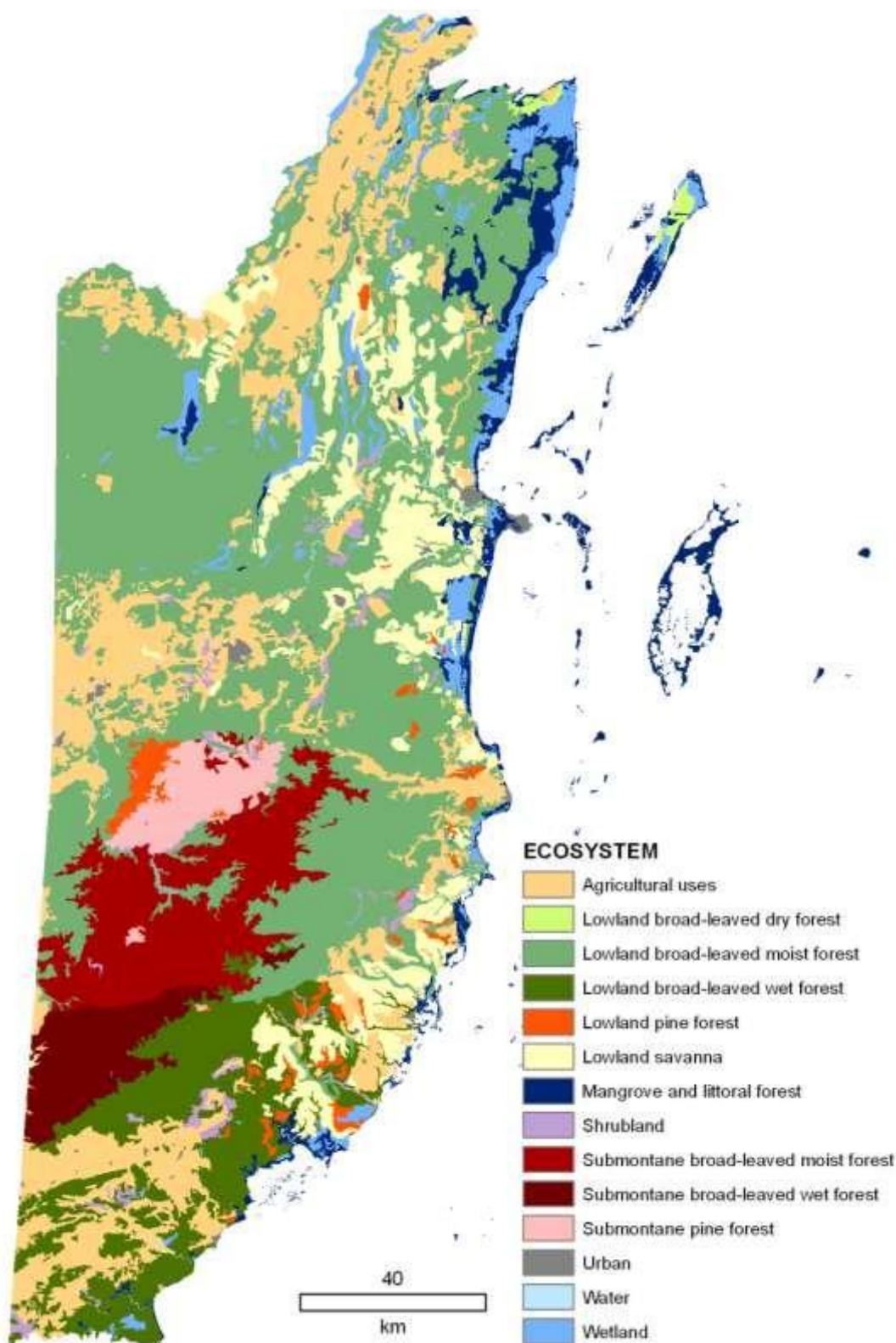


Figure 3: The Belize Ecosystem Map: 2004 (Meerman & Sabido, 2001)

## **2 The 2010 Savanna Ecosystem Map**

### **2.1 Objectives**

The core purpose of the 2010 Savanna Ecosystem Map, as laid out by the SEA: Belize project, is:

“To provide improved baseline mapping to inform management and conservation decisions in the lowland savannas of Belize.”

The map has been designed to:

1. Provide up-to-date mapping of the extent of the remaining lowland savanna,
2. Provide the first nationwide assessment of the internal composition of lowland savanna
3. Allow for the identification of lowland savanna areas that may be under threat and aid in the recognition of priority areas for conservation.

### **2.2 Requirements**

The following requirements for the map were specified, drawing from project objectives, consultation with intended users in Belize and consideration of similar projects in Belize and elsewhere:

1. The map and vegetation classification implemented needs to be both botanically and geographically consistent. I.e. the botanical definitions of vegetation assemblages need to reflect units that can be mapped.
2. As the map is intended as a national product, class definitions need to be applicable nationwide. Localised definitions should be avoided where possible.
3. The map needs to be compatible with existing practices. In Belize, this means that the map needs to identify familiar landcover units. More specifically, it should facilitate comparison with the existing Ecosystem map of Belize (Meerman & Sabido, 2001).

The different scales of vegetation assemblages observed within savanna assemblages should be described in a single, coherent system that works at a national scale.

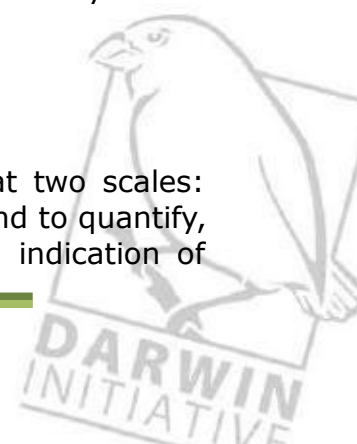
### **2.3 Specifications**

The 2010 Savanna Ecosystem Map is designed to provide an assessment of the extent and composition of lowland savanna across Belize. A mosaic of remote sensing imagery acquired from a variety of sensors was used to deliver nationwide coverage. This core dataset is comprised of:

- 5 SPOT images,
- Advanced Land Observation Satellite Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) images and,
- Landsat Images.

#### ***2.3.1 Vegetation mapping scales***

These data have been used to provide savanna ecosystem mapping at two scales: *landscape*-level and *patch*-level. Landscape level is designed to show, and to quantify, the overall extent of lowland savanna across Belize, together with an indication of



associated forest and wetland ecosystems that we argue form part of the wider "savanna landscape" (see section 3.1.2). The minimum-mapping area for landscape level units was 50 hectares. Thus these data are considered suitable for use at a nation-scale.

Patch-level mapping is designed to provide more detailed information on the internal composition of the lowland savanna ecosystem. The minimum-mapping area for patch level units was 5 ha, and is most suitable for application at the regional or administrative district level.

### *2.3.2 Planimetric accuracy*

The remote sensing datasets are considered spatially accurate to within 30m, with SPOT expected to be accurate to within 10-20m over areas with elevations below 100m. However, the mapping has been produced at a generalised scale for ease of use and portability. Consequently, boundaries of map units at both landscape and patch level are expected to be accurate to within 50m. For details on the methods used for generalisation, refer to section 4.3.6.

### *2.3.3 Mapping scale*

The landscape- and patch-level mapping are considered appropriate for presentation at map scales of between 1:250,000 and 1:50,000. Vegetation classification, particularly with respect to vegetation polygon boundaries, is unlikely to be reliable if reproduced at resolutions higher than 1:50,000.

### *2.3.4 Temporal currency*

The temporal currency of the mapping depends upon the date of the images in the mosaic. For the landscape-level mapping, the savanna extents were defined using SPOT imagery and updated with Landsat imagery from 2009 and 2010 to provide an up-to-date assessment of lowland savanna extents. **The landscape-level mapping is considered current to 2009/2010.**

As Landsat lacks the spatial resolution required to resolve the internal savanna composition within Belize, the **patch-level mapping is current to the SPOT images used.** Most of these images are relatively recent, with 92.5 % of the area mapped drawn from SPOT images since 2006, and 33.5% since 2009. For exact details of the SPOT image acquisition dates, refer to section 4.1.1.

### *2.3.5 Geographic coverage*

As figure 17 and 18 show, although entire country-wide coverage was not obtained from both SPOT and ALOS imagery, all areas of lowland savanna were were imaged by eth available SPOT and ALOS data, with the possible exception of some very small patches of savanna within areas of broadleaf forest or saline scrubland in north eastern Corozal. Investigation of ASTER and Landsat imagery suggests that these areas are largely below the minimum mapping scale for landscape level units. The other possible area where small patches of savanna may occur in areas not imaged by the sensors are small remenants near the western highway between Belmopan and San Ignacio and around Spanish Lookout. While cloud-free ASTER images were available for these areas, it was not possible to identify potential new areas of savanna, i.e. areas not shown in the Meerman & Sabido map of Belize.



### **3 The Darwin Initiative Savanna Classification for Belize**

#### **3.1 Classification principles**

##### *3.1.1 Lowland savanna definition*

For this study we define lowland savanna as;

*Any natural or semi-natural, fire-influenced ecosystem within the confines of Belize under 500m in altitude with a continuous herbaceous layer dominated by native grasses. Trees and shrubs may occur to a lesser or greater extent. Where they do exist, *Pinus caribaea*, *Acoelorrhaphe wrightii*, *Byrsonima crassifolia*, *Curatella americana*, *Melastomataceae* spp. and *Quercus* spp. are usually amongst the most structurally conspicuous non-herbaceous elements. Savannas that experience annual sequences of flooding and drought related to the wet and dry seasons (i.e. hyperseasonal sensu Sarmiento (1984)) are included.*

This is broad and inclusive definition of savanna that can be considered akin to the lowland savanna ecosystem as defined by Meerman & Sabido (2004). At the more "tree-dense" end of the savanna spectrum we also include some areas of pine woodland that have been previously mapped as pine forest, or tropical evergreen seasonal needle-leaved lowland forest (IA2a(2)(b)) under the UNESCO classification (Meerman & Sabido, 2004). As these forests have a dominant graminoid layer and, to our knowledge, do not have typically exhibit closed canopies we contend that this class is better considered as part of the lowland savanna.

Note that we explicitly exclude the upland savannas of Mountain Pine Ridge for the following reasons;

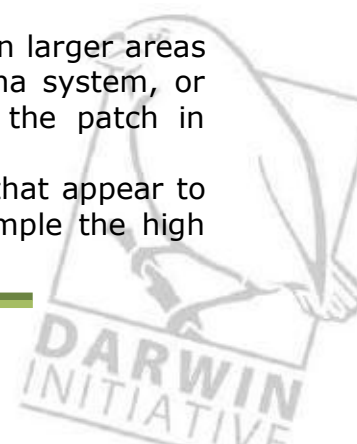
1. These savannas are predominantly within protected areas and are not under the same degree of threat from human activity as lowland savannas and;
2. Relatively well-defined species lists already exist for this ecosystem type

##### *3.1.2 Savanna landscapes*

For management and conservation purposes we contend that the lowland savanna ecosystem should be seen as a functional element of a wider system, or "savanna landscape". This recognises that savannas are dynamic systems that are strongly associated with vegetation assemblages that do not necessarily fit within the precise description above. A clear example of this would be the broadleaf gallery forests that often cut through lowland savanna. Although botanically distinct, it is difficult to argue that such assemblages should be separated from the savanna system from either a management or conservation perspective.

The key reasons we allow for non-savanna vegetation types being included within the savanna landscape are scale and context;

- **Scale.** Isolated units of non-savanna vegetation may occur within larger areas of savanna. Whether these get classified as part of the savanna system, or placed into a separate class is dependent upon the scale of the patch in question.
- **Context.** This refers to larger units of non-savanna vegetation that appear to be functionally associated with the savanna landscape. For example the high





forest/lowland savanna boundary would not be considered part of the savanna landscape, but a gallery forest surrounded on both sides by lowland savanna would be.

### 3.1.3 The class hierarchy

The mapping is restricted to areas identified as lowland *savanna landscape* in Belize. Within these areas, this product contains two nested scales of thematic mapping, represented by *savanna landscape* and *savanna component* polygons.

The landscape level shows the overall extent of lowland savanna across Belize, and includes some areas of forest and wetland vegetation (referred to as *forest patches* and *wetland patches*) that occur within the *savanna landscape*. Savanna landscape is a general term that refers to core savanna vegetation types, together with associated areas of wetland and broadleaf vegetation that function as part of the savanna system as a whole. A gallery forest is a good example of a broadleaf vegetation assemblage that is botanically distinct from savanna, but functions as a part of the savanna landscape.

The savanna patch-level mapping provides a detailed expansion of the internal composition of the lowland savanna class, by splitting the landscape-level class into 5 sub-classes as shown in figure 1. This includes 3 core savanna classes: *open savanna*, *dense tree savanna* and *seasonally waterlogged savanna with shrubs and trees*, together with small *inclusions* of forest and wetland (<50 ha in area). The landscape-level wetland and forest classes are also shown for comparison, but are not further subdivided into component units. To get an idea of typical components of forest and wetland areas, please refer to the Ecosystems Map of Belize (Meerman & Sabido, 2001). Figure 5 shows how the savanna landscape and savanna patch-level classes inter-relate.

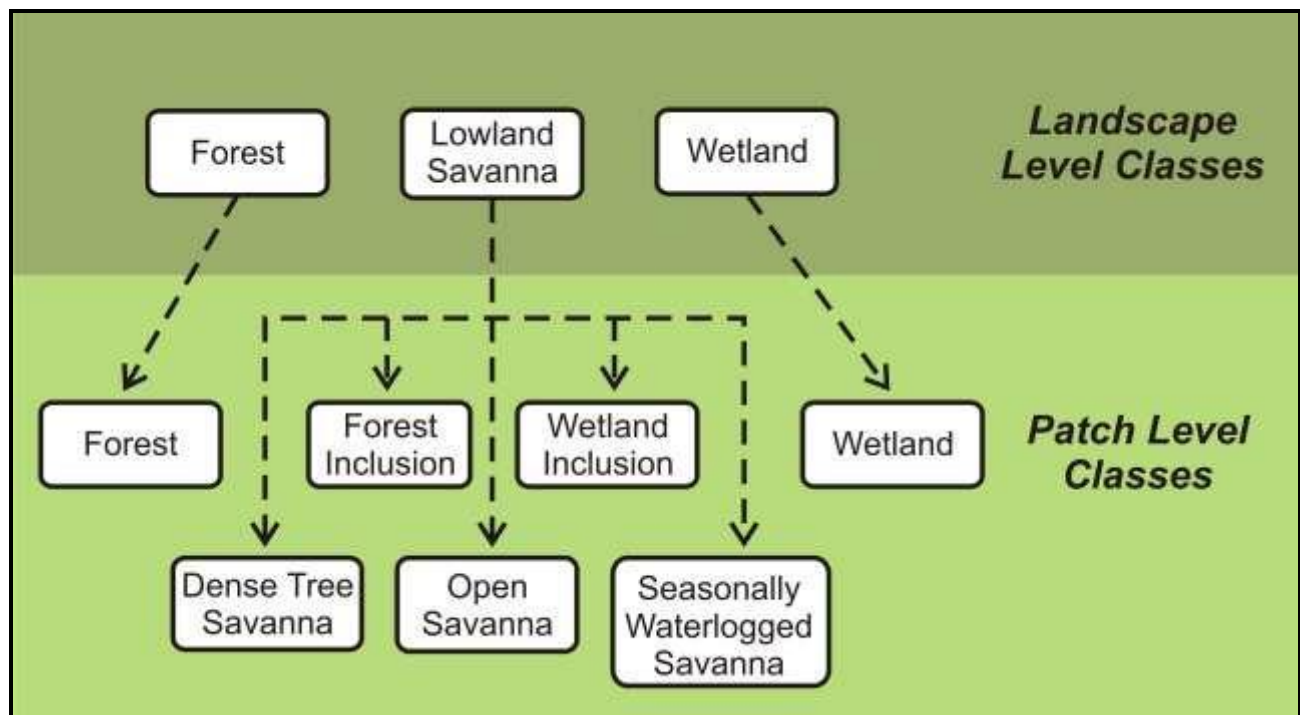


Figure 4: The savanna landscape class hierarchy, comprised of landscape-level and patch-level classes for vegetation polygons.

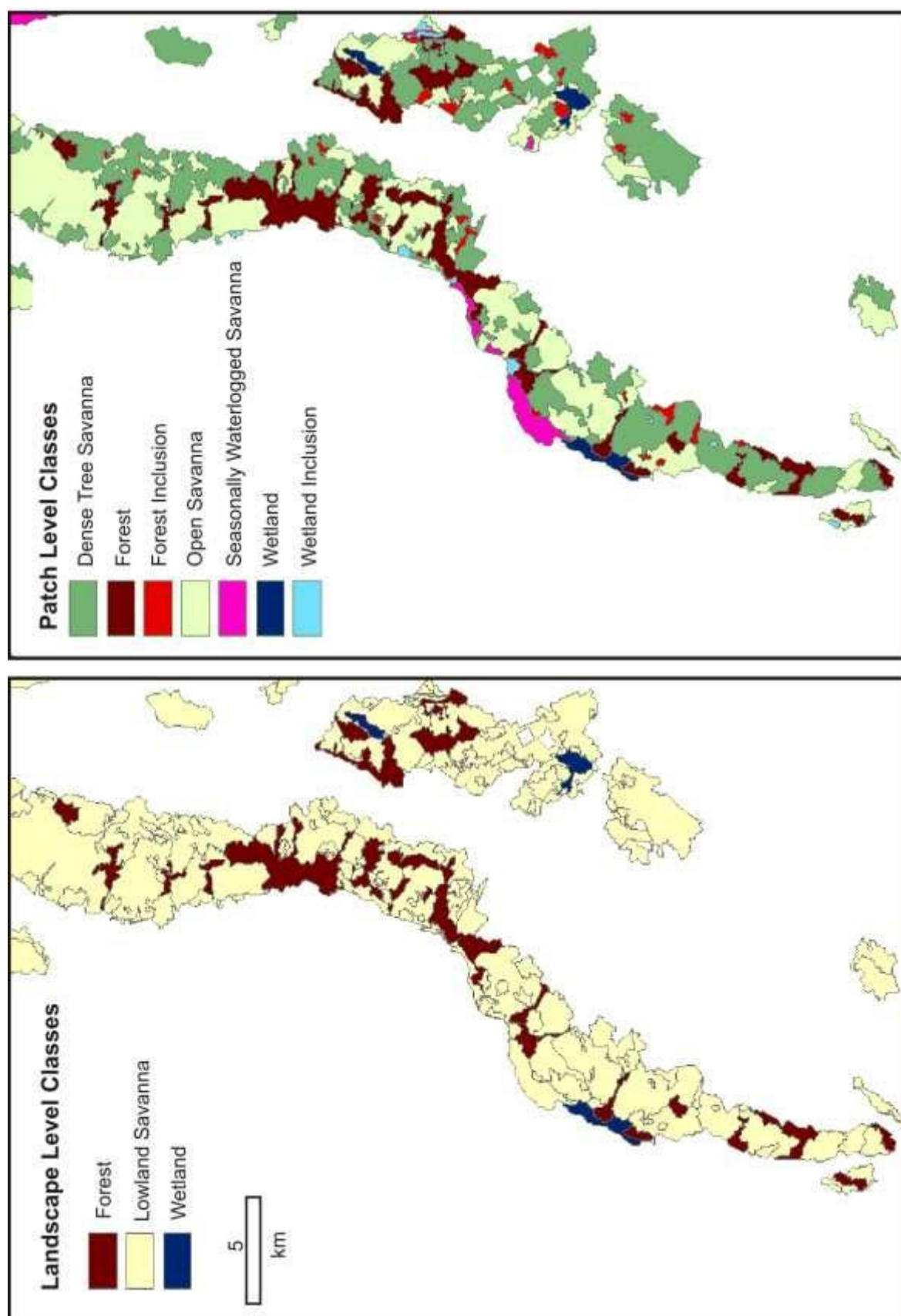


Figure 5: Landscape level polygons are shown on the left, and patch level polygons on the right. Note that the patch-level includes areas of forest and wetland that are too small to be identified at the landscape level.

## 3.2 Landscape level vegetation classes

### 3.2.1 Lowland savanna

This class reflects the broad description outlined in section 3.1.1, i.e.;

Any natural or semi-natural, fire-influenced ecosystem within the confines of Belize under 500m in altitude with a continuous herbaceous layer dominated by native grasses. Trees and shrubs may occur to a lesser or greater extent. Where they do exist, *Pinus caribaea*, *Acoelorrhaphe wrightii*, *Byrsonima crassifolia*, *Curatella americana*, *Melastomataceae spp.* and *Quercus spp.* are usually amongst the most structurally conspicuous non-herbaceous elements. Savannas that experience annual sequences of flooding and drought related to the wet and dry seasons (i.e. hyperseasonal sensu Sarmiento, 1983) are included.

### 3.2.2 Forest

This class includes all broadleaf, closed canopy forest and are characterised by the absence of a continuous herbaceous layer. In some places predominantly savanna species may be present, such as pine within the broken ridge formations observed in Stann Creek and Toledo districts, but they are rarely dominant. Mangrove forest is not included here as it is not typically associated with savanna landscapes. Areas identified as forest have to be greater than 50ha in area.

### 3.2.3 Wetland

These areas are predominantly waterlogged year-round and expected to be dominated by sedges, but lack a dominant tree layer, e.g. eleocharis marsh, cutting grass marsh. Areas identified as wetland have to be greater than 50ha in area.



Figure 6: Examples of broadleaf forest (left) and wetland (right) ecosystems.



### 3.3 Patch-level vegetation classes (Zoe Goodwin)

#### 3.3.1 Forest and wetland Inclusions

Forest and wetland patches have the same definition as the respective forest and wetland landscape-level classes, with the additional distinction of being less than 50 hectares in area.

#### 3.3.2 Open savanna (Savanna with scattered trees and/or shrubs)

Encompasses semi-open to very open areas of pine, oak, palmetto and craboo. The following general characteristics can be applied to this type (however they are not exclusive and any given area may be composed of a mix of savanna woodland and open savanna):

- Although trees are present, and often conspicuous, open savanna has a canopy closure of under 10%. The tree layer of open savanna tends to have scattered pine and palmetto, with little to no mature oak.
- The shrub layer of open savanna tends to consist of little patches of small shrubs and geoxylic suffrutices (shrubs with underground stems) such as *Clidemia sericea*, *Calea* spp. and *Melochia* spp. clustered around the scattered pine trees, or scattered small stunted individuals of *Byrsonima crassifolia*, *Curatella americana* and Myrtaceae spp. It may contain small but dense patches of immature oak (to 1 m).
- The herbaceous layer of open savanna tends to be grass and sedge dominated, with the proportion of each depending on local drainage patterns. The non-graminoid component of the herb layer tends to be more species rich than more closed savanna types with ephemeral herbs like *Agalinis* spp., *Buchnera pusilla* and *Polygala* spp., moisture-loving species such as *Utricularia* spp. & *Drosera capillaris* and geophytes such as *Alophia silvestris* all present although often only seasonally conspicuous.



Figure 7: Examples of open savanna containing dense patches of palmetto (left) and scattered pine trees (right)

### 3.3.3 Dense tree savanna (Savanna with dense trees and/or shrubs – savanna woodland)

Encompasses semi-open to dense areas of pine, oak, palmetto and craboo, with the distinction relating to the degree of canopy closure, although field distinction between this formation and very dense forms of open lowland woody savanna can be problematic. Often, these two forms occur as complex mosaics:

- Savanna woodland tends to exhibit canopy closure of between 10 and 50% and is either usually conspicuously dominated by pine (pine woodland) or oak (oak woodland), the former occasionally with an understory of oak that can be quite dense in places. *Ilex guianensis* (to 5 to 8 m) tends to only be found in the denser areas. Palmetto can also be present, although individual clump sizes tend to be smaller than observed in open savanna. In the drier oak and pine stands (especially the former) many broadleaf species normally associated with lowland broadleaf forests start to appear, and there is a significant similarity in the flora. Typical forest elements appearing include *Casearia* sp., *Tabernaemontana* sp., *Xylopia frutescens*, *Simarouba glauca*, *Metopium brownii* and *Ficus* sp.
- Savanna woodland tends to have a lower shrub layer of 1-2 m dominated by species such as *Calliandra houstoniana*, *Miconia albicans*, *Clidemia sericea*, *Calea* spp., *Melochia spicata*, *Davilla kunthii*, *Erythroxylum guatemalense* and *Myrtaceae* spp. A few species may attain c. 3m in height. These include *Byrsonima crassifolia*, *Curatella americana* and *Acoelorrhaphe wrightii*.
- The herbaceous layer of savanna woodland tends to contain more grasses than sedges in the herb layer reflecting its tendency to have a good water drainage regime. The non-graminoid component of the herb layer is marginally poorer than open savanna areas, with fewer ephemeral, seasonal herbs such as *Polygala* spp. or *Agalinis* spp. represented. Other well-represented species include *Diodia apiculata*, *Spermacoce* spp., *Hypericum* spp., *Sauvagesia erecta* and abundant *Cassytha filiformis*. Geophytes such as *Alophia silvestris* and *Curculigo scorzonifolia* are well represented. In oak dominated woodlands there tends to be a higher diversity and abundance of Fabaceae species such as *Chamaecrista* spp. (8 species), *Clitoria guianensis*, *Tephrosia nitens* and *Zornia reticulata*, although these species are not restricted to these areas.



Figure 8: Examples of dense tree savanna with little understory, possibly due to a recent fire, (left) and with a well established understory (right)

### 3.3.4 Seasonally waterlogged (Seasonally waterlogged savanna with shrubs and trees/Wet savanna orchard)

Unlike all forms of wetland, this vegetation usually has the appearance of an 'orchard' with trees appearing evenly spaced. The majority rarely exceeding 5 – 8 m, although some mature individuals of *Bucida buceras* may be emergent and can attain 15m. It has a greater density of woody shrubs and small trees than other savanna subtypes, but its relatively open canopy, small stature and the absence of pine and oak easily distinguishes savanna orchard botanically from broadleaf forest and savanna woodland. It has a strong affinity with wetland areas, often forming a transition between wetland and other savanna types.

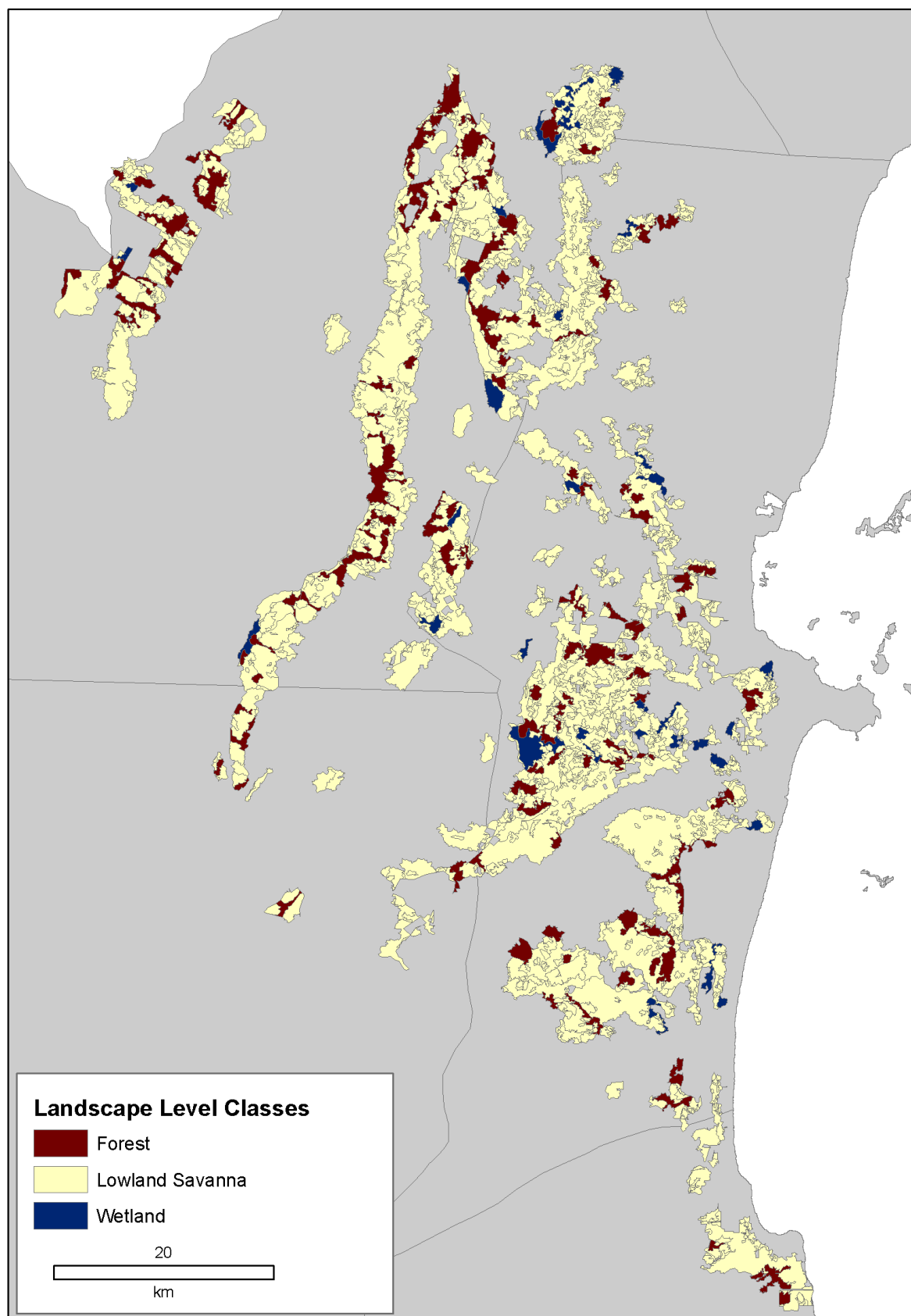
The woody species composition of savanna orchards varies greatly, but they tend to be dominated by *Bucida buceras*, *Dalbergia glabra*, *Haematoxylon campechianum*, *Heteropterys lindeniana*, *Cameraria latifolia*, *Crescentia cujete* and *Myrica cerifera*. *Crescentia cujete* is a common associate in wetter areas, sometimes even to the extent of dominating the vegetation (eg. close to Booth River). Other important woody species include *Malpighia glabra*, *Jacquinia macrocarpa*, *Coccoloba reflexiflora*, *Semialarium mexicanum*, *Chrysobalanus icaco*, and occasional clumps of *Acoelorrhaphe wrightii*. *Pinus caribaea* and *Quercus oleoides* are conspicuously absent. The trees and shrubs can support an abundant epiphytic flora of *Tillandsia* sp., other bromeliads, orchids and parasitic mistletoes, *Phthirusa* sp.

The herbaceous layer is open and dominated by sedges, with the herbaceous flora more depauperate than in drier savanna vegetation. Sedges and grasses may form dense tussocks between shrubs allowing water intolerant herbs such as *Cassytha filiformis* to thrive raised above the standing water. The strong influence of water is often reflected in the ground flora which can often be dominated by a single species of sedge (*Eleocharis interstincta*), with *Nymphoides humboldtianum*, *Sagittaria lancifolia* and *Mimosa* sp. sometimes present.



Figure 9: Examples of seasonally waterlogged savanna while under standing water (left) and dried out (right).





*Figure 10: The Savanna Ecosystems Map 2010 landscape level classes (northern Belize).*

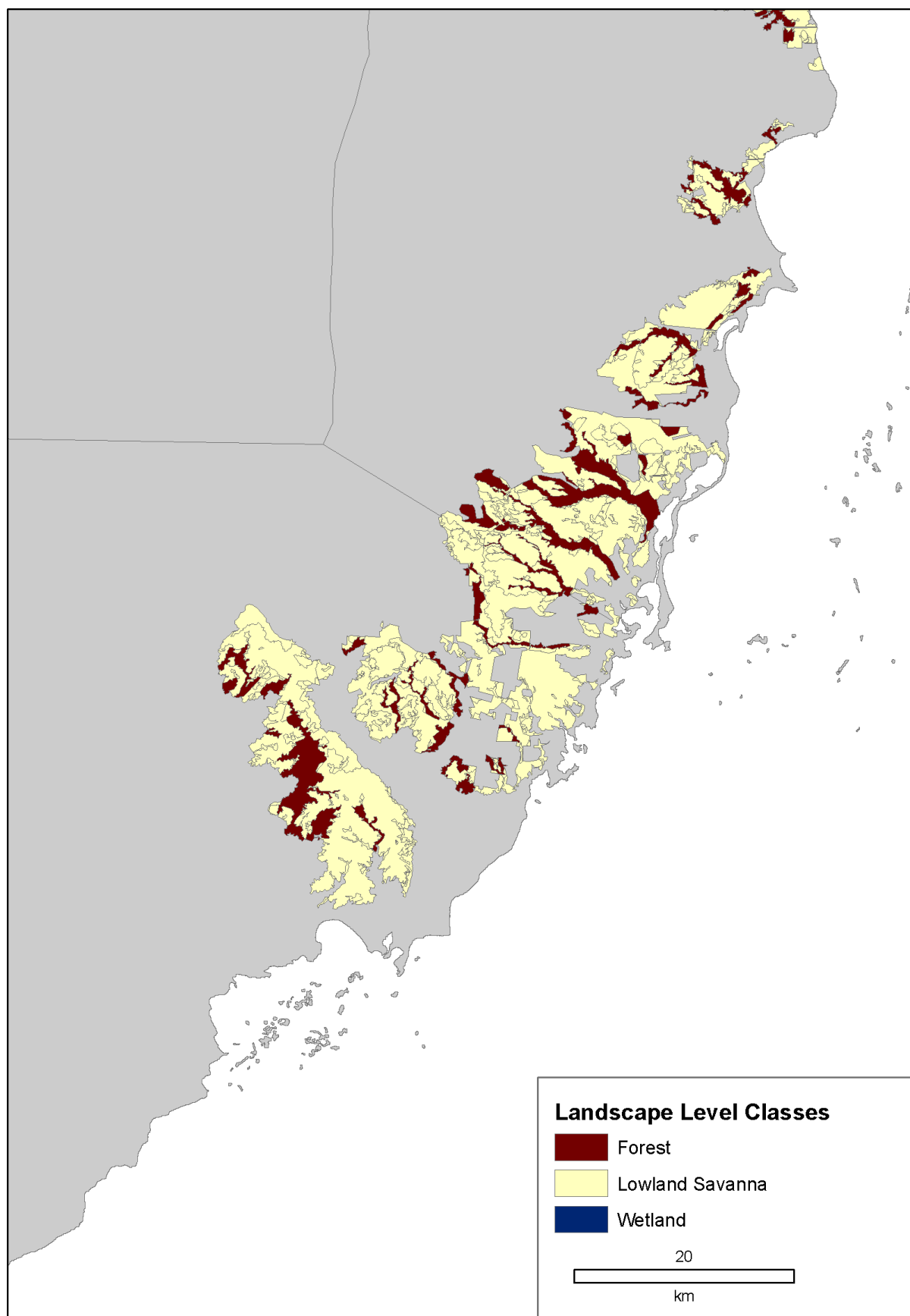


Figure 11: The Savanna Ecosystems Map 2010 landscape level classes (southern Belize).

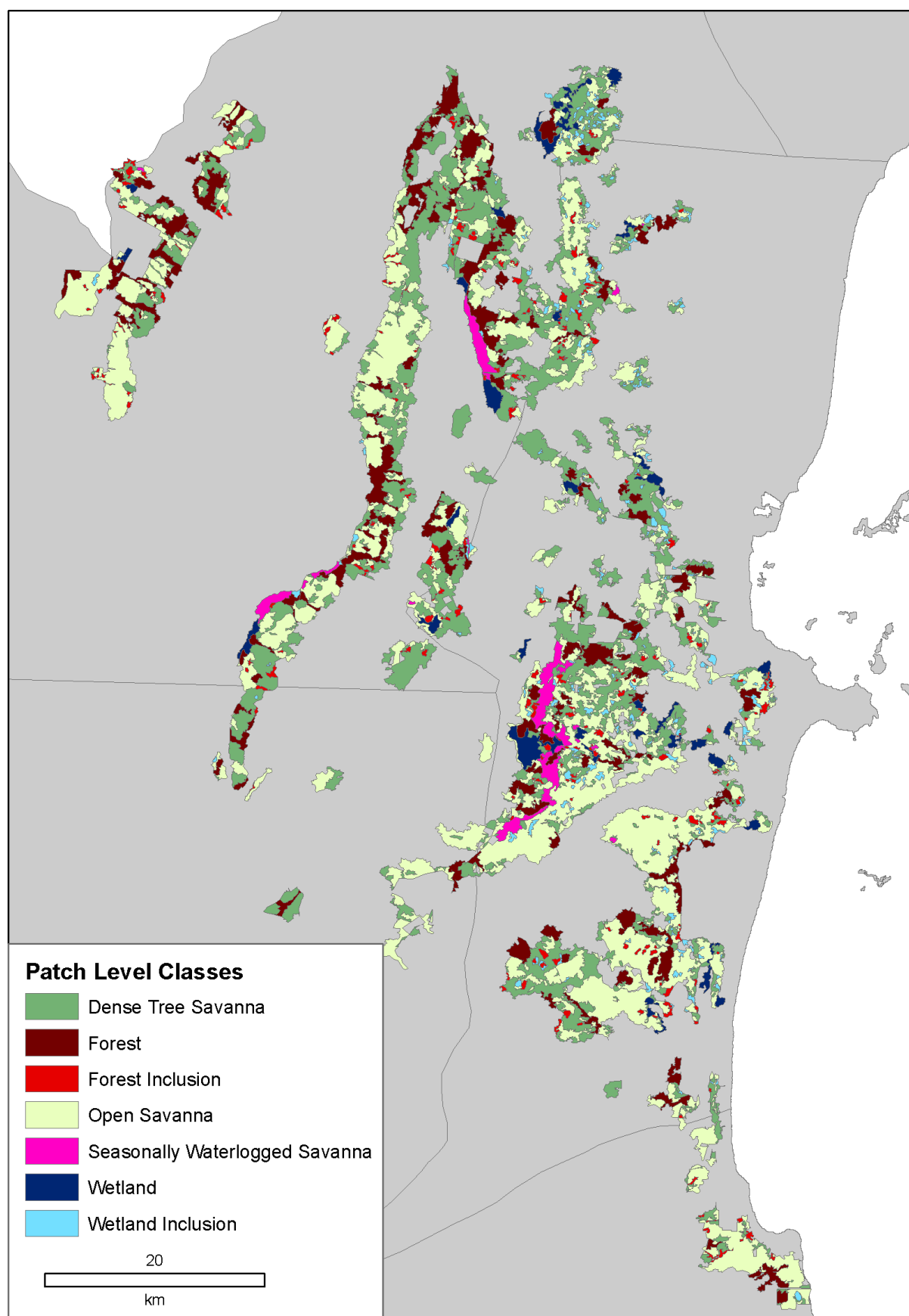


Figure 12: The Savanna Ecosystems Map 2010 patch level classes (northern Belize)

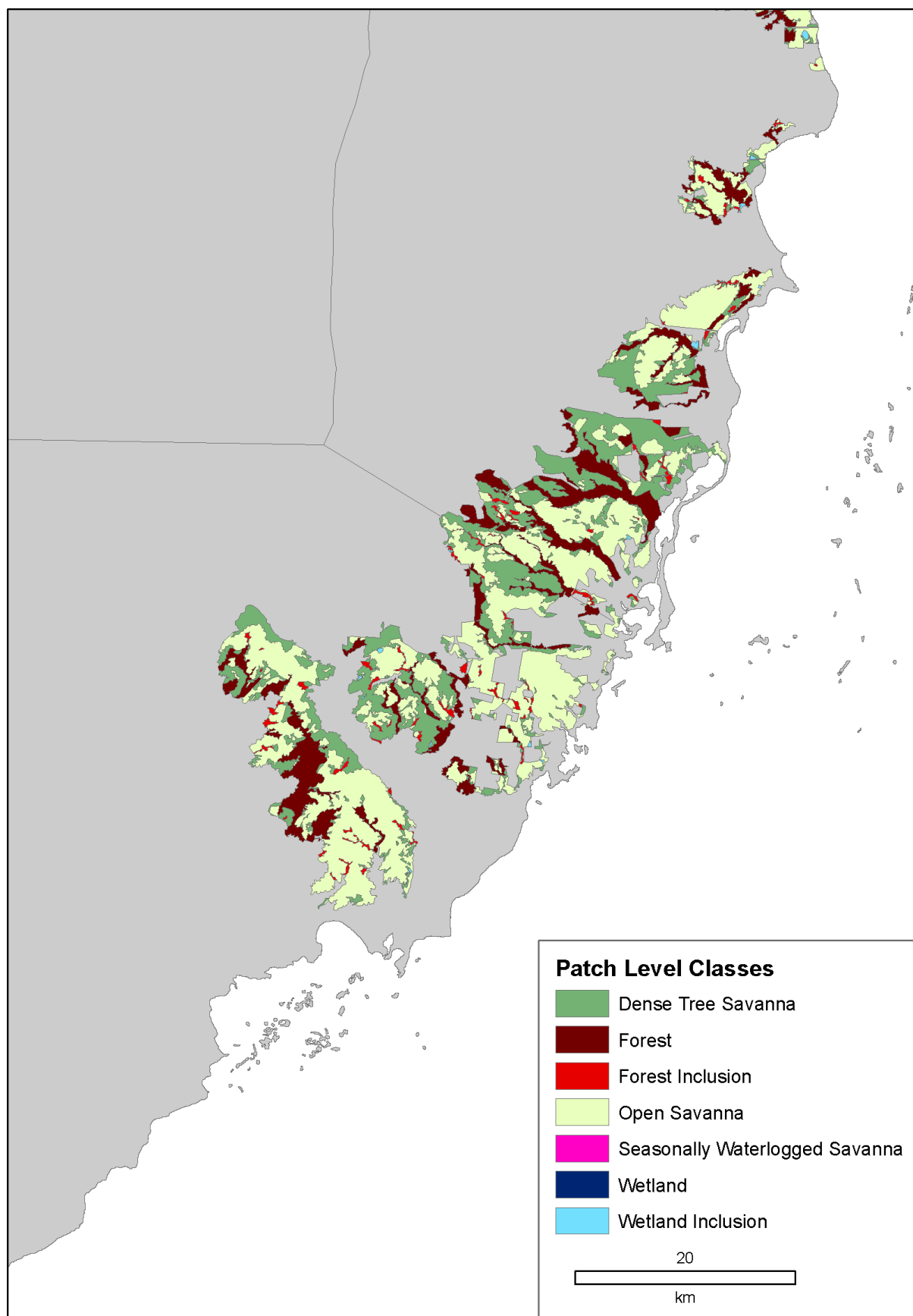


Figure 13: The Savanna Ecosystems Map 2010 patch level classes (southern Belize)



### 3.4 Summary Statistics

#### 3.4.1 Landscape level analysis

Table 1 presents the areas of each class for the landscape and patch level classifications respectively. At the landscape level we identify 1685.10 km<sup>2</sup> of lowland savanna, together with some significant areas of forest and wetland (369.71 km<sup>2</sup> in total) which, as Figure 14 illustrates, connect sizable portions of the lowland savanna. While they are clearly not lowland savanna *sensu stricto*, we contend that any integrated lowland savanna management and conservation plan should at least consider including these areas of wetland and forest.

Table 1: Areas of landscape level vegetation classes and percentage of total per class

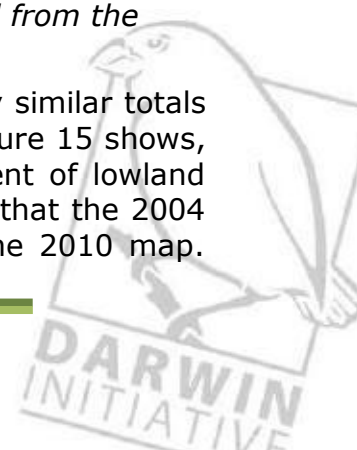
Landscape Level Class	Area (km <sup>2</sup> )	Percentage of Total
Forest	327.13	15.92
Lowland Savanna	1685.10	82.01
Wetland	42.57	2.07
Grand Total	2054.80	100

Table 2: Areas and percentage of patch level classes under protection with regards to the total for each patch level class

Patch Level Class	Area Under Protection	Area Unprotected	Percentage Under Protection
Forest	85.69	241.44	26.19
Forest Inclusion	12.52	43.21	22.46
Dense Tree Savanna	160.60	476.15	25.22
Open Savanna	263.56	664.13	28.41
Seasonally Waterlogged Savanna	8.64	22.37	27.87
Wetland Inclusion	4.96	37.61	11.65
Wetland	3.02	30.89	8.90
Grand Total	538.99	1515.82	26.23

The total area of lowland savanna identified by the Savanna Ecosystems Map of Belize 2010 (SEM 2010) is somewhat lower than the ~1903 km<sup>2</sup> estimated from the Meerman & Sabido map of 2004 (M&S 2004) as

Table 3 shows. However, for the 2008 protected areas we find that very similar totals are found between M&S 2004 (452 ha) and SEM 2010 (448 ha). As Figure 15 shows, there also is good agreement overall on the general location and extent of lowland savanna between the two maps. In the northern part of Belize we see that the 2004 map estimates considerably more lowland savanna than is found in the 2010 map.



This is probably a result of the following factors:

1. Image resolution dependencies. As the SPOT and ALOS data used in SEM 2010 is capable of resolving considerably greater detail than the Landsat used in the 2004 map, there is potential for disagreement between mapped savanna extents. In particular, SEM 2010 resolves smaller areas of forest and wetland than was achieved in M&S 2004. As small forest and wetland patches (~50-200 ha) are more prevalent in the north eastern savannas, this may explain the lower estimate of savanna area for this region in SEM 2010.
2. Identification of the wetland/savanna boundary is strongly related to inundation levels at the time of image acquisition, introducing potential for discrepancies in savanna extents.
3. Land use change, such as conversion to agriculture, may have occurred in the intervening years.

On the other hand, Figure 15 also reveals extensive areas in the south of Belize where SEM 2010 shows greater savanna extent than was mapped in M&S 2004. This discrepancy can mainly be explained by the incorporation of areas identified as pine forest by Meerman & Sabido (2004) within the dense tree savanna class.

*Table 3: Area of lowland savanna ecosystem with respect to national protected area for 2004 and 2010 ecosystem maps*

	<b>National Total (km<sup>2</sup>)</b>	<b>Area Protected (km<sup>2</sup>)</b>	<b>Percent Protected</b>
2005 Gap Analysis	1903.237	436.33	22.93
2004 Ecosystems map vs 2008 protected areas	1903.25	451.98	23.75
2010 Savanna Ecosystem map vs 2008 protected	1685.1	448.33	26.61



### 3.4.2 Patch-level analysis

At the patch level (Table 4) we see that the dominant classes are open savanna and dense tree savanna which together comprise over 92% of the lowland savanna ecosystem. Considering the areas of these classes under protection (Table 2), we can see that 28.41% of open savanna is protected as opposed to 25.22% of dense tree savanna. Seasonally waterlogged savanna is found to be considerably rarer, with only 31 km<sup>2</sup> identified (~2% of the lowland savanna). Given its rarity, unique botanical assemblage and the fact that only ~9 km<sup>2</sup> is under protection, it is tempting to suggest that this class warrants special attention from a conservation perspective.

*Table 4: Areas of patch level classes and percentage of total per class*

<b>Patch Level Class</b>	<b>Area (km<sup>2</sup>)</b>	<b>Percentage of Total</b>	<b>Percentage of Lowland Savanna</b>
Forest	327.13	15.92	
Forest Inclusion	55.73	2.71	3.31
Dense Tree Savanna	636.75	30.99	37.79
Open Savanna	927.69	45.15	55.05
Seasonally Waterlogged Savanna	31.02	1.51	1.84
Wetland Inclusion	33.91	1.65	2.01
Wetland	42.57	2.07	
<i>Grand Total</i>	<i>2054.80</i>		



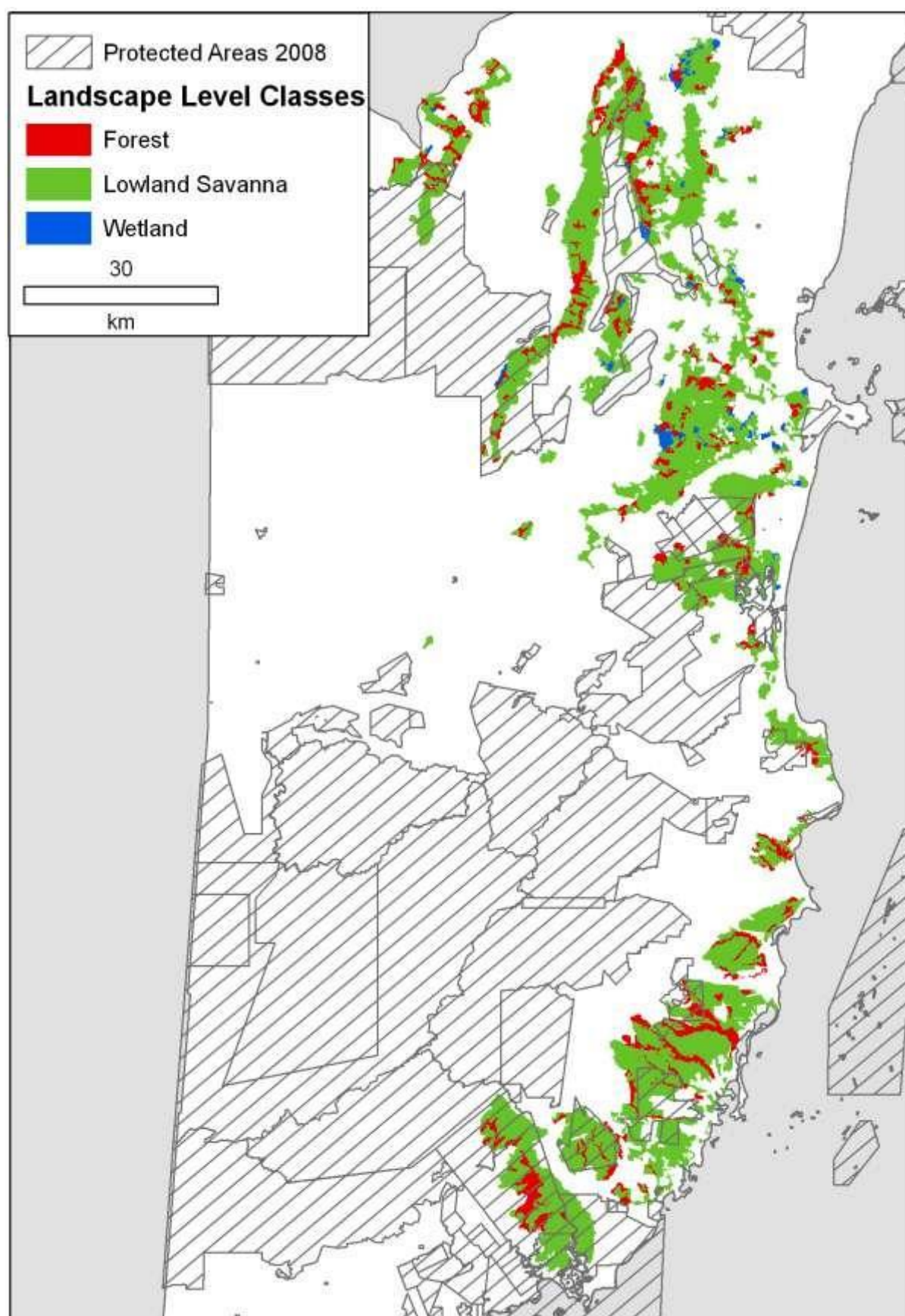


Figure 14: The savanna landscape is comprised of lowland savanna together with associated areas of forest and wetland. 2008 protected areas overlaid for comparison.



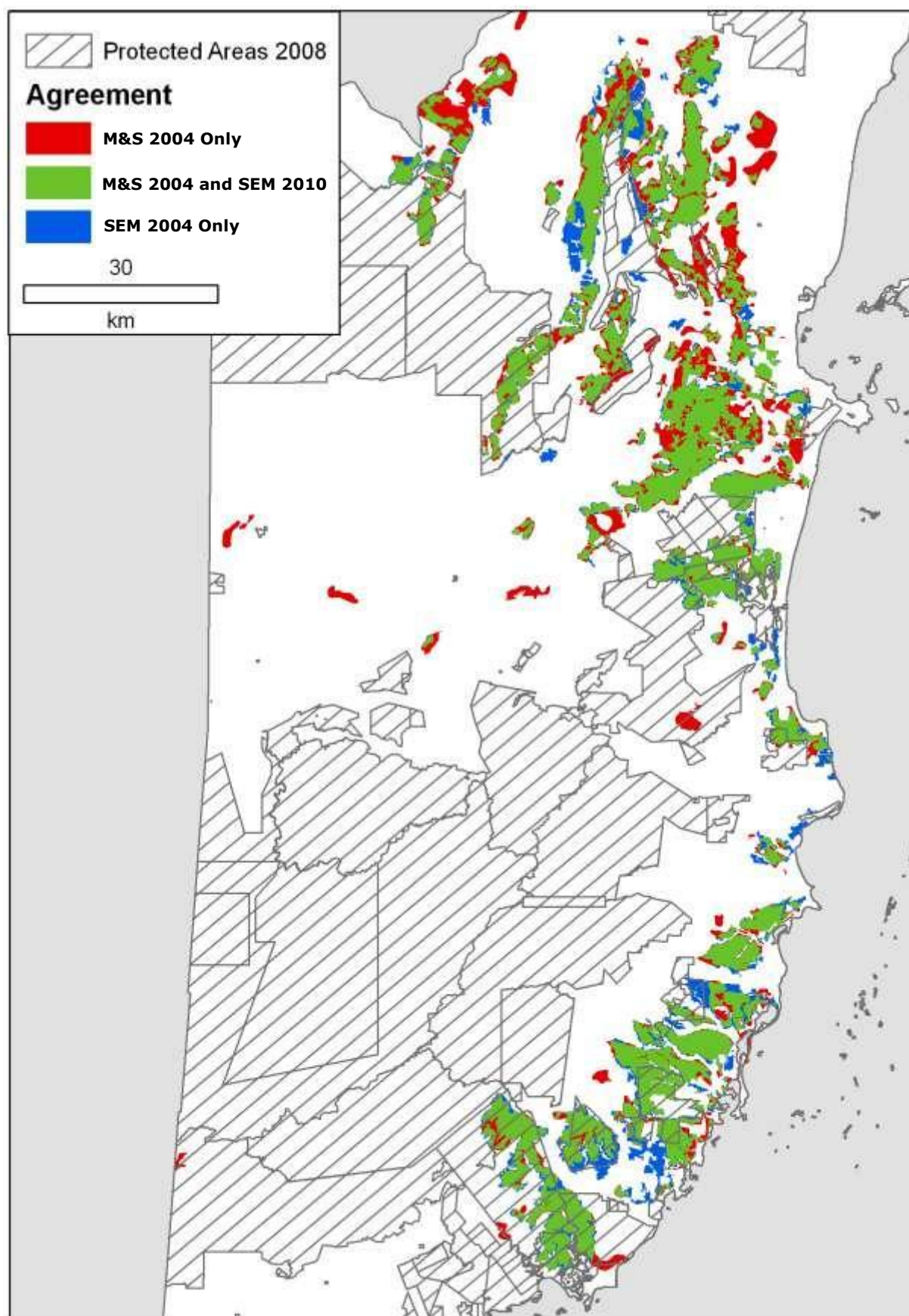


Figure 15: Comparison of lowland savanna estimates from the 2004 and 2010 ecosystems maps. 2008 protected areas overlaid for comparison.

## 4 Methodology

This section provides a detailed overview of the data and methods used in the Savanna Ecosystems Map of Belize 2010. For reference a summary of the map production process is provided in below.

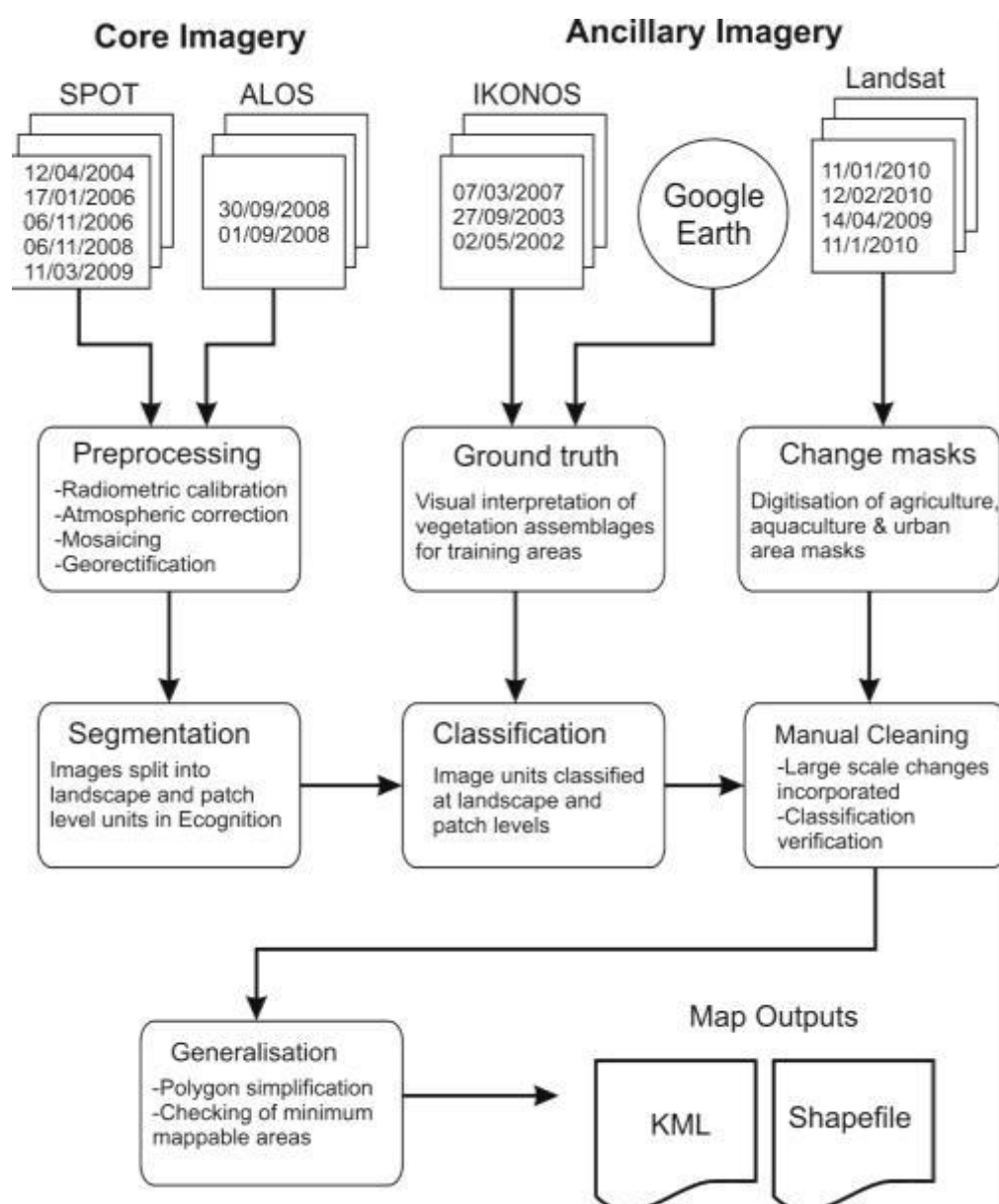


Figure 16: Summary of the Savanna Ecosystems Map of Belize 2010 production methodology

## 4.1 Remote Sensing Datasets

### 4.1.1 SPOT -5

SPOT-5 is a French satellite that carries two push-broom optical sensor operating at a variety of bands and resolutions, as shown in Table 5. While conceptually similar to the Landsat data used in previous ecosystems maps of Belize (e.g. Meerman & Sabido, 2001), SPOT has the advantage of considerably higher spatial resolution, allowing for more accurate discrimination of savanna boundaries and, potentially, an improved ability to identify internal savanna vegetation assemblages. This comes at the expense of a smaller spatial coverage than Landsat, hence a number of SPOT images are required to provide coverage over the whole of Belize. For this project seven archive images from the SPOT-5 satellite were provided by Planet Action to form the base-line dataset for the savanna map. As the data grant was limited in size, only bands 1-4 were acquired, with images provided at a pixel-sampling of 10m for all bands.

*Table 5: SPOT-5 sensor characteristics*

<b>Band</b>	<b>Wavelength (µm)</b>	<b>Spatial Resolution (m)</b>
P: Panchromatic	0.48 - 0.71	5
B1: Green	0.50 - 0.59	10
B2: Red	0.61 - 0.68	10
B3: Near Infra Red (NIR)	0.78 - 0.89	10
B4: Short-Wave Infra Red (SWIR)	1.58 - 1.75	20

Archive images were selected from the online SIRIUS catalogue (<http://sirius.spotimage.com/>) to cover the main savanna tracts identified from the Belize Ecosystems Map. Obtaining complete SPOT coverage for the savannas was complicated by the prevalence of cloud cover, with ~6% of images post January 2004 showing less than 10% cloud cover, and the challenges of SPOT-5 tasking. Of particular note is the presence of a gap in the cloud-free SPOT-5 coverage over most of Stann-Creek district since April 2004. The final images selected came from 5 swaths, details of which are summarised in Table 6 and Figure 17.

*Table 6: Details of SPOT-5 images used*

<b>Date</b>	<b>Main Districts Covered</b>	<b>Cloud Cover</b>	<b>Notes</b>
12/04/2004	Stann Creek, Belize	Slight haze	
17/01/2006	Belize, Orange Walk, Corozal	None	Two images in swath.
19/11/2006	Orange Walk	Slight Haze in places	
06/11/2008	Belize, Orange Walk	Distinct haze and cloud	Significant flooding. Two images in swath.
11/03/2009	Stann Creek, Toledo	Significant over mountains; less than 5% over lowland	





*Figure 17: Footprints of SPOT images and dates shown over administrative districts*

In order to account for viewing geometry and solar-insolation differences, images were converted to top of the atmosphere (TOA) reflectance. In circumstances where haze and cloud are present it is normal to apply atmospheric correction to account for the influence of scattering in the atmosphere upon image reflectance. Methods investigated included radiative transfer models (ATCOR), pseudo-invariant features (PIF's) and the dark-pixel method (Chavez, 1988, 1996). While attractive for its simplicity, the limited areas of overlap between many of the images and paucity of truly invariant features precluded the use of the pseudo-invariant features (PIF's) technique.

The ATCOR Radiative transfer model was also with model parameters estimated using database spectra for generic targets such as asphalt and deep water. It was found that database spectra did not match up well with targets in the imagery, resulting in significant variation between corrected images. Haze removal and cloud-shadow correction algorithms also performed poorly, being unable to accurately distinguish between shadow, burn scars and wetlands. However, the ATCOR cloud masks were found to be accurate, and were used to mask out to areas of heavy cloud.

Consequently the dark-pixel, or histogram method, (e.g. Chavez, 1996) was applied. This approach is based on the assumption that atmospheric haze will increase the

reflectance of dark objects that should theoretically be near zero, such as clear water or deep shadows. Assuming that a dark object is present in an image, the lowest reflectance pixels in the visible and near-infrared wavelengths provide an approximation of atmospheric path length. The difference between the lowest reflectance and zero is removed from each pixel, shifting the whole histogram. Note that this approach will not be reliable for images where haze varies markedly across the image such as the 06/11/2008 image.

Comparing dark-pixel corrected images showed that NDVI values for overlapping closed forest areas varied by  $\sim 0.01$ , as opposed to  $\sim 0.2$  for the ATCOR corrected images, demonstrating that the simpler approach produced more reliable results in this case.

Images were georeferenced using ground control points (GCP's) from three sources: 1999-2000 D-GPS survey of RBCMA and surrounding area (129 points).

2009 D-GPS survey of southern highway (65 points).

ASTER imagery georeferenced by NASA. These images were found to be internally consistent for Northern part of country, but inaccurate south of the Western Highway due to the influence of topography.

Overlapping areas between images were also used as additional tie-points to ensure the greatest degree of consistency across the SPOT dataset. The Universal Transverse Mercator, North American Datum 1927 (UTM-NAD27) was used, with GCP's were projected from WGS 1984 into NAD27 using 4 parameter Helmert transformation. This transformation was defined by Measurement Science in 1996, and is considered to provide the most accurate definition of NAD27 for Belize (Measurement Science, 1996). The images were projected using a second order polynomial transformation with nearest neighbour resampling. The nearest neighbour method was found to preserve image texture better than bilinear resampling. RMSE values estimated for each transformation are shown in Table 7

*Table 7: RMSE values in pixels estimated for each SPOT image*

<b>Image</b>	<b>RMSE (Pixels)</b>
12/04/2004	1.00
17/01/2006	0.93
06/11/2006	0.61
06/11/2008	0.93
11/03/2009	0.70

#### **4.1.2 ALOS PALSAR**

The Phased Array L-band Synthetic Aperture Radar (PALSAR) is a synthetic aperture radar (SAR) system carried by the Japanese Advanced Land Observing Satellite (ALOS). ALOS PALSAR is a fully polarimetric SAR system operating at a wavelength of 23.6cm (1270 MHz). As an active microwave system, PALSAR transmits a polarised wave which interacts with and is scattered by a target. The intensity of the returned, or backscattered, signal measured by the sensor is fundamentally related to target structure; generally speaking a rougher target will generate higher backscatter. One of the key advantages of SAR systems for use in the tropics is their ability to ignore cloud cover when taking observations, allowing operation in almost all weather conditions.

PALSAR also measures backscatter at a variety of different polarisations, or channels, which provide different information on target structure. PALSAR can measure and transmit either horizontally or vertically polarised signals. A co-polarised channel (HH or VV) denotes that the system is measuring the component of backscatter that is in the same polarisation as the transmitted signal. These channels are particularly sensitive to scattering from surfaces, such as buildings. Of particular interest for vegetation mapping is the cross-polarised channel (HV). In this configuration a horizontally-polarised wave is transmitted, and the vertically polarised component of backscatter is measured. If HV backscatter is high, this indicates that volume scattering has occurred, and is usually an indication that vegetation is present. Furthermore, many studies have shown that there is generally a good relationship between vegetation biomass and HV backscatter (Le Toan *et al*, 1992; Ranson *et al*, 1994; Kelldorfer *et al*, 2003; Viergever *et al*, 2009).

For this study PALSAR data was acquired in the fine-beam dual polarisation mode, where HH and HV channels are recorded over a 70km wide swath. The images were provided by JAXA through the Earth Observation Laboratory (EOL) at Aberystwyth University, Wales. The data were pre-processed by EOL from the raw level-1 images to a 4-look product with a spatial resolution of  $\sim 12\text{m}$ . Images were also terrain corrected using a DEM and converted to calibrated backscatter intensity, or sigma-0 ( $\sigma_0$ ), values.

Pre-processing was continued at UoE with the generation of a HH/HV ratio band and the conversion of HH and HV bands to a logarithmic (dB) scale. When images were projected from WGS-84 latitude/longitude to UTM-NAD27 and resampled to 26m resolution ( $\sim 16$  looks) to reduce the influence of speckle upon the images<sup>1</sup>. A consistent offset of  $\sim 60\text{m}$  in X and Y between ALOS and SPOT imagery was also found. This was corrected for by using control points that could be clearly identified to bring the ALOS imagery into agreement with the SPOT dataset. The locations of the ALOS images are shown in Figure 18.

---

1 Speckle is a noise-like phenomenon that gives SAR images their characteristic “salt and pepper” appearance. For a discussion on the trade-off between spatial resolution and speckle see Woodhouse *et al* (2009).





*Figure 18: Footprints of ALOS images and dates shown over administrative districts*

#### 4.1.3 IKONOS

IKONOS is a satellite operated by GeoEye that carries a high resolution optical sensor. The sensor has 4 multi-spectral bands (blue, green, red, NIR) that have a spatial resolution of 3.28 m at nadir, plus one panchromatic band with a spatial resolution of 0.82m at nadir. Band characteristics are shown in Table 8. While the very small coverage of an IKONOS image precludes its use for regional mapping, the very high resolution of these images is ideal for accurately identifying and mapping vegetation assemblages in lieu of, or to supplement, field-verification. Two IKONOS images were thus acquired from the GeoEye foundation over areas that proved difficult to reach on-foot, i.e. Paynes Creek (IKONOS 27/09/2003) and the wetland area NW of Hattieville (IKONOS 02/05/2002). This latter image was also chosen to help delimit the extent of the seasonally inundated seasonally waterlogged savanna with shrubs ecosystem that had been observed during field survey in this region. A third image had been already acquired by UoE over the Hillbank Savanna (IKONOS 07/03/2007), supplementing existing vegetation mapping gathered by UoE researches for this area. The locations of these images are shown in Figure 19.



Figure 19: Footprints of IKONOS images and dates shown over administrative districts

Table 8: IKONOS sensor characteristics

Band	Wavelength ( $\mu\text{m}$ )	Spatial Resolution (m)	Pixel Spacing (m)
Pan (Panchromatic)	0.52–0.92	0.82	1
1 (Blue)	0.44–0.51	3.28	4
2 (Green)	0.50–0.59	3.28	4
3 (Red)	0.63–0.69	3.28	4
4 (NIR)	0.75–0.85	3.28	4

These images were provided orthorectified and were subsequently re-projected into UTM-NAD27. A slight offset with the SPOT data was found and corrected for using common reference points between SPOT and IKONOS. Pansharpening was applied to improve the resolution of the multispectral bands, effectively resampling the multispectral data to one metre resolution. A variety of pan-sharpening methods were investigated, with the high pass filter (HPF) merge method in ERDAS Imagine found to produce the most suitable results.

#### 4.1.4 ASTER

ASTER VNIR is an multispectral optical sensor carried by the Terra satellite, launched in December 1999. It has a spatial resolution of 15m which is suitable for savanna component mapping, yet lacks a SWIR band which makes discrimination of wetland and lowland savanna. ALOS and SPOT acquisition was not warranted for the Cayo district as savanna areas in this region are extremely limited in extent. Thus ASTER was used as a substitute.

Band	Wavelength ( $\mu\text{m}$ )	Resolution (m)
1 (Green)	520 - 600	15
2 (Red)	630 - 690	15
3N (NIR)	760 - 860	15

Table 9: Landsat sensor characteristics



Figure 20: Footprints of ASTER images and dates shown over administrative districts

#### 4.1.5 Landsat

Landsat-7 is latest in the Landsat series of satellites that have provided the bedrock for global landcover mapping since the 1970's. It carries a multispectral sensor with 8 bands ranging from blue to thermal infra red (TIR), as shown in Table 5. Since April 2003 Landsat-7 has suffered from gaps between scan lines due to the scan-line corrector failure. Additionally Stuart *et al* (2006) identified that, although Landsat is capable of accurately identifying the forest/savanna boundary, it is of too poor a resolution to accurately delimit assemblages within Belizean savannas. Although Landsat data does not provide a suitable base dataset for the 2010 savanna map, its large swath-width provided a useful snapshot for identifying major changes in agricultural and urban extents for the older SPOT images. This was particularly important for the 12/04/2004 SPOT image over Stann Creek where major agricultural expansion has been observed.

<b>Band</b>	<b>Wavelength (<math>\mu\text{m}</math>)</b>	<b>Resolution (m)</b>
1 (Blue)	0.45 - 0.51	30
2 (Green)	0.52 - 0.60	30
3 (Red)	0.63 - 0.69	30
4 (NIR)	0.75 - 0.90	30
5 (SWIR)	1.55 - 1.75	30
6 (TIR)	10.4 - 12.5	60
7 (SWIR)	2.09 - 2.35	30
8 (Panchromatic)	0.52 - 0.90	15

Table 10: Landsat sensor characteristics

Level 1T (terrain corrected) Landsat images were downloaded from the United States Geological Service (USGS) Earth Resources Observation and Science (EROS) Center. Selecting overlapping images with offset scan-lines allowed most gaps to be filled in; however there were distinct variations in reflectance between scanlines. As these images were intended for visual interpretation, these offsets were accounted for by colour balancing performed in ERDAS Imagine. Images were projected from UTM WGS84 to UTM NAD27 and found to agree well with the SPOT mosaic given the differences in resolution (see Figure 21).







*Figure 21: Footprints of Landsat images and dates shown over administrative districts*

#### 4.1.6 Google Earth

Google Earth provided the final source of geospatial imagery for this study. Google Earth contains a number of high-resolution, optical images for Belize, provided by sensors such as IKONOS, and QuickBird. While Google make no guarantees as to the spatial accuracy of Google Earth layers, over Belize the data appeared internally consistent and positions agreed to within 30-50m of the SPOT mosaics. The greatest challenges of Google Earth images are the influence of cloud and haze on many images, the considerable variation of reflectance between images and its inability to display a NIR band where available. These factors mean that, although Google Earth can provide a useful source of information, great care must be displayed when interpreting vegetation assemblages from it.



## 4.2 Ground-Truth Data

Ground truth information is an essential element of landcover classification as it allows for both the development of classification rules (training) and validation of mapping outputs. Importantly training and test datasets should be independent to get a true assessment of map accuracy.

### 4.2.1 Training data

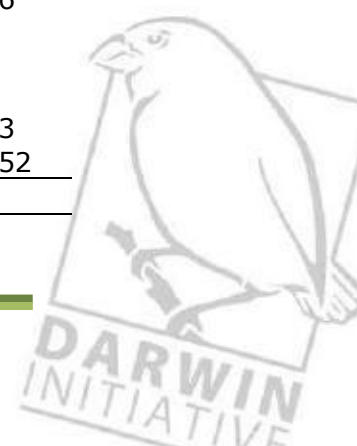
For the rule based classification implemented, land cover polygons collected over areas similar in size to the output mapping units are preferable as this provides robust image statistics for each object. Refer to section 0 for more information on rule-based classification. Thus training polygons was gathered from two sources: ground survey, and image interpretation.

Ground survey data was primarily sourced from land-cover polygons collected during field surveys in 1997 and 1998 (Moss, 1998) for the savannas of the Rio Bravo Conservation Management Area (RBCMA). These were mapped on the ground using differential-GPS (D-GPS), and have boundaries that are accurate to within 2.3m. As these landcover polygons were 13 years old at the time of this project, there was the distinct possibility of change to the units mapped. This was partly accounted for by checking the polygons against high-resolution imagery (IKONOS and Google Earth) and discounting those that had clearly changed, e.g. due to deforestation. The vast majority of polygons (~95%) appeared consistent with the imagery, perhaps due to the fact that most of these data were collected in the RBCMA which has largely been protected from large-scale land cover changes due to human action. A total of 145 landcover polygons were available from this source.

To provide a more widely distributed set of land cover polygons, image interpretation was conducted using IKONOS and high-resolution Google Earth imagery. Polygons were only digitised for areas where expert analysts had a high degree of confidence in the land cover type, and care was taken to restrict polygons to core regions of each landcover type. 135 polygons were collected in this way from Google Earth and 156 from IKONOS. Table 11 shows a break down of all landcover polygons and points collected according to class and data source.

*Table 11: Ground-truth land cover polygons and points according to class and data source*

	Ground Survey 1997	IKONOS	Google Earth	Sum of Class	% of Total
Forest	1	54	41	96	21.29
Open Savanna	46	46	26	118	26.16
Dense Tree Savanna	69	24	45	138	30.6
Seasonally Waterlogged Savanna with Shrubs and Trees	14	13	2	29	6.43
Wetland	34	20	16	70	15.52
Sum	164	157	130	451	



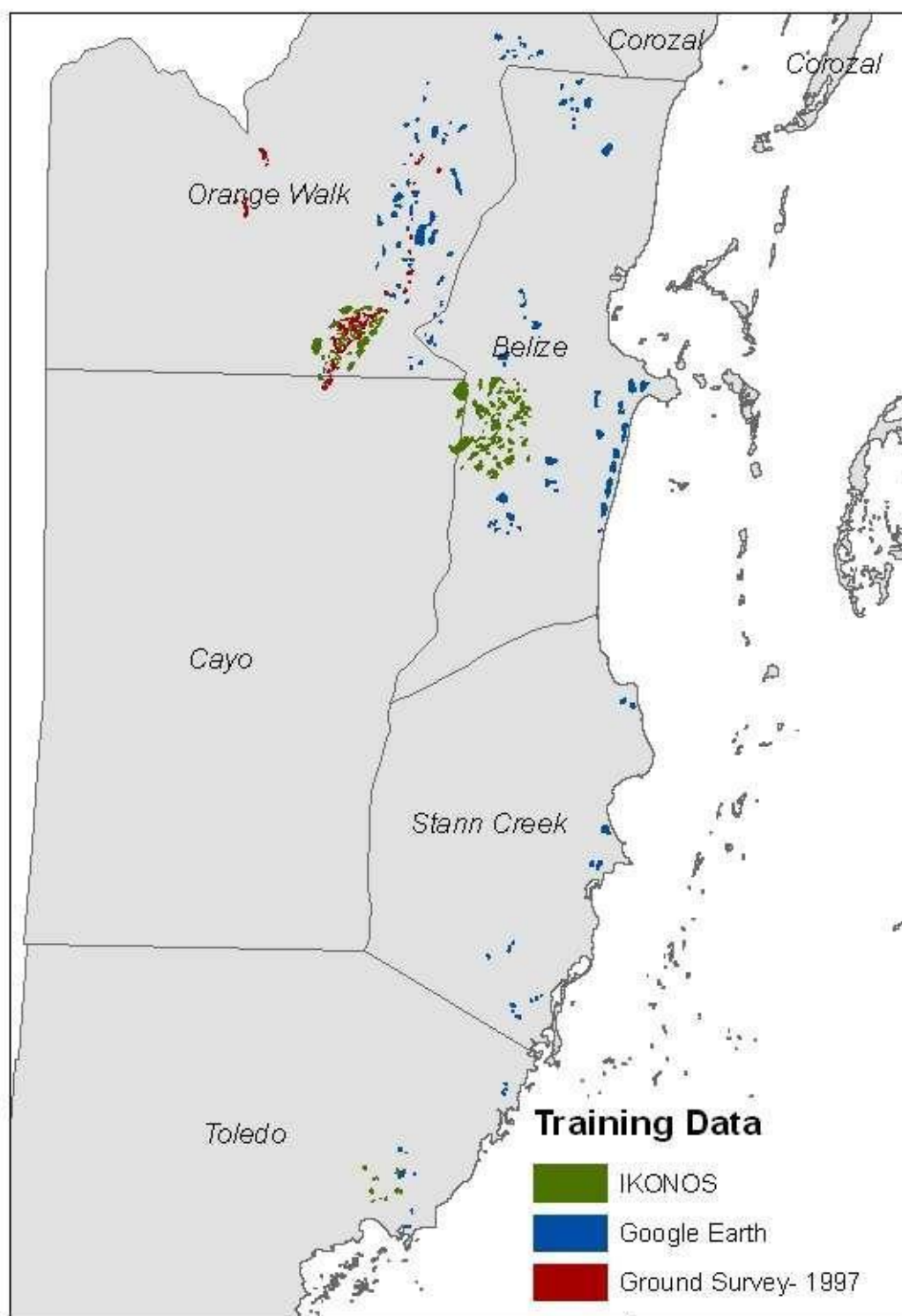


Figure 22: Distribution of training polygons from ground survey and interpreted from high-resolution imagery.

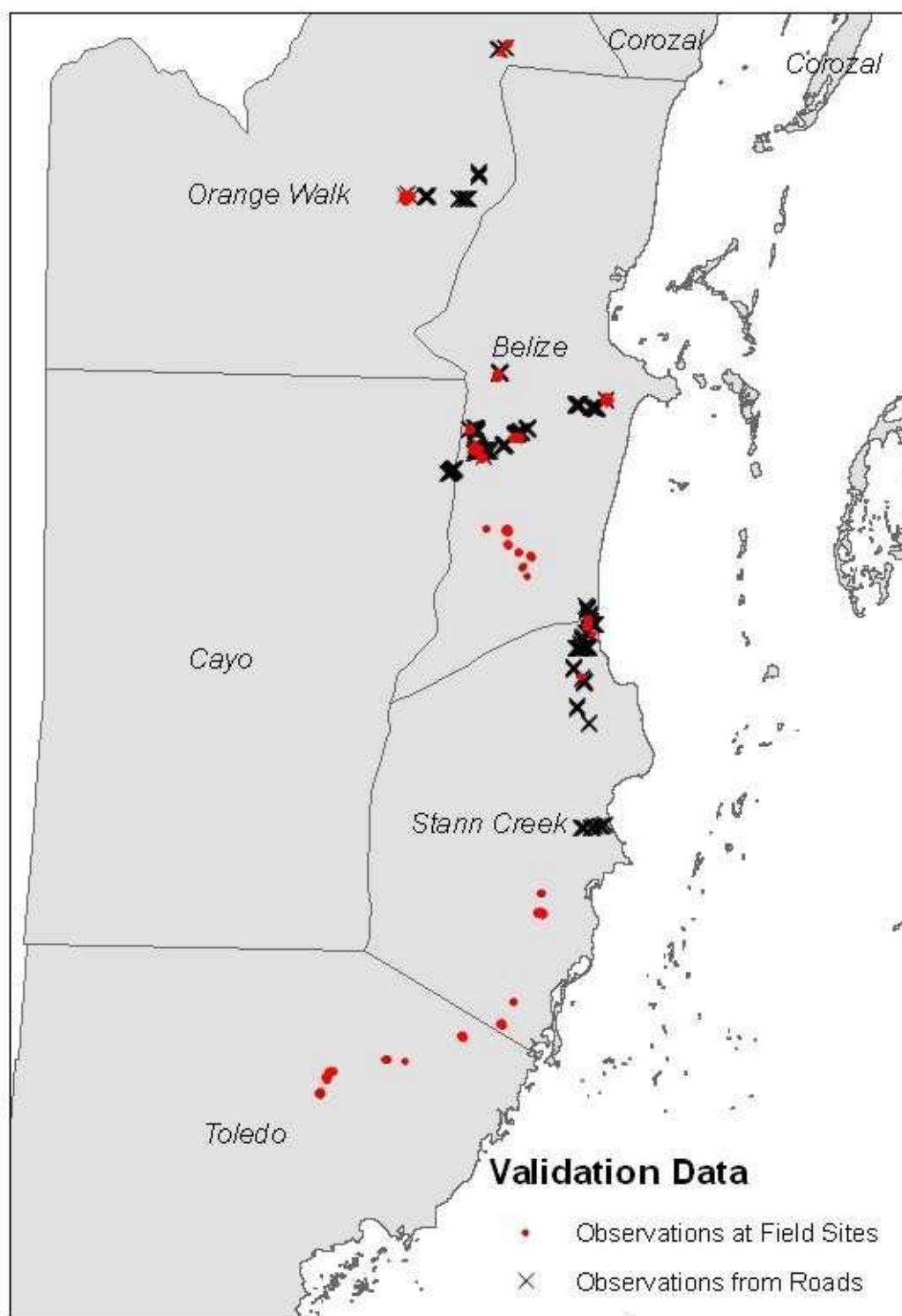


Figure 23: Distribution of validation points from ground survey conducted in 2010

#### 4.2.2 Validation data

A key criteria of validation data is that it should be independent of the training data to ensure that accuracy statistics are not artificially high. Also, as the test data is intended to assess the accuracy of the final map, up-to-date information is ideally required. To this end an extensive, rapid ground survey was conducted in January 2010. In this two week survey 25 field sites and were visited across Belize, as well as a number of observations made of ecosystems near to major roads.

Surveys at field sites were conducted on foot, with validation points recorded using D-GPS every 100-200 m along randomly oriented transects through savanna. At each validation point a description of the ecosystem representative of at least the surrounding 50m was made, and a savanna ecosystem landscape-level class assigned. A total of 322 points were recorded in this manner. Additional ecosystem observations were recorded relative to road centrelines by placing the GPS antenna on the roof of a moving vehicle. In these cases observations were offset from the road centreline so that they would lie more than 50m within the ecosystem recorded. 185 observations at a minimum of 200m apart were made using this method. The positional accuracy of D-GPS observations in both of these cases is expected to be between 2-5 m RMSE, depending on the distance from the base-station in Belmopan.

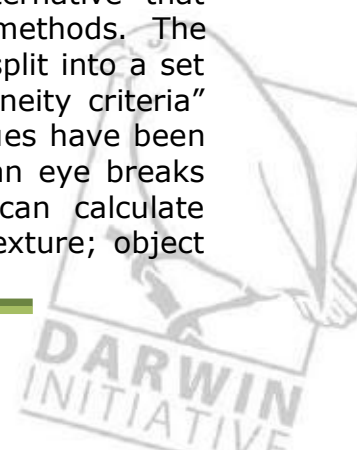
### 4.3 Land-Cover Classification

#### 4.3.1 Object-oriented classification

Traditionally land-cover classification of remotely-sensed imagery was performed manually, digitising land cover polygons from hard-copy images or within a GIS/image interpretation program. However, such approaches are limited by display technology, as it is virtually impossible to communicate the full richness of multi-spectral/multi-channel imagery. While a skilled and knowledgeable interpreter may be able to produce high-quality results, manual interpretation lacks transparency. Furthermore, it has been demonstrated that even equally-skilled interpreters can produce widely varying results (Jaas, 2007).

Automated per-pixel classification offers one alternative to manual interpretations. In per-pixel classifications each image pixel is assigned a land-cover class based upon spectral characteristics. While per-pixel classifiers are well-developed and include variations, such as spectral-unmixing, that have been demonstrated to work well for savanna ecosystems (Stuart *et al.* 2006), per-pixel classifications do not account for the influence of image texture or contextual information. Consequently land-cover maps drawn from a per-pixel approach often appear to miss features that the human eye can clearly identify.

In recent years object-based classification has been offered as alternative that combines the advantages of both manual and automated classification methods. The first step is to perform an image segmentation, whereby the image is split into a set of "discrete, non-overlapping regions on the basis of internal homogeneity criteria" (Devereux *et al.*, 2004) such as size, shape and colour. These techniques have been drawn from advances in machine vision and emulate the way a human eye breaks images into discrete objects. For each object thus created we can calculate parameters based upon; image colour, such as mean reflectance or texture; object





shape, such as object complexity; or its relationship to neighbour objects. Using these different parameters, classifiers similar to those used in per-pixel approaches can be applied to assign a class to each object. Object-oriented approaches have been widely found preferable to per-pixel classifications as they often produce more accurate classifications and better reflect features on the ground (e.g. Gao *et al*, 2006; Rego & Koch, 2003, Shackelford & Davis, 2003). However, the quality of image segmentation is highly sensitive to input parameters, and as of yet there is no clear agreement on how best to set these parameters. Furthermore, object-oriented classifications tend to be complex to implement and are considerably more computationally expensive than per-pixel approaches.

In this study we opted to use the Definiens Developer 7<sup>2</sup>, or Ecognition, program to generate an object-oriented classification for the lowland savannas of Belize. This is perhaps the most widely used object-oriented classification program, and provides a stable and advanced image interpretation environment.

#### 4.3.2 Image segmentation in Ecognition

A core concept in the Ecognition approach is the generation of an image-object hierarchy. Figure 24 shows how objects in each level in the hierarchy are built from objects in the level below. This allows access to information regarding neighbour objects both horizontally and vertically, allowing context to be explicitly assessed during the classification process. Segmentation is used to grow objects at each level in the hierarchy, usually growing upwards from the pixel level.

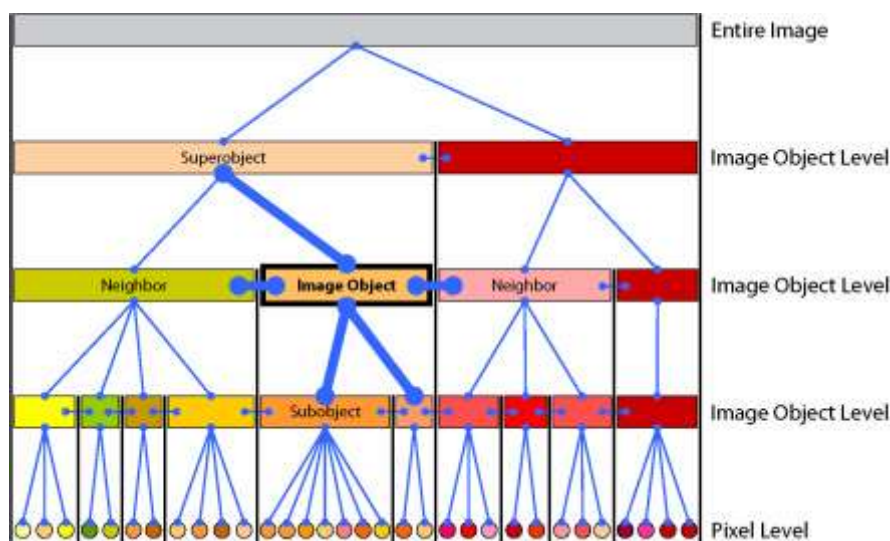


Figure 24: An example of the image-object hierarchy implemented in Ecognition (Definiens, 2007)

The multi-resolution segmentation algorithm implemented in Ecognition is a bottom-up region-merging technique. Starting with one-pixel objects, larger objects are iteratively grown by merging candidate objects. This process is controlled by both a scale and homogeneity criteria, with the objective being to maximise homogeneity

<sup>2</sup> This is now called Ecognition Developer 8, and is often colloquially referred to as simply Ecognition. We adopt this term for simplicity.

within each object. The homogeneity criterion is a combination of colour and shape properties calculated for both the initial and resulting image objects of any intended merging, as Figure 25 shows. Definiens recommend manually tuning the homogeneity parameters to generate a satisfying result. In practice it was found that keeping all factors equally balanced (i.e. shape, colour, smoothness and compactness all set to 0.5) generated the most suitable image objects. The scale criterion defines the maximum standard deviation of homogeneity criteria for resulting image objects, with higher scale values allowing larger objects to be grown. However, it should be noted that the scale parameter is not directly related to image resolution or pixel sizes. We opted to grow a 2-level image-object hierarchy, with scale parameters of 50 and 100, which were found to best fit the minimum-mappable areas defined in section 3.1.

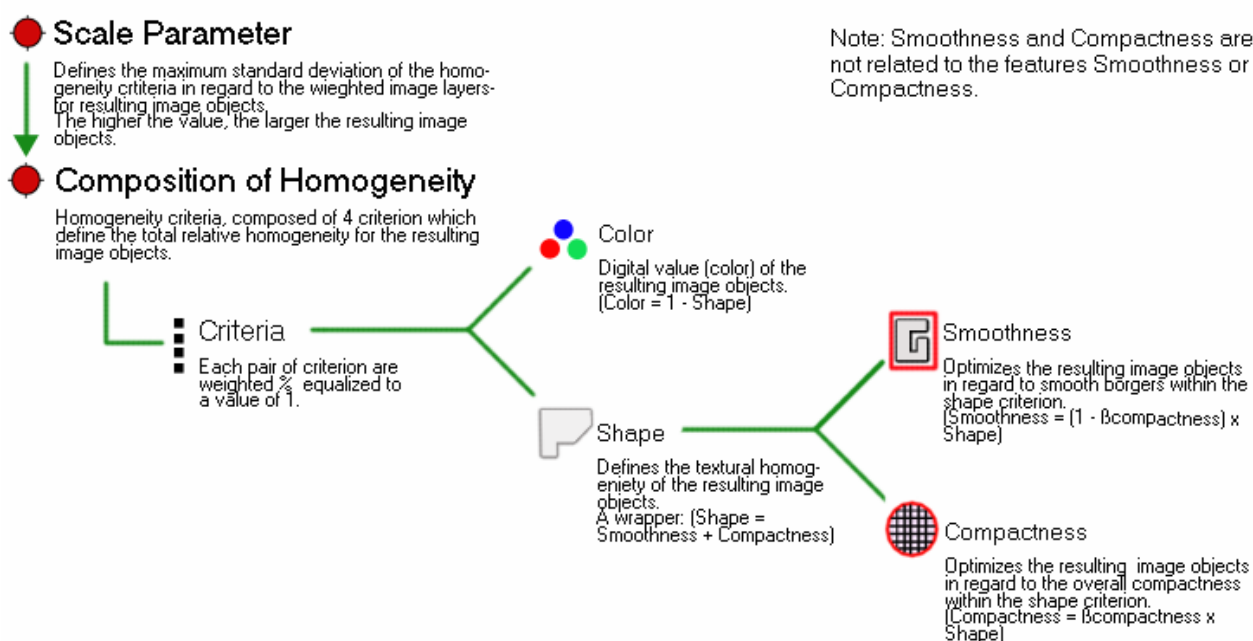


Figure 25: Multiresolution concept flow diagram (Definiens, 2007, pp23)

As segmentation is a computationally intensive process, the full mosaic of imagery for Belize was processed in sections. Thus, a segmentation was run for each SPOT image with the output classifications merged in post-processing. For each segmentation seven image layers were input to Ecognition, comprising the four SPOT bands and three ALOS bands. To avoid smearing of object boundaries, it is recommended that only highest resolution bands are used for the segmentation (Definiens User Guide), with object attributes for the other layers calculated after segmentation. This is particularly important when merging optical and SAR datasets as speckle tends to degrade segmentation quality. We used SPOT bands 1, 2 and 3 (blue, green, NIR) as core layers to grow objects from the segmentation. Each object contained information drawn from each of the seven bands.

The full segmentation and classification workflow is shown in Figure 26. The process begins with segmentation at a scale factor (SF) of 100, using homogeneity criteria of 0.5 for colour, shape, smoothness and compactness. This breaks the image into its main constituent objects which are then assigned landscape-level classes according to a rule-based classification system. The rule-based classification system is discussed in detail in section 4.3.3.

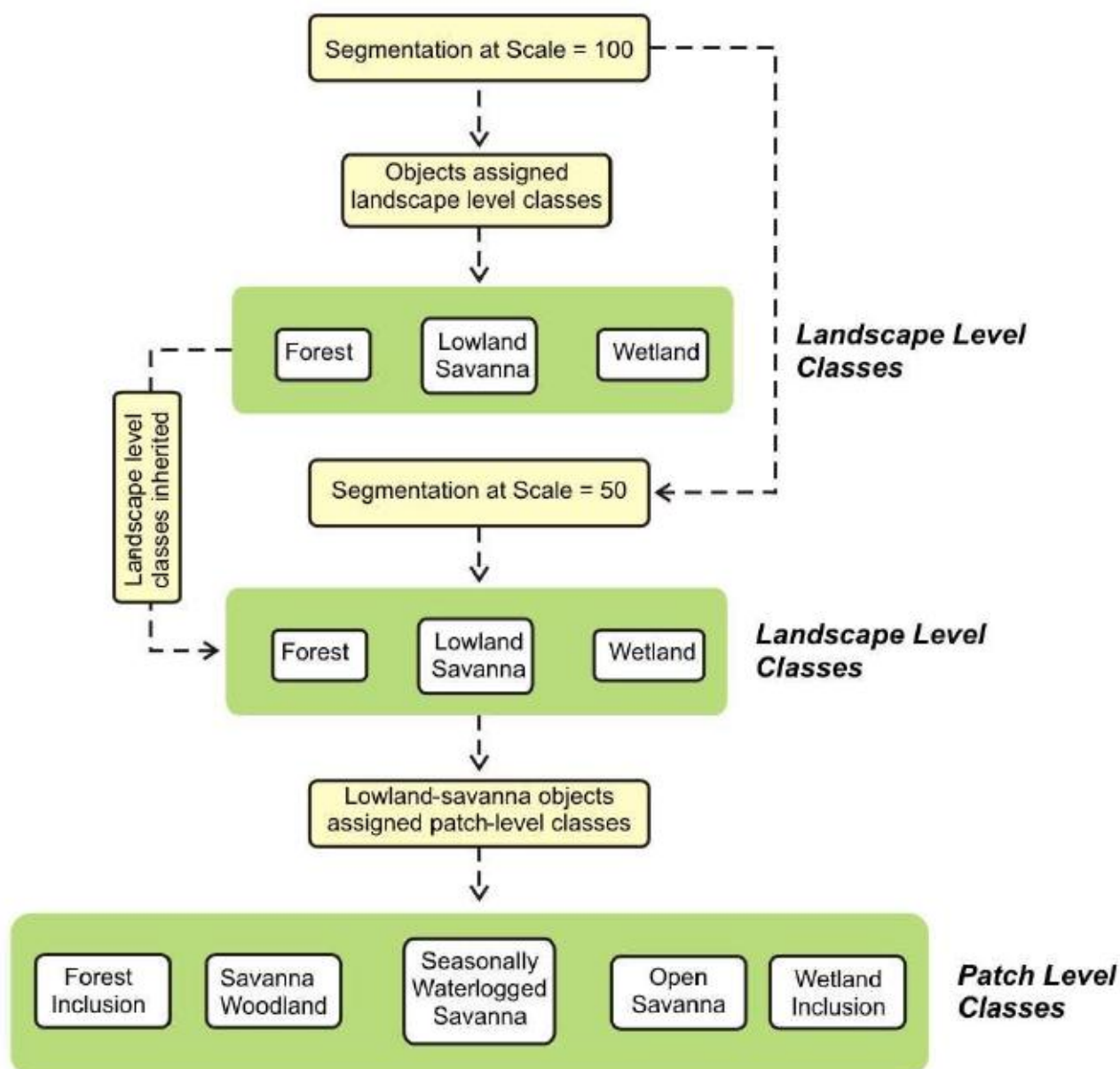


Figure 26: The Ecognition segmentation and classification workflow for landscape-level and patch-level classes. White boxes denote Ecognition processes, grey boxes denote the classes defined at each step.

For the patch-level classification, a finer-level segmentation was generated using a scale factor of 50 and the same homogeneity criteria. The SF-50 objects respected the boundaries of the SF-100 objects, as Figure 27 illustrates. This allowed the landscape-level classification to be inherited by the SF-50 objects. Finally the patch-level classes were assigned to SF-50 objects classified as lowland savanna. This process facilitated the exclusion of large areas of wetland and forest from the patch-level classification. Small inclusions of forest and wetland within areas identified as lowland savanna were also identified during this step.



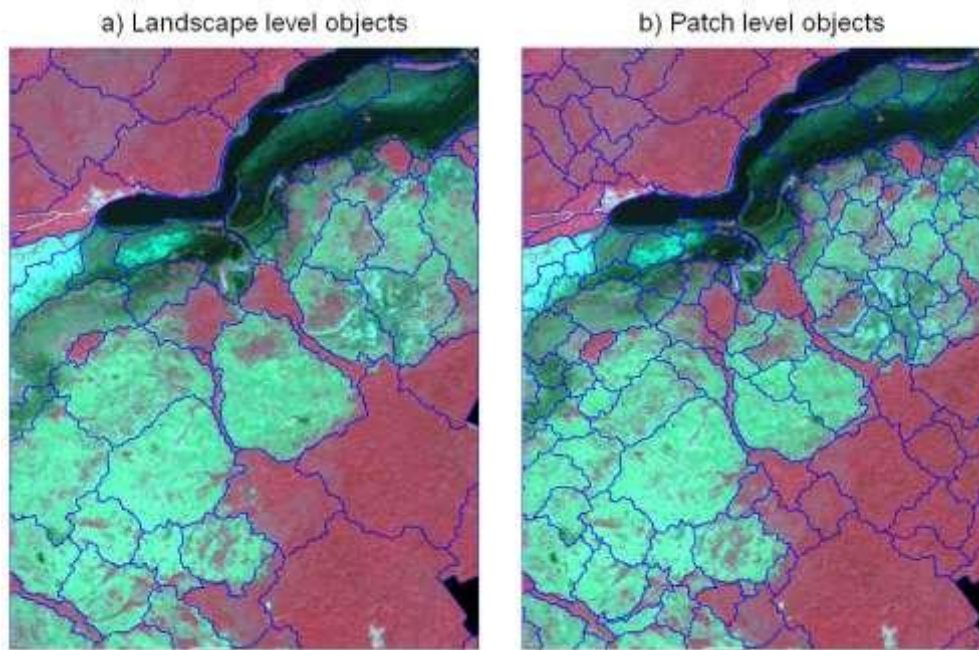


Figure 27: Segmentation of an image into landscape and patch level objects. Note that landscape-level objects respect the boundaries of patch-level objects

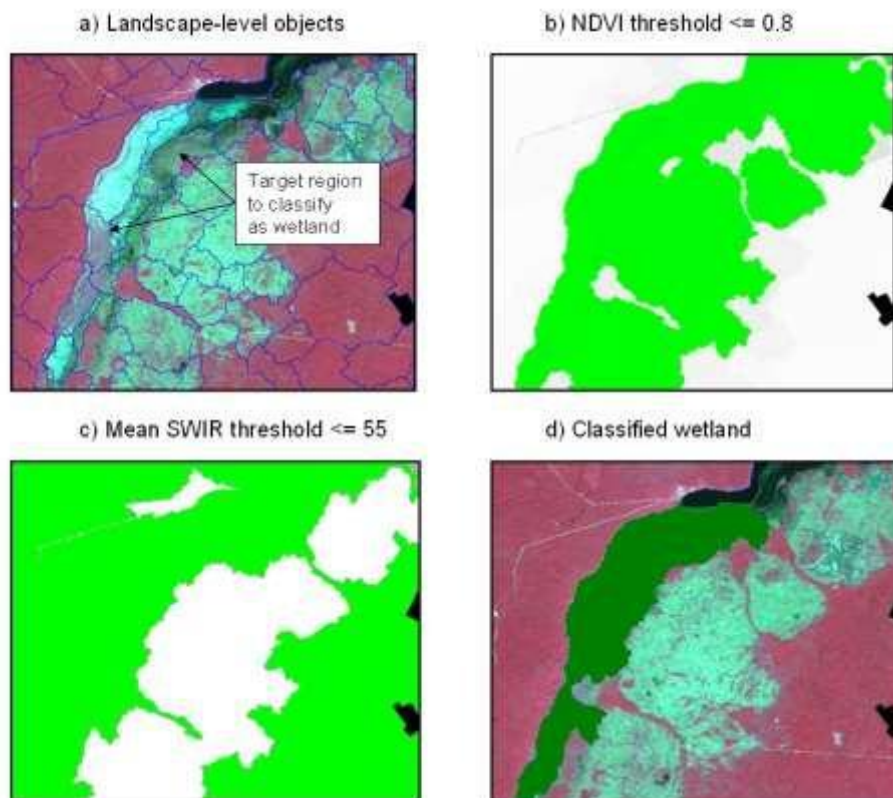


Figure 28: Example of a rule-based classification for a wetland in the RBCMA. The landscape-level objects are shown with the SPOT imagery as a backdrop (a.). Selecting an threshold values of less than 0.8 for NDVI (b.) we can separate densely vegetated forest from savanna and wetland (shown in green), whilst defining a mean SWIR threshold of  $\leq 55$  (c.) separates savanna from forest and wetland. From the union of these two rules (i.e.  $[NDVI \leq 0.8]$  AND  $[SWIR \leq 55]$ ), we can isolate and classify the wetland area, shown in dark green (d.).

### 4.3.3 Rule-based classification

The rule-based classification was implemented by specifying a set of rules for each class based upon object attributes. Usually a rule defines a threshold value for an attribute, such as reflectance, that the object must meet in order to be considered a member of a given class. Multiple rules can be defined for each class, and can be combined using logical operators to generate rich class descriptions. Attributes derived from the objects themselves include: layer values, such as mean reflectance at each band; object shape, such as length/width or roundness and; texture, such as GLCM homogeneity. Texture attributes are drawn from the work of Harlick *et al* (1973) and provide a variety of measures that describe local variations in pixel intensity. Figure 28 illustrates the set of rules that can be used to classify a wetland formation in the RBCMA at the landscape level.

While trial and error can be used to determine suitable ranges of values for the rules in each class description, a more rigorous approach is preferable. Ground truth training areas (see section 4.2) were used to guide the development of class descriptions. For each SPOT image, Ecognition attributes were extracted for each ground truth land cover polygons. This was achieved by generating a segmentation for each image where the objects were constrained to fit each of the ground-truth polygons. A comprehensive set of 82 object attributes were subsequently calculated for each object, together with the vegetation class for each object. These were exported to the statistics package R, and the attributes for these classes were used to:

Identify suitable values for defining rules, and combinations of rules, that separated the identified classes,

Reduce the 82 investigated attributes to a smaller subset suitable for classification,

Identify variations between images caused by atmospheric and calibration variation (see section 4.1.1), and modify the rules accordingly to ensure that the classifications were consistent across all the images.

Box and whiskers plots were used to identify which attributes and threshold values allowed for the separation of landcover classes. A box and whiskers plot is a useful exploratory data analysis technique which shows the distribution of values for each sample in a concise manner. The sample is shown as a box with top and bottom drawn at the upper and lower quartile to encompass the central 50% of observations, and the box is itself divided at the median. The whiskers are drawn to encompass values within 1.5 interquartile ranges of the top and bottom of the box; values beyond this range are plotted individually (Sokal & Rohlf, 1995). These plots gave a good indication of class separability for each attribute, and allowed effective threshold values to be estimated. These values could be subsequently encoded within Ecognition and manually tuned as necessary to produce the best possible classification.

These investigations confirmed that many of the attributes were highly correlated, particularly in the case of the textural measures. Thus, it was possible to reduce the available attributes to four which adequately separated classes: Mean HV, Mean SWIR, normalised vegetation difference index (NDVI), and GLCM Homogeneity (Red). Examples of the plots for each of these attributes are shown in Figure 29 to Figure 32 for the SPOT 19/11/2006 image; while a list of each of the threshold values used for all images is provided in Table 12.



NDVI is a commonly applied index that calculates the normalised ratio of NIR to red reflectance<sup>3</sup>. As vegetation characteristically absorbs red light and reflects NIR, higher NDVI values (i.e. approaching 1) indicate denser vegetation cover. Also, as it is based upon the ratio between two bands, NDVI is less sensitive to calibration and atmospheric variations between different images in a mosaic. As Figure 29 shows, NDVI clearly separates forest from all other classes; however, it does not clearly separate open savanna from the wetland or seasonally waterlogged savanna classes. This is unsurprising, given that these landcover types are all forms of low-density vegetation cover.

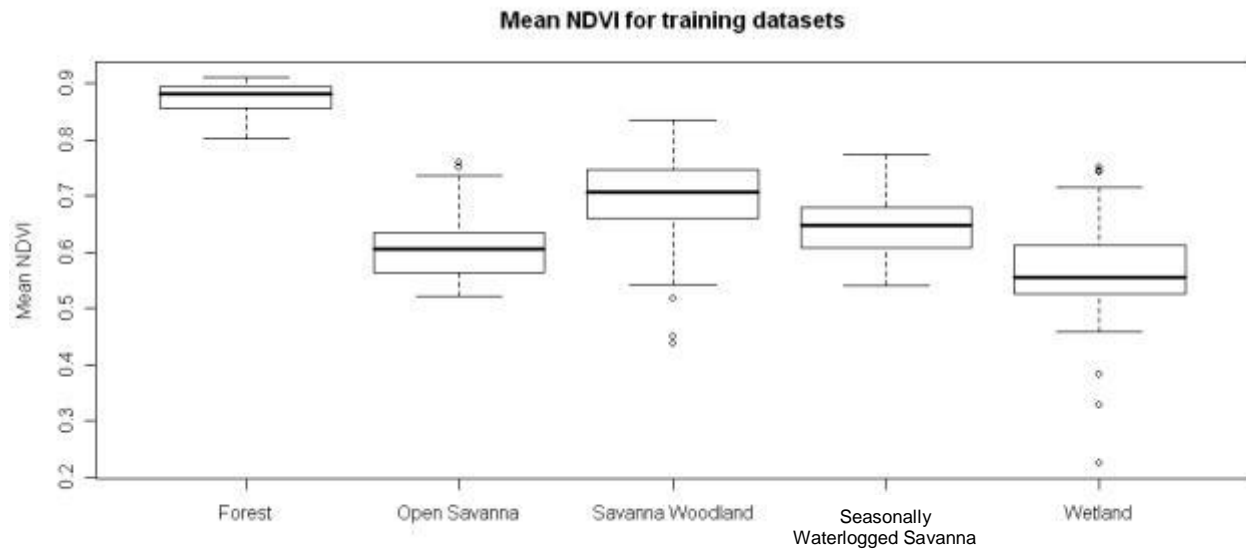


Figure 29: Box and whiskers plot showing the distribution of NDVI values for patch-level training datasets for the SPOT 19/11/2006 image

As discussed in section 0, HV backscatter from ALOS PALSAR is related to the degree of volume scattering generated by a target and, in turn, should be well correlated with tree cover. From Figure 30 we see that the woody classes (forest, dense tree savanna and seasonally waterlogged savanna) are more clearly separated from the more open assemblages than is the case with NDVI.

<sup>3</sup> Calculated as:  $[\text{NIR} - \text{Red}] / [\text{NIR} + \text{Red}]$



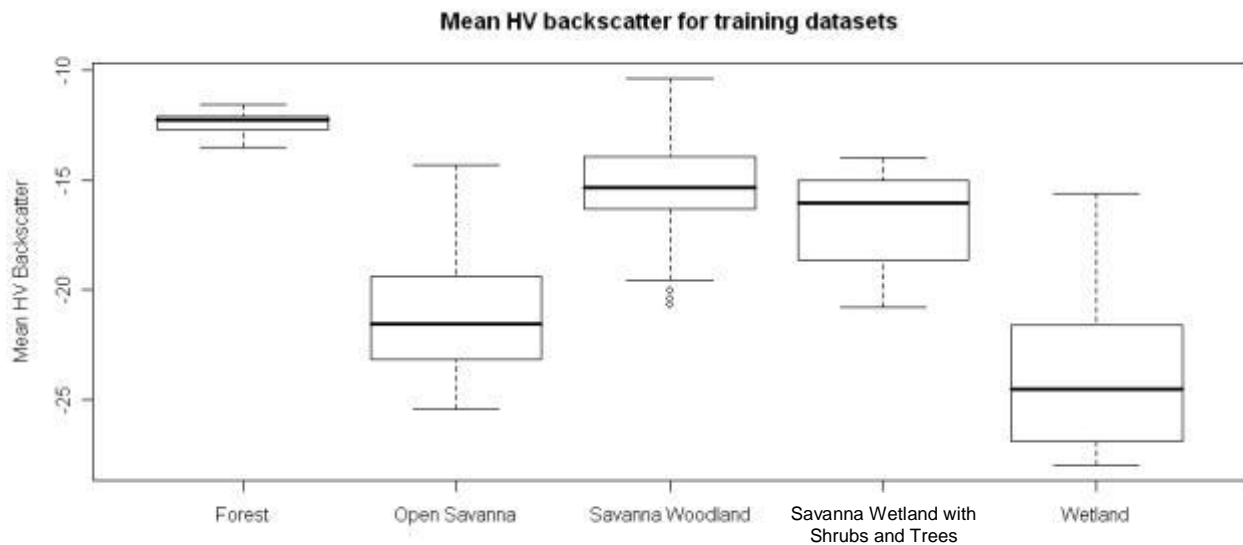


Figure 30: Box and whiskers plot showing the distribution of mean HV backscatter values for patch-level training datasets for the ALOS 30/09/2008 image

For non-forest areas, mean SWIR reflectance (see Figure 31) was found to be good indicator of soil moisture, with wetland and seasonally waterlogged savanna areas displaying characteristically low reflectance at this wavelength. Thresholds based on this attribute needed to be carefully tuned for each SPOT image because:

1. Soil moisture is very sensitive to inundation levels. For example the 06/11/2008 image was acquired during an extensive flooding event; using this image alone could lead to greatly overestimating the extent of wetland areas.
2. This attribute is based upon the reflectance at a single wavelength, thus it sensitive to calibration and atmospheric variations between images. As band ratios are less sensitive to calibration variations, the modified green normalized difference vegetation index (MGNDVI)<sup>4</sup> was investigated, but was found to provide less class separability.

In addition to being a characteristic of wetland areas, low SWIR reflectance is also found for areas of burn-scars, cloud shadow and forests. While forests could be clearly separated based upon high NDVI and high HV backscatter, it was considerably more difficult to automatically eliminate burn-scars and cloud-shadows from consideration as wetlands or seasonally waterlogged savannas. Ultimately these areas needed to be manually identified and classified appropriately.

<sup>4</sup> Similar to NDVI, this is the ratio of SWIR vs Green reflectance and is calculated as:  $[\text{SWIR} - \text{Green}] / [\text{SWIR} + \text{Green}]$



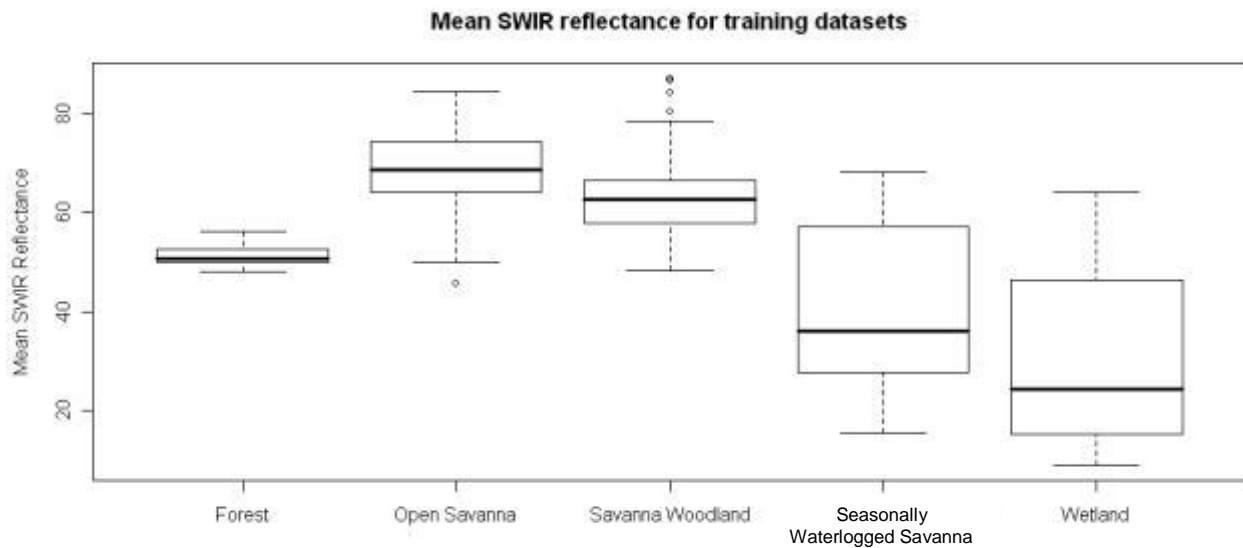


Figure 31: Box and whiskers plot showing the distribution of mean SWIR reflectance values for patch-level training datasets for the SPOT 19/11/2006 image

GLCM global homogeneity for SPOT red reflectance was a texture measure found to delimit dense tree savannas particularly well. This attribute measures the degree of intensity variation for pixels in all directions for each object. If the object is homogenous, i.e. pixel values are locally similar, then homogeneity is high. The low red homogeneity found for dense tree savannas is directly related to the heterogeneity of the dense tree savanna, with red reflectance being high for pixels dominated by bare ground and low for pixels dominated by tree canopy. It is probable that this heterogeneity is picked up by the SPOT sensor as it appears to occur at a similar scale to pixel resolution, i.e. dense tree savanna heterogeneity occurs at over distances of 10-20 metres. By contrast, sensors such as Landsat have larger pixels which are unable to characterise these variations as well.

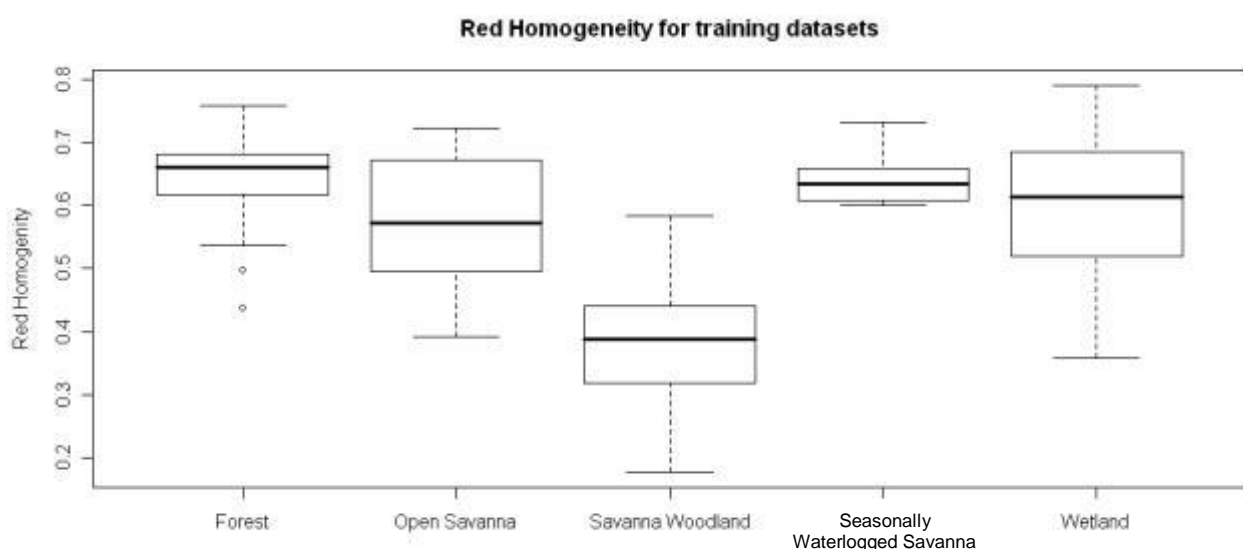


Figure 32: Box and whiskers plot showing the distribution of GLCM red homogeneity values for patch-level training datasets for the SPOT 19/11/2006 image

Table 12: Classification ruleset and specific attribute thresholds applied for the each of the SPOT and ALOS images used in the classification.

Level	Vegetation Class	Attribute	Source layer	Thresholds for each SPOT/ALOS combination			
				SPOT 12/04/04	SPOT 17/01/06	SPOT 19/11/06	SPOT 11/03/09
Landscape	Forest	Mean HV	ALOS	>= -14	>= -14	>= -14	>= -14
		NDVI	SPOT	>= 0.8	>= 0.8	>= 0.8	>= 0.8
	Lowland Savanna	Mean HV	ALOS	< -14	< -14	< -14	< -14
		NDVI	SPOT	< 0.8	< 0.8	< 0.8	< 0.8
		Mean SWIR	SPOT	>75	>65	>45	>65
	Wetland	Mean SWIR	SPOT	<= 75	<= 65	<= 45	<= 65
		Mean SWIR	SPOT	>=20	>=20	>=20	>=20
		Mean HV	ALOS	< -14	< -14	< -14	< -14
		NDVI	SPOT	< 0.8	< 0.8	< 0.8	< 0.8
Patch	Forest Patches	Classified as Lowland Savanna	Landscape Level Objects	TRUE	TRUE	TRUE	TRUE
		Mean HV	ALOS	>= -14	>= -14	>= -14	>= -14
		NDVI	SPOT	>= 0.8	>= 0.8	>= 0.8	>= 0.8
	Open Savanna	Classified as Lowland Savanna	Landscape Level Objects	TRUE	TRUE	TRUE	TRUE
		Classified as Lowland Savanna	Landscape Level Objects	TRUE	TRUE	TRUE	TRUE
	Dense Tree Savanna	GLCM Homogeneity (Red)	SPOT	<= 0.5	<= 0.5	<= 0.5	<= 0.5
		Mean HV	ALOS	>= -20	>= -20	>= -20	>= -20
	Seasonally Waterlogged Savanna with Shrubs and Trees	Classified as Lowland Savanna	Landscape Level Objects	TRUE	TRUE	TRUE	TRUE
		GLCM Homogeneity (Red)	SPOT	>=0.6	>=0.6	>=0.6	>=0.6
		Mean HV	ALOS	>= -20	>= -20	>= -20	>= -20
		Mean SWIR	SPOT	<= 80	<= 80	<= 80	<= 80
		Classified as Lowland Savanna	Landscape Level Objects	TRUE	TRUE	TRUE	TRUE
	Wetland Patches	Mean SWIR	SPOT	<= 75	<= 65	<= 45	<= 65
		Mean SWIR	SPOT	>=20	>=20	>=20	>=20
		Mean HV	ALOS	< -14	< -14	< -14	< -14
		NDVI	SPOT	< 0.8	< 0.8	< 0.8	< 0.8

#### 4.3.4 Manual classification of savanna in Cayo district

As discussed above (section 4.1.4), ALOS and SPOT data was not available for the Cayo district. Instead one cloud free ASTER image was acquired and used to identify the extent of remaining lowland savanna in these areas. Given its limited spectral coverage and poorer spatial resolution than SPOT, ASTER alone was not found appropriate for mapping potential new areas of savanna in this region. Instead, areas of savanna shown in the Meerman & Sabido map were identified and their extent updated by visual interpretation of the ASTER image. Four areas of savanna solely within this scene were identified from the Meerman and Sabido ecosystems map. Areas were discounted as they were either heavily modified and fragmented so that no surviving portion was above the 50ha minimum mapping area, or not positively identifiable as savanna from ASTER, and thus discounted awaiting field validation. Only the one area, Savanna Bank, was found to be both extant savanna from the image and ground checking in January 2010 and also above the 50ha minimum mapping unit. The extent of this area from Savanna Bank was subsequently updated from the Landsat data and found to be unchanged. Figure XX illustrates these areas identified from ASTER.

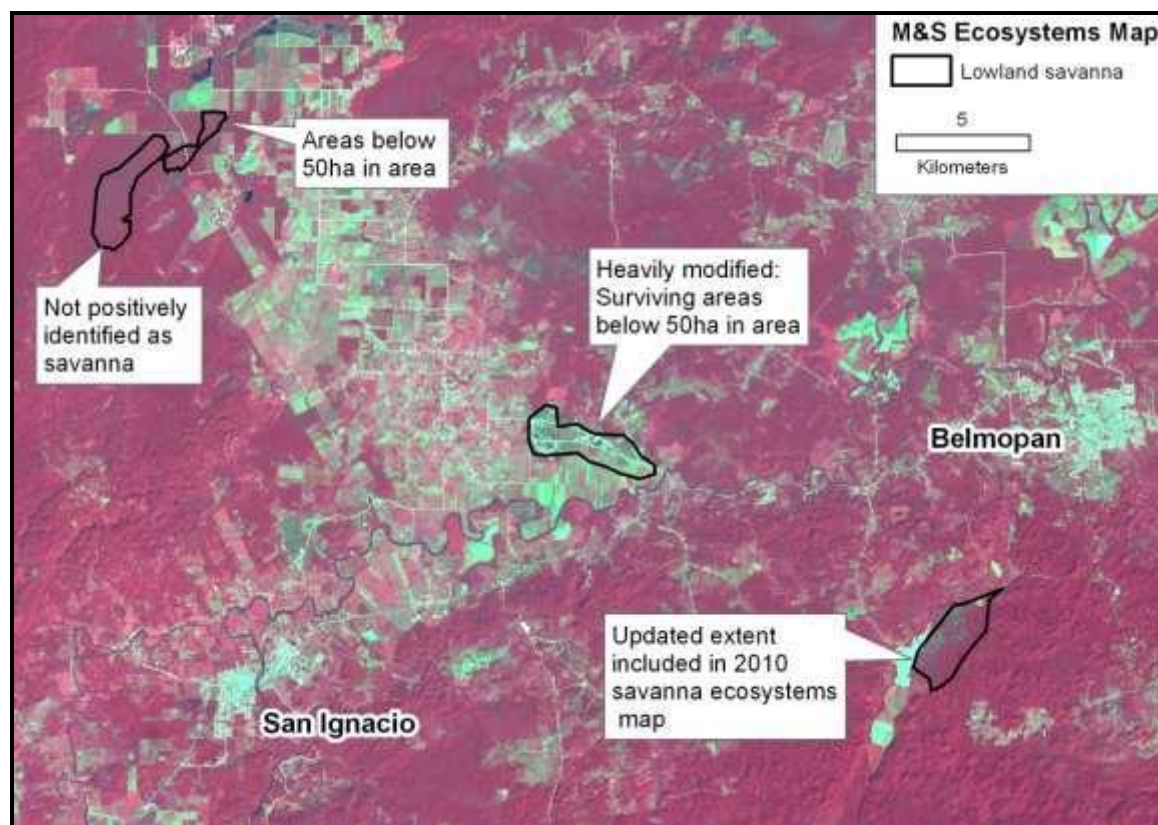


Figure 33: Identification of lowland savanna from ASTER image.



#### 4.3.5 Manual classification of problem classes

After the automated classification was completed, the classifications were visually inspected and any clearly erroneous objects manually reclassified. The lowest classification accuracy was found for cloud shadows, burn-scars and seasonally waterlogged savanna with shrubs and trees. As discussed above, the low reflectance of burn-scars and cloud shadow leads to confusion with wetland patches. Comparison between overlapping SPOT and LANDSAT images allowed many burn-scars to be identified and reclassified appropriately. Cloud-shadow is easier to identify, due to the association with clouds, and were manually re-classified in the same fashion as burn scars. As can be clearly seen from Figure 29 to Figure 32, seasonally waterlogged savanna with shrubs and trees overlaps with a number of classes due to its structural similarity to dense tree savanna leading to a similar HV backscatter signature, and its similarity in reflectance to wetlands. Thus much of this class had to be manually identified by visual inspection of the IKONOS imagery where available. The ground-survey data, together with notes gathered while in the field and Google Earth interpretation were also used to guide the identification of this class.

- It was difficult to develop accurate class descriptions for agriculture, aquaculture and urban areas, for the following reasons:
- Reflectance over aquaculture varies greatly dependant upon the layout and water-levels within ponds.
- The configuration and appearance of urban areas varies markedly across Belize, making classification based on reflectance or texture measures not consistently reliable.
- Agriculture, such as pasture or citrus farms, is difficult to automatically separate from open or wooded savannas based upon reflectance alone. In some cases it was possible to define rules based upon the shape of objects, as agricultural fields tend to have straight boundaries, which are particularly clear at the agriculture/forest edge. However, it was almost impossible to accurately define the boundary between savanna and agriculture.
- In all of these cases a manual interpretation of the SPOT imagery was conducted in ArcGIS. Recent Landsat imagery from 2009 and 2010 was subsequently used to update the extent of these classes, based on the observation that these were all land uses to which former savanna areas have been converted.



#### 4.3.6 Output generalisation

The final stage of processing was to merge and generalise the classification results from each SPOT image to produce a suitable cartographic product for Belize. Objects were exported from Ecognition as shapefiles, with the generalisation steps outlined below then conducted in ArcGIS. Figure 34 summarises each of these steps.

1. Gaps in the classification resulting from the cloud mask (see section 4.1.1) were manually filled based on contextual information where available and by inspection of the more recent LANDSAT imagery.
2. Neighbouring objects of the same class were merged together using a dissolve function based upon the patch-scale classes. This preserved the common boundaries between landscape and patch scales, ensuring that all landscape-level objects were comprised of patch-scale objects.
3. Classifications from the different SPOT images were merged together with a union function. In overlapping regions between images, differences between classes were resolved manually.
4. The updated agriculture, aquaculture and urban-area masks were incorporated by overlaying these layers and deleting the underlying savanna classification.
5. Isolated patches of savanna landscape less than 100 ha in size were identified and removed from the classification.
6. Isolated forest and wetland patches less than 50 ha in size were incorporated into the lowland savanna class. Steps 5 and 6 were designed to address the shortcomings of the scale parameter for defining the minimum-mappable area (see section 4.3.2).
7. Polygons were simplified using a point removal algorithm. This step was vital to reduce data volumes, as the polygons exported from Ecognition followed pixel boundaries, and this generates many superfluous polygon vertices. Using a line-offset tolerance of 50m was found to produce the best compromise between reducing data volumes and preserving polygon shape.
8. As shapefiles do not handle topology well, step 7 introduced many sliver polygons. These were found to generally be less than 5 ha in size, and were removed by an eliminate function. This assigned sliver polygons to the neighbouring polygon with the greatest border.



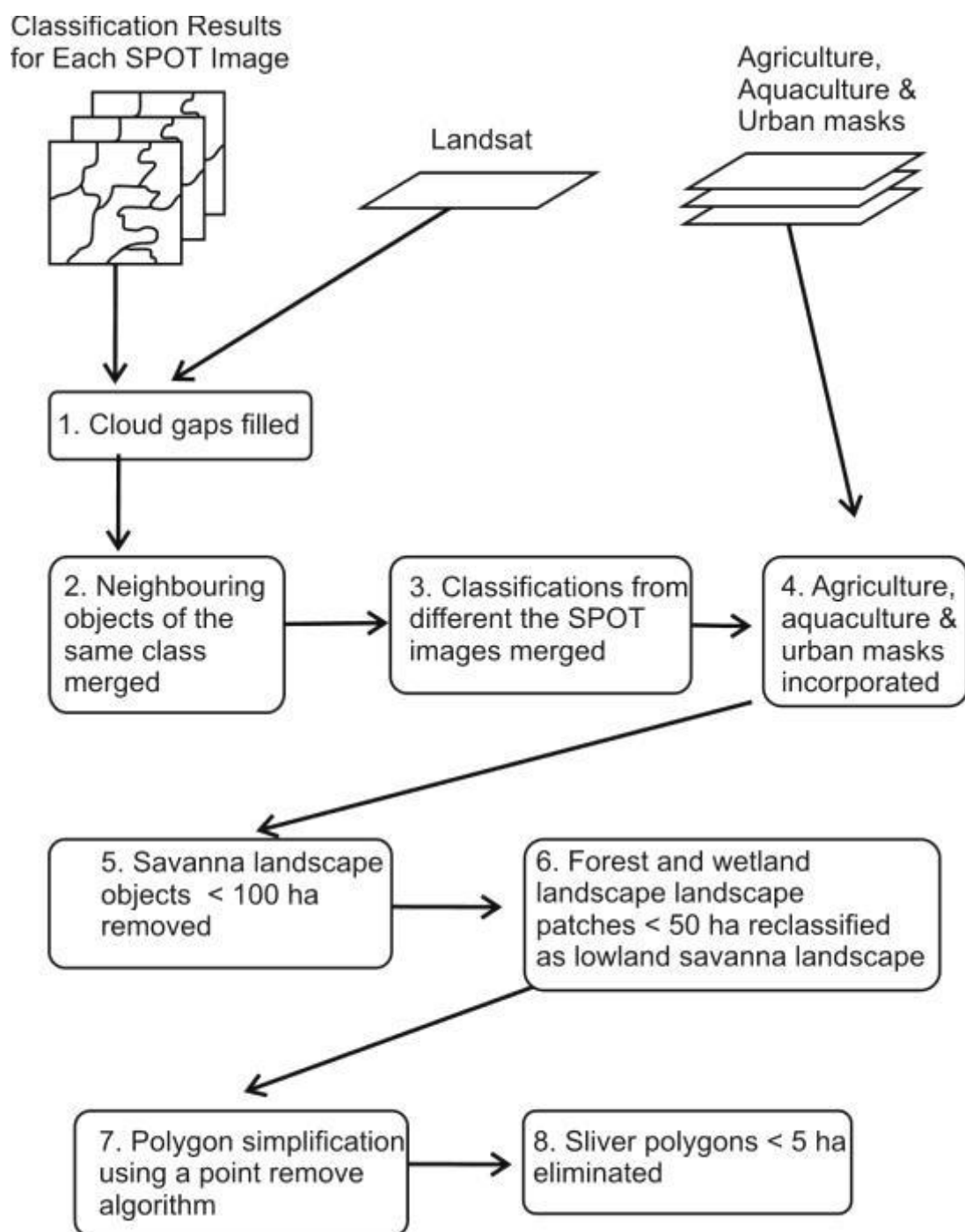


Figure 34: Summary of processing steps used in output generalisation.

## 4.4 Map Validation

### 4.4.1 Comparison against validation points

Validation points collected during ground survey (see section 4.2.2) were intersected with the savanna ecosystems map, with 415 points falling within polygons. The predicted map classifications were compared against the observed vegetation classes for both the landscape and patch levels. Note that there was no distinction made between forest/forest patch or wetland/wetland patch as the botanical descriptions at patch vs landscape level are identical and it was not possible to accurately assess the size of an assemblage in the field.

Results at the patch level proved promising, with an overall accuracy of 71.6%. As Table 13 shows, a major source of confusion was between dense tree savanna and open savanna, with accuracies for these two classes being 72% and 61% respectively (Table 14). The slight oversubscription of open savanna to dense tree savanna, reflects the fact that the boundary between these two classes is not sharp; in practice we may be slightly underestimating the lower range of density required to attribute savanna to a woodland class based upon the imagery. Forest and wetland areas appear to be relatively well classified, although we do find some confusion between wetland and seasonally waterlogged savanna with trees and shrubs as may be expected. Given the strong over representation of lowland savanna observations, further validation work is required before a clear assessment of landscape-level classification accuracy can be evaluated.

*Table 13: Classification error matrix for patch-level classes*

Actual Classification	Predicted Classification					Grand Total
	Forest	Open Savanna	Dense Tree Savanna	Seasonally Waterlogged Savanna	Wetland	
Forest	18	9	5		1	33
Open Savanna	1	180	22	1		204
Dense Tree Savanna						
Seasonally Waterlogged Savanna	2	35	61			98
Wetland		26	9	31	2	68
			3	3	5	11
Grand Total	21	250	100	35	8	414

*Table 14: Classification accuracy per patch-level class*

	Classification Accuracy Per Class
Forest	85.71
Open Savanna	72
Dense Tree Savanna	61
Seasonally Waterlogged Savanna	88.57
Wetland	62.5



## 5 References

Bridgewater, S., Ibanez, A., Ratter, J. A. (2002) Vegetation classification and floristics of the savannas and associated wetlands of the Rio Bravo Conservation and Management Area, Belize, *Edinburgh Journal of Botany*, 59:3, pp. 421-442

Definiens (2007) Definiens Developer 7: Reference Book, <http://www.ecognition.cc/download/ReferenceBook.pdf>, last accessed 04/10/2010

Gao, Y., Mas, J. F., Maathuis, B. H. P. (2006) Comparison of pixel-based and object-oriented image classification approaches - a case study in a coal fire area, Wuda, Inner Mongolia, China, *International Journal of Remote Sensing*, 27: 18, pp. 4039-4055

Gitelson, A.A., J.J. Kaufman, and M.N. Merzlyak. (1996). Use of a green channel in remote sensing of global vegetation from EOS-MODIS. *Remote Sensing of Environment* 58:289-298.

Haralick, R.M. Haralick, K. Shanmugam and I. Dinstein, (1973) Textural features for image classification, *IEEE Transactions on SMC*, Piscataway, New Jersey, pp. 610-621.

Jaas, T., (2007) Value of visually interpreted high resolution IKONOS imagery of a tropical savanna in Belize, Central America – Technical Report. Unpublished MSc dissertation, The University of Edinburgh, Department of Geography.

Kellendorfer, J. M., Dobson, C., Vona, J., and Clutter, M. (2003) Toward precision forestry: Plot-level parameter retrieval for SlashPine plantations with JPL AirSAR, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 41, pp. 1571-1582

Le Toan, T., Beaudoin, A. Riou, J. and Guyon, D. (1992) Relating forest biomass to SAR data, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 30, pp. 403-411

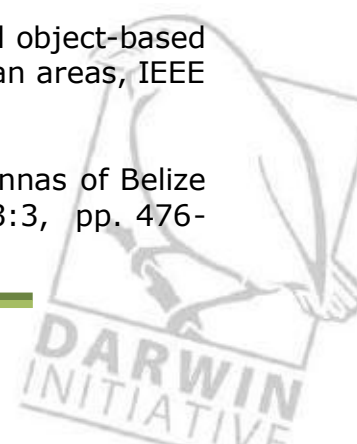
Meerman, J. and W. Sabido. (2001). Central American Ecosystems: Belize. Programme for Belize, Belize City. 2 volumes 50 + 88 pp.

Ranson, K.J. and Sun, G. (1994) Mapping biomass of a northern forest using multifrequency SAR data., *IEEE Transactions on Geoscience and Remote Sensing*, vol. 32, pp. 388-396.

Rego, L. F. G., Koch, B. (2003) Automatic classification of land cover with high resolution data of the Rio de Janeiro city Brazil, 2nd GRS/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas, Berlin, May 22-23, 2003, pp. 172-176

Shackelford, A. K., Davis, C.H. (2003) A combined fuzzy pixel-based and object-based approach for classification of high-resolution multispectral data over urban areas, *IEEE Transactions on Geoscience and Remote Sensing*, 41:10, pp. 2354-2363

Stuart, N., Barratt, T., Place, C (2006) Classifying the Neotropical savannas of Belize using remote sensing and ground survey, *Journal of Biogeography*, 33:3, pp. 476-490





Viergever, K. M., Woodhouse, I. H., Marino, A., Brolly, M. and Stuart, N. (2009) Backscatter and interferometry for estimating above-ground biomass of sparse woodland: A case study in Belize, IEEE International Geoscience and Remote Sensing Symposium, July 12-17, 2009 Cape Town, South Africa, vol. 1-5, pp. 2349-2352

Vreugdenhil, Daan, Jan Meerman, Alain Meyrat, Luis Diego Gómez, and Douglas J. Graham. (2002). Map of the Ecosystems of Central America: Final Report. World Bank, Washington, D.C.



**Appendix A:**  
**Loading and displaying the Savanna Ecosystems Map in ArcGIS**

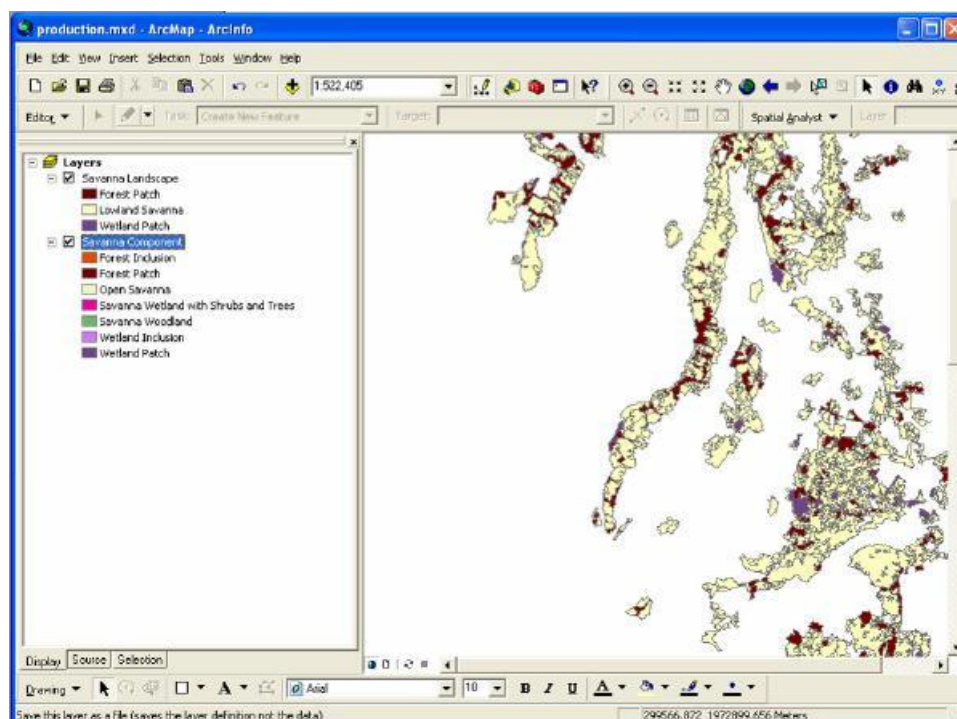


The ecosystem map is provided as a shapefile (*bz\_sav\_ecosystems\_2010\_utm nad27*) plus two layer files (*bz\_sav\_ldscp\_2010\_utm nad27.lyr* and *bz\_sav\_comp\_2010\_utm nad27.lyr*). The shapefile contains the polygons plus attribute data, and is the core dataset.

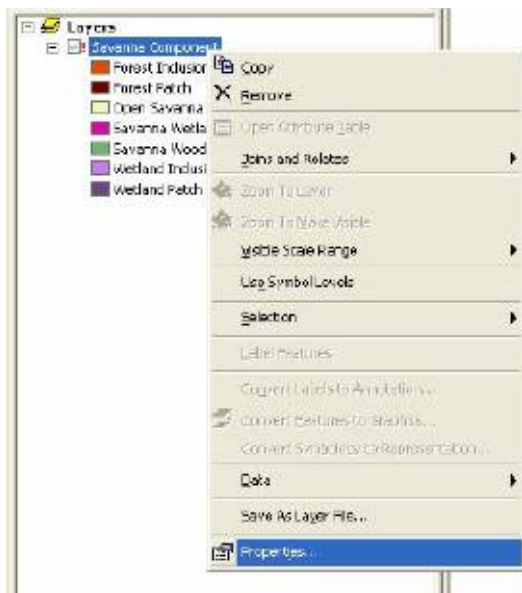
The three attributes for this shapefile are:

- SAV\_LANDSCAPE- Savanna Landscape-level classes (Lowland Savanna, Forest, Wetland)
- SAV\_COMPONENT- Savanna component-level classes (*open savanna, savanna woodland, seasonally waterlogged savanna, forest inclusions, forest patches, wetland inclusions and wetland patches*)
- AREA\_HA- Area in hectares of each polygon.

The layer files contain pre-built colour schemes for the landscape and patch level classes. To view these data in ArcGIS, open a new project and bring them in using the *ADD DATA* button, navigating to the folder where these files are located. Note that, in order for the layer files to operate correctly, they must be kept in the same folder as the shapefile. If you have loaded the two layer files correctly you will see the following:

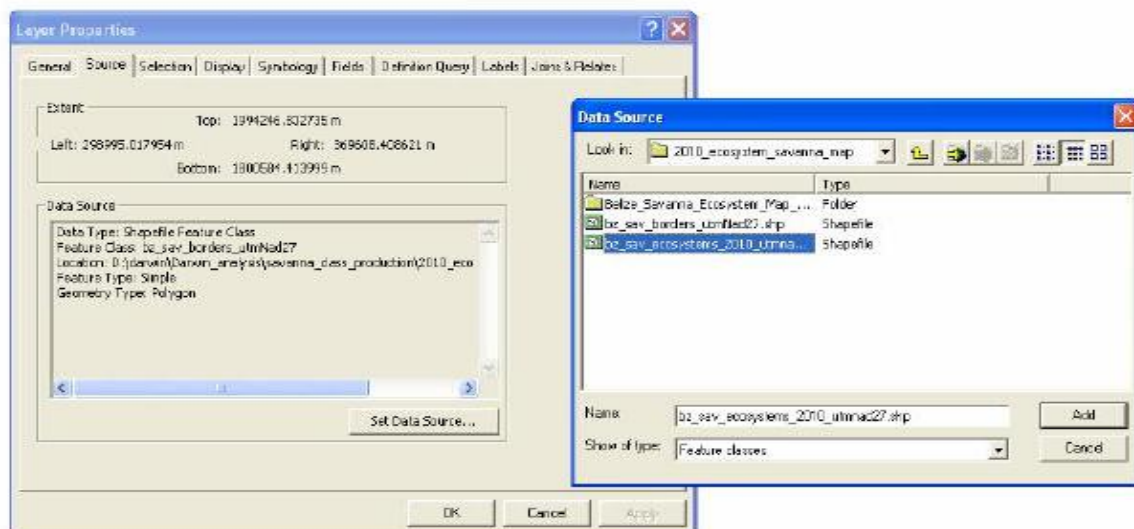


If the map is blank and the layer in the table of contents has a red exclamation mark next to it, this means you need to make sure that ArcGIS knows the location of the underlying shapefile.



Right click on the layer name and open the Properties.

Navigate to the *Source* tab, click *Set Data Source* and navigate to the folder containing the ecosystems map shapefile (*bz\_sav\_ecosystems\_2010\_utm nad27*). Select it and click *Add*.



Now make the link permanent by right clicking the layer name, and selecting *Save Layer*. Save over the original layer file (*bz\_sav\_ldscp\_2010\_utm nad27.lyr* or *bz\_sav\_comp\_2010\_utm nad27.lyr*) to make the update permanent.

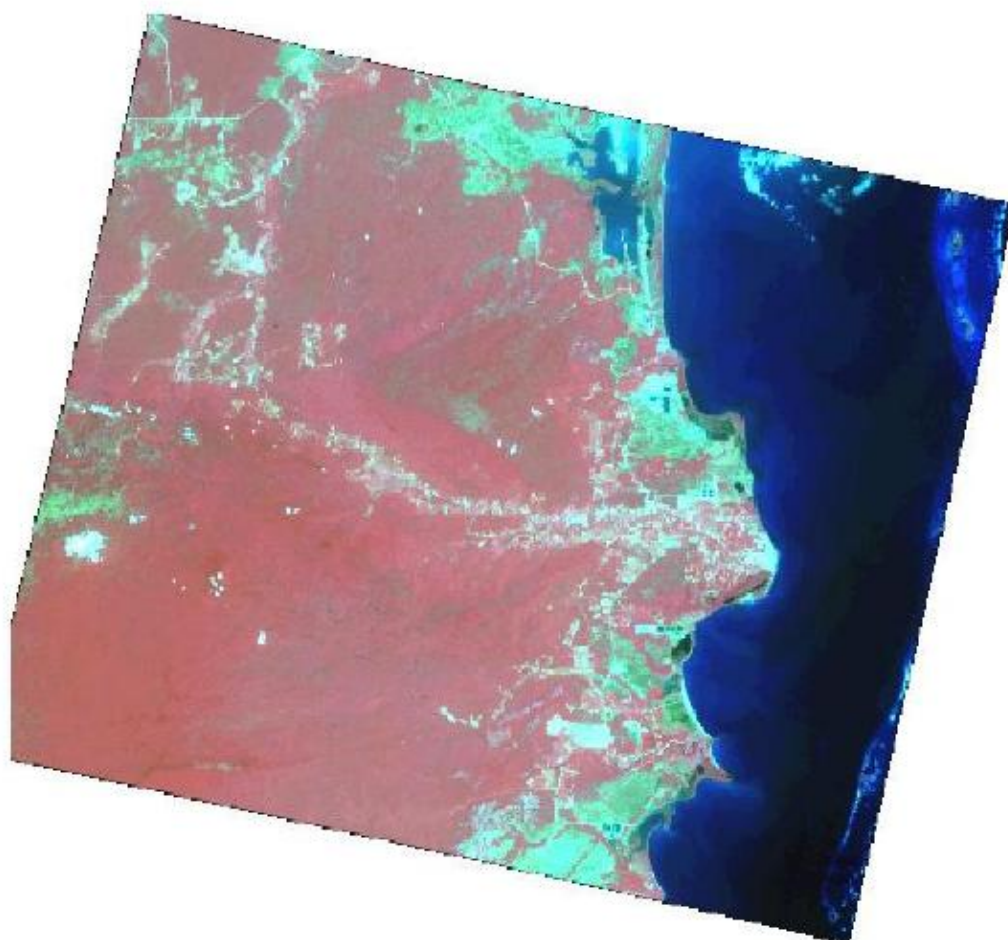
## **Appendix C:**

### **Quicklooks of key remote sensing datasets**

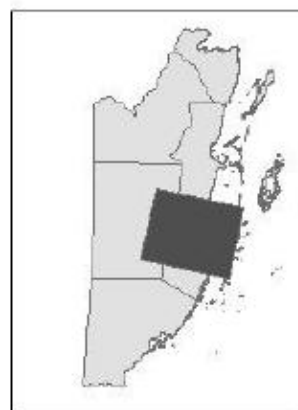




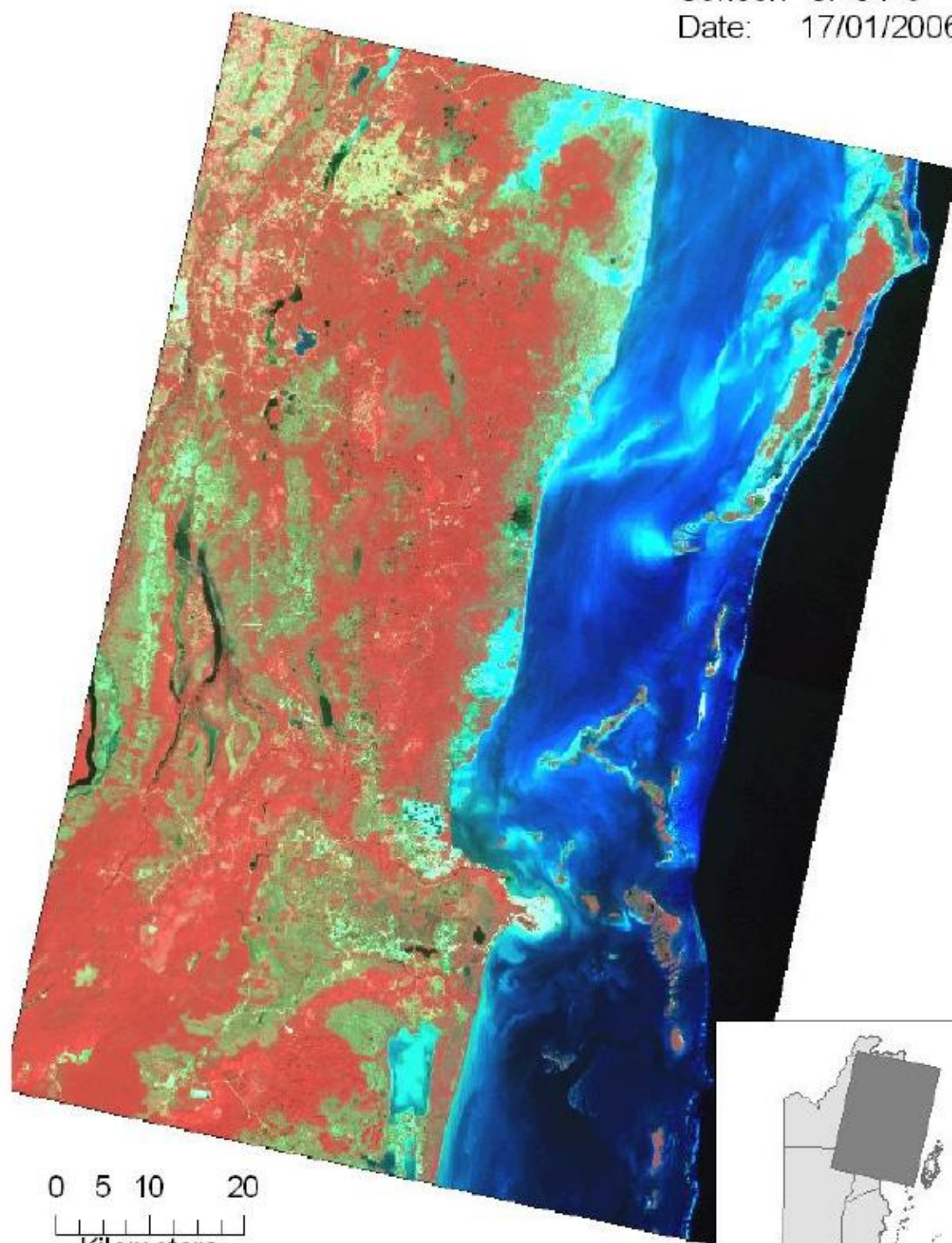
Sensor: SPOT-5  
Date: 12/04/2004



0 5 10 20  
Kilometers



Sensor: SPOT-5  
Date: 17/01/2006

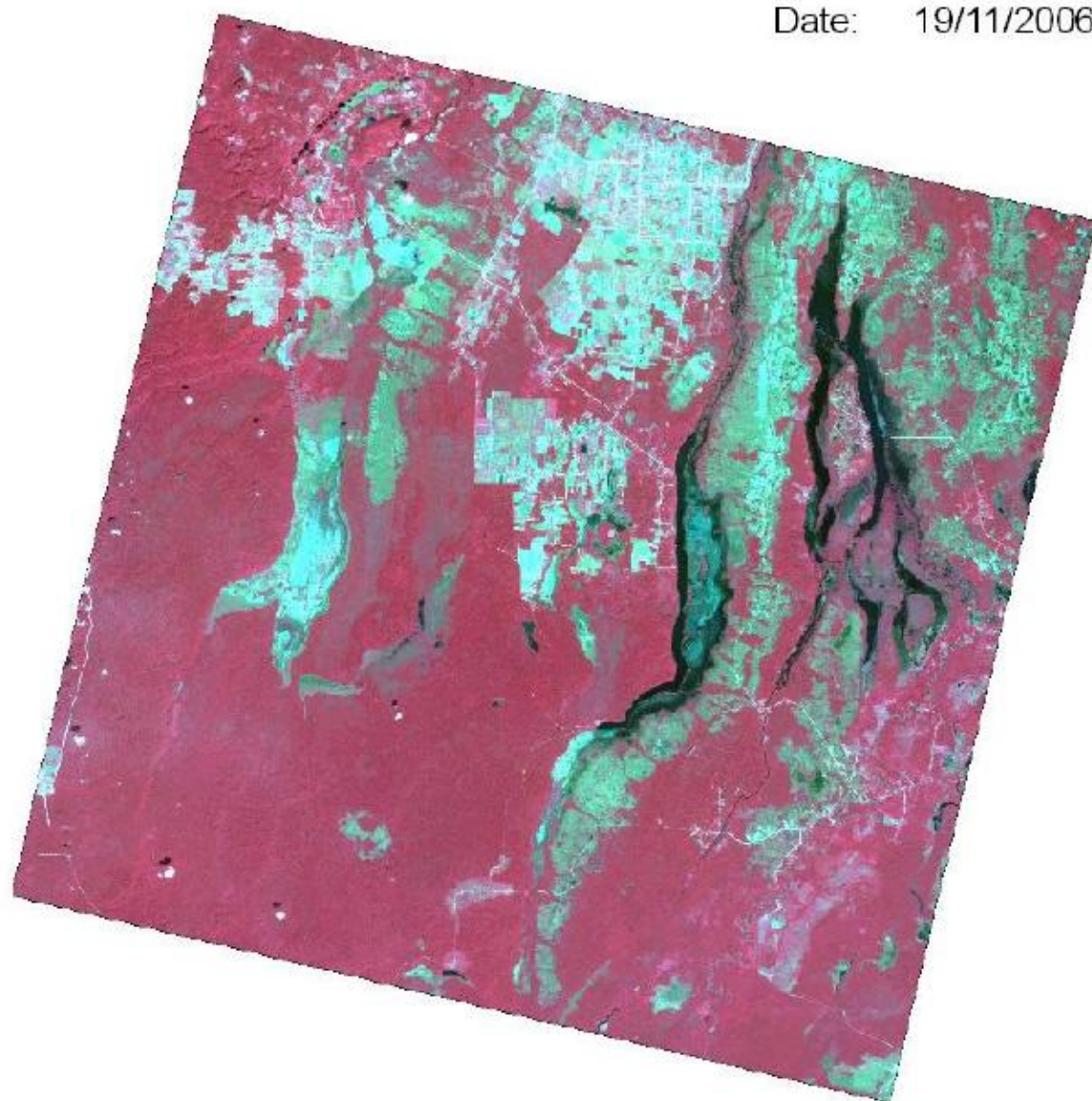


0 5 10 20  
Kilometers



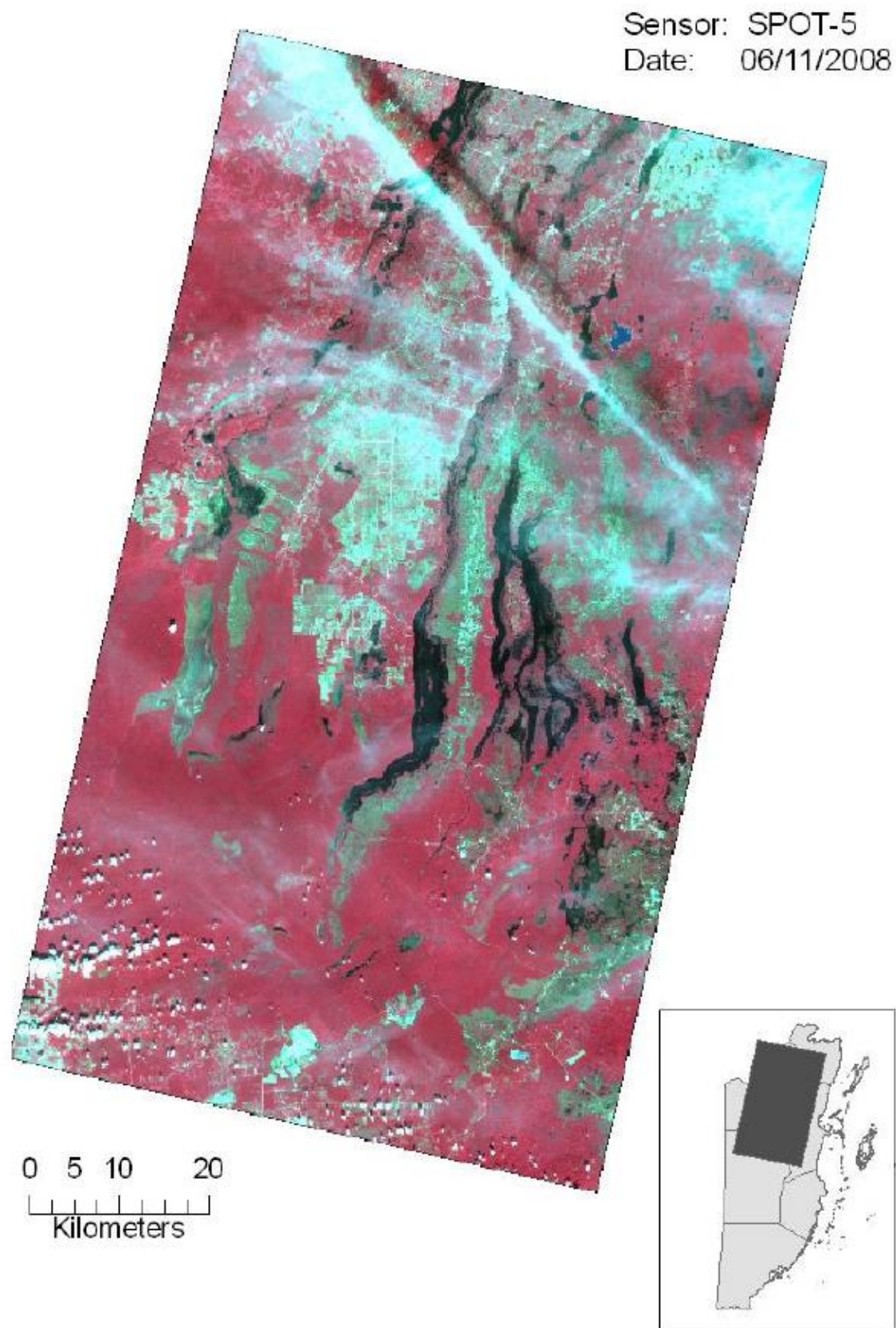


Sensor: SPOT-5  
Date: 19/11/2006



0 5 10 20  
Kilometers







Sensor: SPOT-5  
Date: 11/03/2009

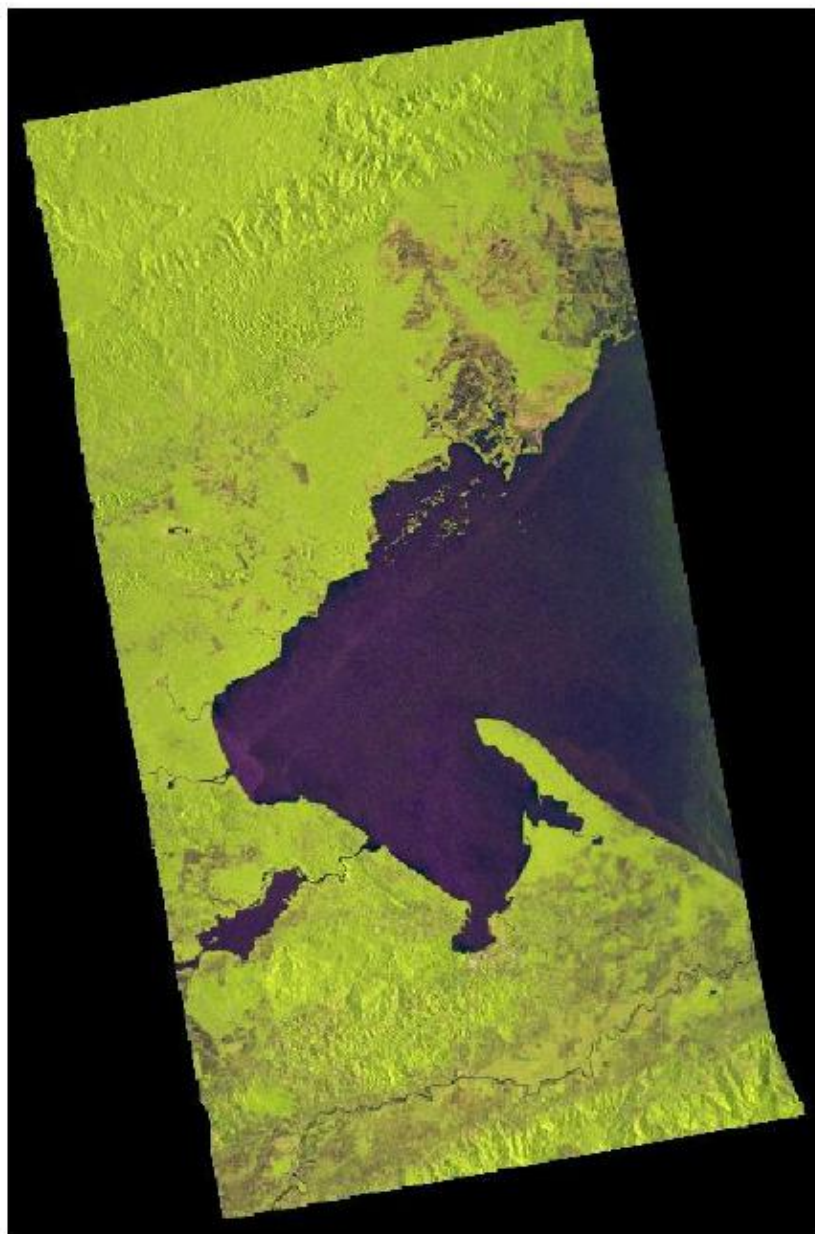


0 5 10 20  
Kilometers





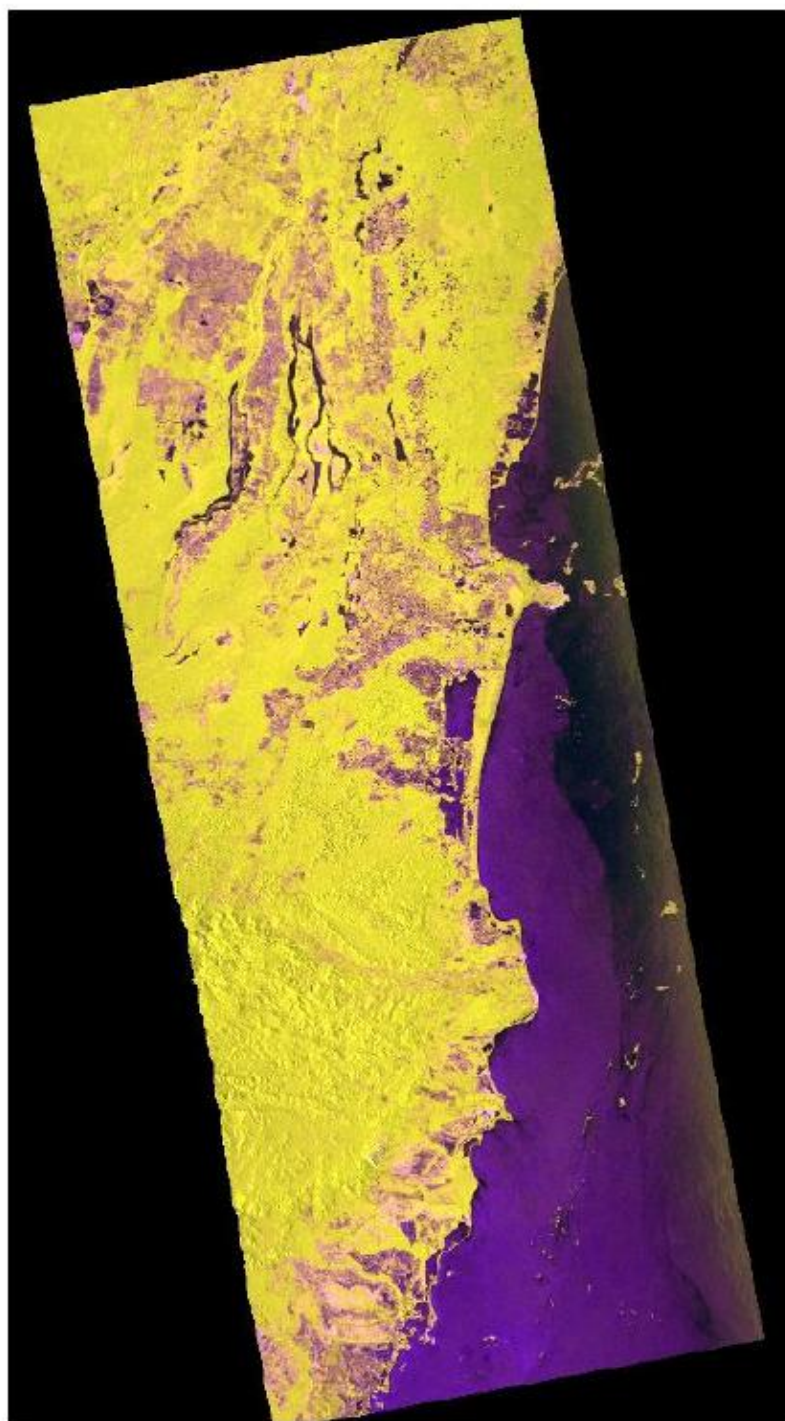
Sensor: ALOS PALSAR  
Date: 10/09/2008



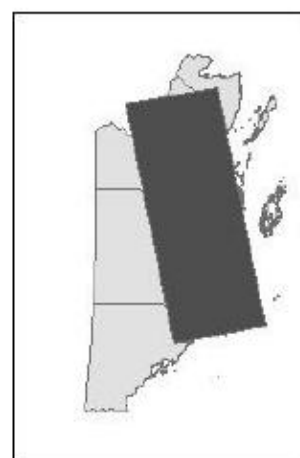
0 10 20 40  
Kilometers



Sensor: ALOS PALSAR  
Date: 30/09/2008



0 10 20 40  
Kilometers





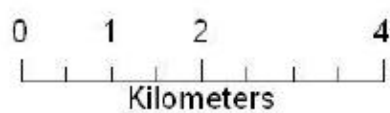
Sensor: IKONOS  
Date: 02/05/2002



0 1 2 4  
Kilometers

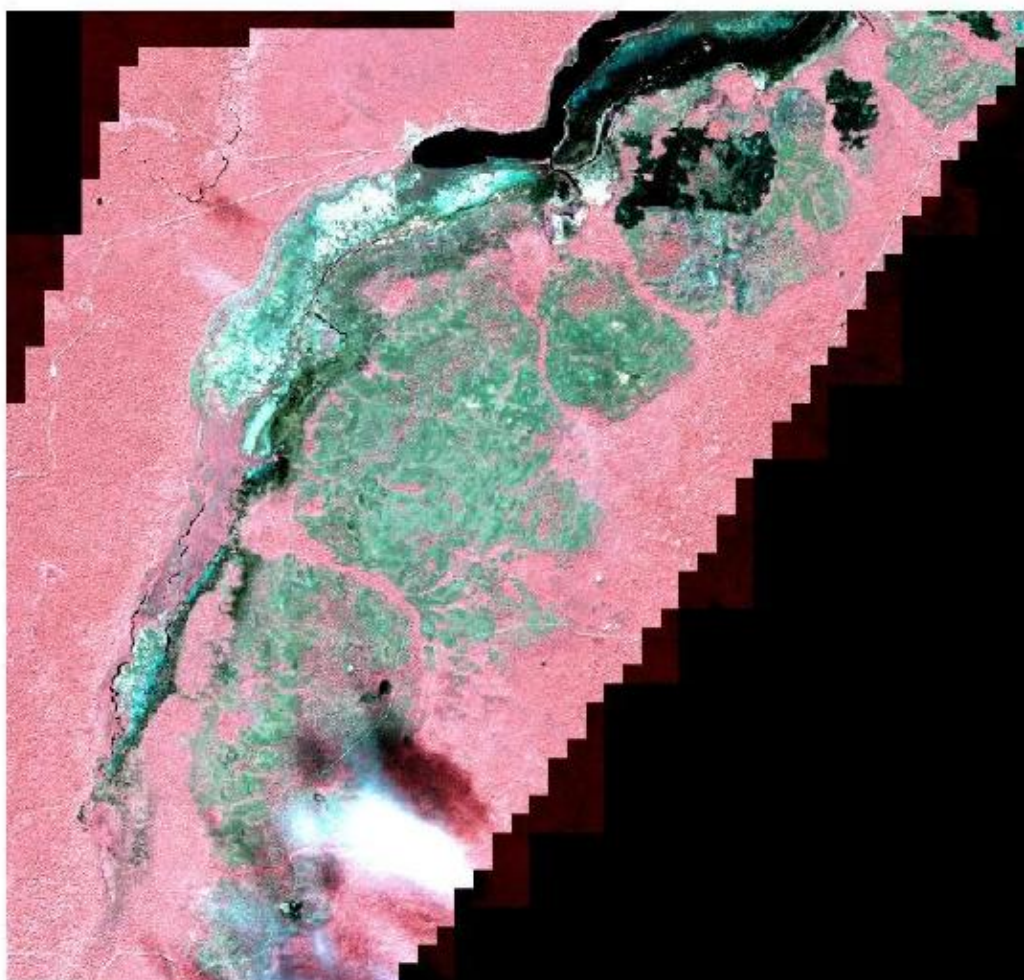


Sensor: IKONOS  
Date: 27/09/2003





Sensor: IKONOS  
Date: 07/03/2007



0 1.25 2.5 5  
Kilometers

