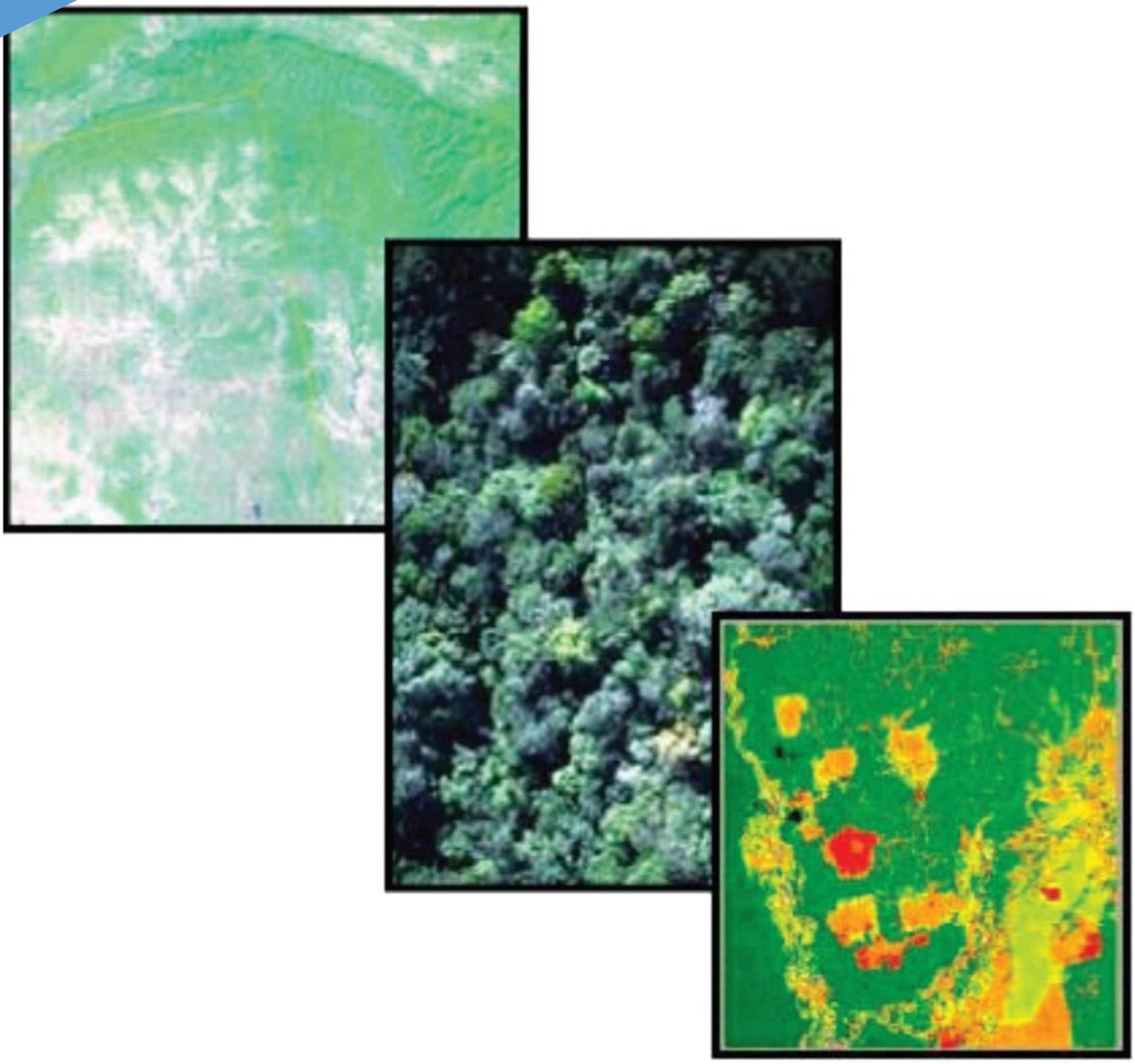
Working Paper



Satellite imagery dataset and index maps for the forest monitoring system of Cambodia

Cambodia, 2013

REDD+ CAMBODIA

Disclaimer

This report prepared by Aruna Technology Ltd., and does not necessarily represent the views of the Cambodia REDD+ Taskforce, the Forestry Administration, the General Department of Administration of Nature Conservation and Protection, the Fisheries Administration, and FCPF Project.

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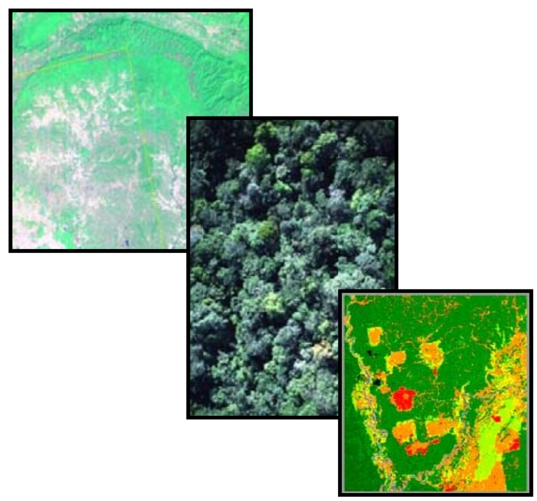
Aruna Technology Ltd.
September 2013
Phnom Penh, Cambodia



The UN-REDD Programme, implemented by FAO, UNDP and UNEP, has two components: (i) assisting developing countries prepare and implement national REDD strategies and mechanisms; (ii) supporting the development of normative solutions and standardized approaches based on sound science for a REDD instrument linked with the UNFCCC. The programme helps empower countries to manage their REDD processes and will facilitate access to financial and technical assistance tailored to the specific needs of the countries.

The application of UNDP, UNEP and FAO rights-based and participatory approaches will also help ensure the rights of indigenous and forest-dwelling people are protected and the active involvement of local communities and relevant stakeholders and institutions in the design and implementation of REDD plans.

The programme is implemented through the UN Joint Programmes modalities, enabling rapid initiation of programme implementation and channeling of funds for REDD efforts, building on the in-country presence of UN agencies as a crucial support structure for countries. The UN-REDD Programme encourage coordinated and collaborative UN support to countries, thus maximizing efficiencies and effectiveness of the organizations' collective input, consistent with the "One UN" approach advocated by UN members.

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List of Acronyms

DEM	Digital Elevation Model
DNA	Designated National Authority
ESA	European Space Agency
EULA	End User License Agreements
FFI	Fauna and Flora International
GERES	Groupe Energies Renouvelables Environnement et Solidarités
JAXA	Japan Aerospace Exploration Agency
MOE	Ministry of Environment – Cambodia
FA	Forestry Administration – Cambodia
MLMUPC	Ministry of Land Management, Urban Planning and Construction
MPWT	Ministry of Public Works and Transport
MRV	Measurement, Reporting and Verification
NTFPs	Non-timber Forest Product s (including charcoal and fuelwood)
REDD+	Reducing emissions from deforestation and degradation
RGC	Royal Government of Cambodia
SAR	Synthetic aperture radar
SMA	Spectral Mixture Analysis
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from deforestation and degradation
USGS	United States Geological Survey
VHR	Very high Resolution data
WCS	Wildlife Conservation Society
L1T	A processing level applied to Landsat imagery. Indicated Level 1 Terrain Corrected

1 Executive Summary

This report presents the findings of the study of the Development of Satellite Imagery Data for the Monitoring of Forest Cover in Cambodia, undertaken by Aruna Technology Ltd., based in Cambodia, for the UN-REDD programme in Cambodia. The study is set in the context of the implementation of the UN-REDD programme to support the REDD+ readiness phase in Cambodia. The establishment of a system of forest and land monitoring is necessary for Cambodia to implement REDD+. To enable the establishment of such as system which is adapted to the available data and existing capacity, it is necessary to make an inventory and collect all available data and to estimate their potential use as part of the establishment of a system for the national monitoring of forests and land use change in the context of REDD+.

The objectives of this report are to provide information on: (1) available satellite and aerial photography imagery in Cambodia, (2) quality of these data (spatial, spectral resolution, cloud contamination etc.), (3) identification of possible additional images that are suitable for national forest monitoring. In order to undertake this analysis, all available satellite and aerial photography in Cambodia were archived and organized. The list of available data is provided in Table 3: Summary of Satellite Data in Cambodia. Additionally and in this context, the impact of different forest definitions, provided recommendations for the use of imagery forest cover assessments, stratification and monitoring for REDD+ were analyzed. The imagery retrieval commenced in February 2013 and analysis was completed in September 2013.

A wide range of organizations were contacted to determine what aerial and satellite imagery they might hold, including government, private sector, NGOs and the UN. A short questionnaire was developed to determine if they held data, request for a general description of what they held, if they were willing to share data, and under what conditions. Index maps were developed based on the information provided. Data came directly from the holder of the data or from the public domain. Any image data that was also public domain or with an expanded license was obtained and also incorporated into the catalog.

Since most, especially commercial, satellite image data is governed by license conditions that restrict the free sharing with organizations other than licensee. A great deal of licensed data was identified, but cannot not be physically obtained without additional agreements; or not at all, in which case purchase from the supplier is the only option. A Category system was developed that identified the type of restrictions that applied to the data and how and whether that data could be obtained. The categories range from Category 1, public data such as Landsat to Category 5, commercial data held by an organization under a single user license agreement such as in the case of ALOS. All in all, license conditions vary from one satellite imagery provider to another and some define single user license as being a single organization, while others consider a single user license to be 1-5 organizations. Care needs to be taken in assessing the conditions under which data is licensed and how it can be obtained.

2 Introduction and Background

As part of the United Nations Framework Convention on Climate Change negotiations, REDD+ aims to reduce greenhouse gas emissions from the forestry sector either through an increase in forest cover or as a reduction in its deterioration. In order to assess the forest land area and land area changes in the context of REDD+, it is necessary to develop a reliable and robust forest monitoring system. A system for forest monitoring forest cover and land-use change include software, tools and user's service. To be operational, the system must be suitable to national circumstances, national policies and the human, technical and financial capacities.

The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD Programme) is a collaboration between FAO, UNDP and UNEP. It builds on the convening power of its participating UN agencies, their diverse expertise and vast networks and "delivers as One UN".

The information provided in this reports contributes to the development of a transparent National Forest Monitoring System (NFMS) as part of the national REDD+ process in Cambodia. The national forest monitoring system provides periodic data on forest land area and area changes of the country. The NFMS itself serves two simultaneous functions: a 'monitoring' function and assessing forest emissions by sources and removals by sinks. The "monitoring" function of the NFMS is a primarily a tool which allows countries to acquire different data and assess impacts of policies and measures in the context of REDD+. The assessment of forest emissions by sources and removals by sinks contributes to the preparation of the GHG inventory.

The establishment of a functioning NFMS is one of the preconditions for functioning REDD+ in Cambodia. To enable the establishment of such a system which is adapted to the available data, conditions, and existing capacity, it is necessary to make an inventory and collect all available data and to estimate their potential use as part of the establishment of a system of national monitoring of forest and land use change in the context of REDD+.

3 Data Catalog

3.1 Catalogue and Index Layer Structure

The catalog structure at the highest level first indicates whether the imagery is aerial photography or satellite imagery (see Figure 1). Then, the catalog indicates the satellite type and if necessary, a folder indicating the dataset name. Index layers in shapefile format are organized along the lines of source, scale and year. So for example, the index:

SAT_2002_2004_SPOT5_BND_MLMUPC.shp

contains information on satellite imagery, from years 2002-2004, from the SPOT5 satellite, held by the Ministry of Land Management, Urban Planning and Construction (MLMUPC).

Where data has been obtained, the actual image data will be in the same directory in a standard file format (.tif, .bil, .img etc).

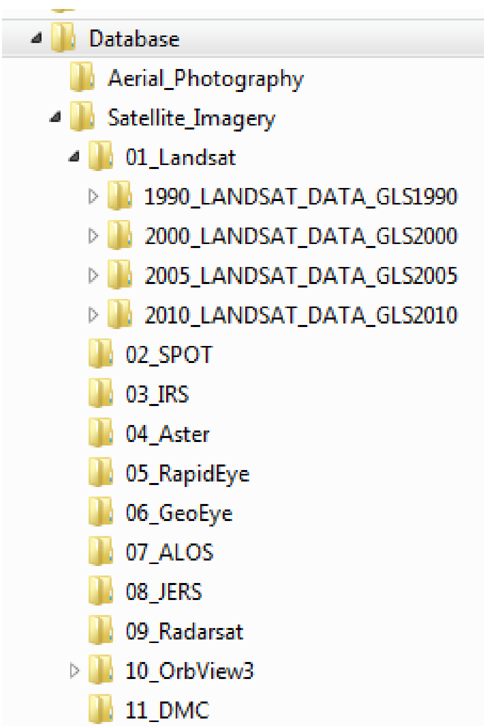

Figure 1: Catalog Structure

Within each index layer shapefile, various relevant information such as date, cloud cover, processing level etc are recorded in the attribute table, as shown in Table 1 below. Where possible, image "Quicklooks" or previews will be included to allow a quick visual assessment.

Item	***e.g.***
Satellite Name	*Landsat7*
Date	*1/8/1990*
Geographic Location	*Kandal Province*
Resolution	*30m*
Data Source	*USGS*
License Type	*Unrestricted Access*
License URL	http://landsat.usgs.gov/documents/Landsat_Data_Policy.pdf
Scene ID	*p124r051_7t20000304_z49*
Path	*124*
Row	*51*
Processing Level from Supplier	*L1G*
Further processing applied ?	*No*
Cloud Cover %	*0*
Horizontal Accuracy	*CE90 30m*
Product URL	http://glcf.umd.edu/data/gls/
Comments	
Mode	Multispectral

Table 1: Attributes stored for each satellite image index file

3.2 Data Access

Satellite imagery and aerial photography are acquired by a range of commercial and non-commercial entities with varying conditions placed on the use and access to that data. To help understand this rather complex picture, a decision tree and Category system was developed to categorize imagery based on license restrictions.

It should be noted that satellite imagery is generally licensed to end users, who have to adhere to the license conditions specified by the licensor. Breach of license conditions can mean that the licensor is entitled to revoke the license granted to the end user and they would no longer be entitled to use the data. For this reason, End User License Agreements (EULAs) need be respected in order not to adversely affect the end user. Each operator has their own EULA with differing wording, which needs to be read and understood carefully to ensure that license conditions are not breached.

A summary of different license conditions are given in Table 2, along with a Category assignment, which is derived from the decision tree in Figure 2.

Category	License Conditions	Examples
Category 1	Unrestricted Access	Landsat
Category 2	Not subject to general license agreement, but access is restricted	Cambodian Government Aerial Photography
Category 3	General data license agreement allows for additional users, subject to agreement	GeoEye-1, QuickBird, WorldView-1 some SPOT Data
Category 4	General data license agreement does not allow for additional users, but license holder is a participant in UN-REDD (MoE, FA etc).	Most commercial satellite imagery (Aster, ALOS, Spot, RapidEye etc)
Category 5	Data is subject to single user license agreement and license holder is NOT a participant in UN-REDD	Most commercial satellite imagery (Aster, ALOS, Spot, RapidEye etc)

Table 2: Data Access Categories based on License Restrictions

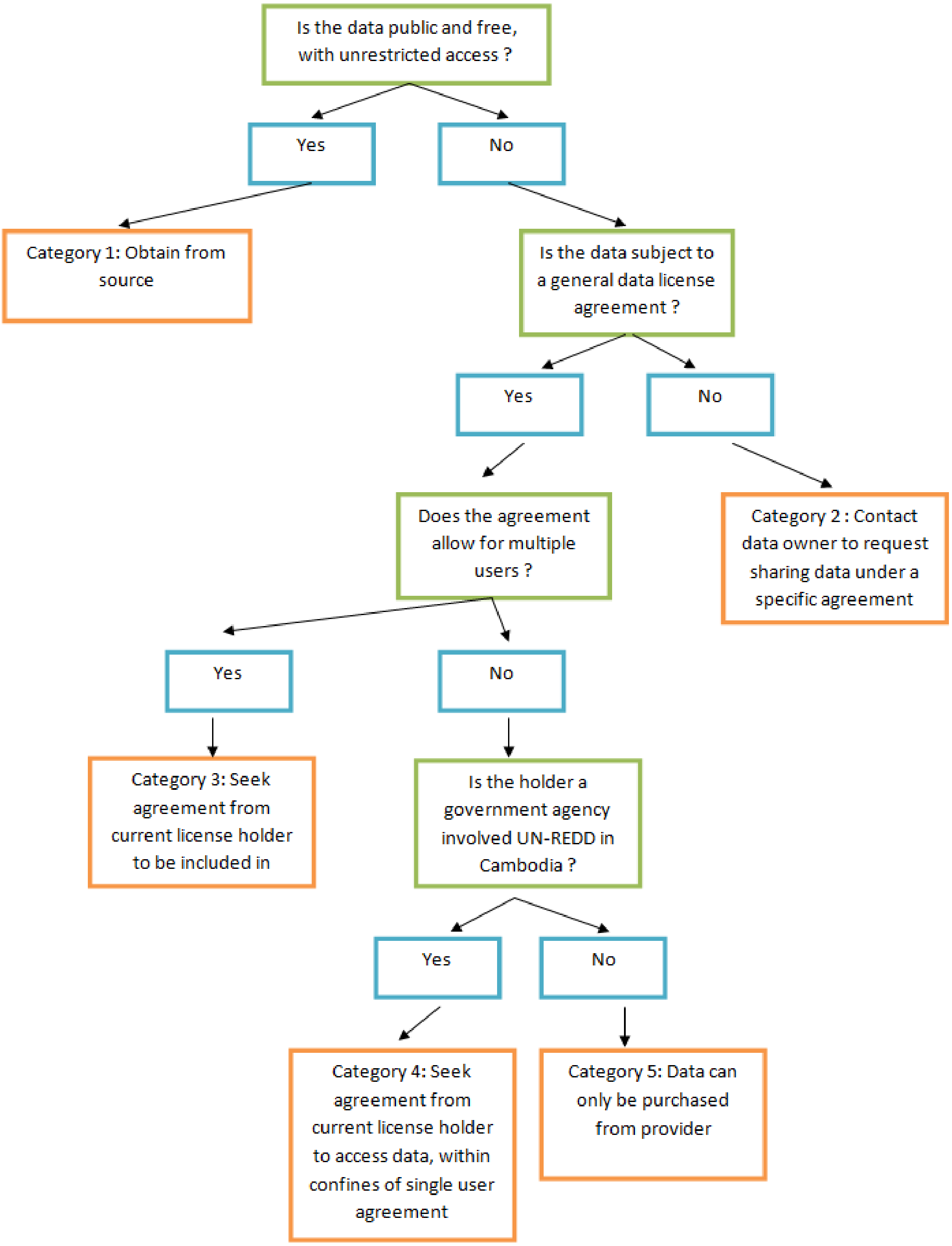

Figure 2: Data Access decision tree

Because multiple-user licenses are more costly than single user licenses, organizations most commonly purchase commercial satellite imagery under a single EULA. As indicated in Figure 2, it may be possible for the agency with responsibility for the National Forest Monitoring System to be added to a multiple user license agreement, by informing the licensor. In cases where the imagery is subject to a single user license agreement and the End User is participating in UN-REDD, it might be permissible for UN-REDD to access the imagery as a sub-contractor type arrangement. However, each license agreement needs to be read carefully and clarifications sought from the licensor.

3.2.1 Category 1 Data Summary

Category 1 datasets are those with unrestricted access and include Landsat and some data from the European Space Agency (ESA). A full list of Category 1 data is provided in Table 3, most of which has been acquired and delivered under this project. Maps for these data are provided in Annex 4.

3.2.2 Category 2 Data Summary

A summary of Category 2 data that identified as part of this study is given in Table 3 below. Most of this data is held by the Cambodian Government and it can be classified as “Category 2” data. Maps for these data are provided in Annex 3.

3.2.3 Category 3 Data Summary

Category 3 data is classified as satellite data with a general data license agreement that allows for additional users, subject to agreement with the licensee. Category 3 data includes high resolution imagery from Digital Globe (GeoEye-1, IKONOS, Quickbird, WorldView-1). Additional users can be considered as sub-licensees, who are nominated by the main license holder as being permitted to have access to the data, subject to the other license conditions. Normally, the satellite imaging company would need to be informed in writing of any such changes to the license agreement involving sub-licensing.

Since Category 3 data is subject to license conditions that prevent unencumbered access, this data has not been acquired during the course of this project. The first step of course would be for the FAO to decide if they want to obtain the data, since not all holdings are in forested or even rural areas. For the FAO to be added as a sub-licensee, direct contact would need to be made with the current licensee seeking to be included.

Table 3 indicates which organizations have responded favourably to the request for access and which have not.

3.2.4 Category 4 Data Summary

Category 4 data is classified as satellite data with a general data license agreement does not allow for additional users, but license holder is a participant in UN-REDD (MoE, FA etc). These data are listed in Table 3 and in Annex 6.

CATEGORY	ID	ORIGINATOR	SENSOR NAME	DATE	COVERAGE/LOCATION	RESOLUTION/ SCALE	MODE	LOCATION	WILLING TO SHARE ?	LICENSE TYPE
1	1.1	USGS	Landsat	GLS1990	Whole country	30m	Multispectral	Supplied to FAO	Not Applicable	Open
1	1.2	USGS	Landsat	GLS2000	Whole country	30m	Multispectral	Supplied to FAO	Not Applicable	Open
1	1.3	USGS	Landsat	GLS2005	Whole country	30m	Multispectral	Supplied to FAO	Not Applicable	Open
1	1.4	USGS	Landsat	GLS2010	Whole country	30m	Multispectral	Supplied to FAO	Not Applicable	Open
1	1.5	USGS	Landsat	2000	Whole country	30m	Multispectral	Held by MRC	No response	Open
1	1.6	USGS	Landsat	1990	Whole country	30m	Multispectral	Held by MRC	No response	Open
1	1.7	USGS	Landsat	2010	Whole country	30m	Multispectral	Held by FA	No response	Open
1	1.8	USGS	Landsat	2013	Whole country	30m	Multispectral	Supplied to FAO	Not Applicable	Open
1	1.9	USGS	Orbview-3	2004 - 2007	Scattered	1m Pan	Pan	Supplied to FAO	Not Applicable	Open
2	2.1	MLMUPC	Aerial Photo	1993	Whole country	25,000	Pan	MLMUPC	No response	
2	2.2	MLMUPC	Aerial Photo	2001	Svay Rieng	15,000	Pan	MLMUPC	No response	
2	2.3	MLMUPC	Aerial Photo	2001	Prey Veng	25,000	Pan	MLMUPC	No response	
2	2.4	MLMUPC	Aerial Photo	2001	Sihanoukville	40,000	Pan	MLMUPC	No response	
2	2.5	MLMUPC	Aerial Photo	2001	North and West Areas	40,000	Pan	MLMUPC	No response	
2	2.6	MLMUPC	Aerial Photo	2001	North and West Areas	40,000	Pan	MLMUPC	No response	
2	2.7	MRC	Aerial Photo	2001	Sihanoukville	8,000	Colour	MLMUPC	No response	
2	2.8	MLMUPC	Aerial Photo	2001	Rattanakiri	Unkown	Unknown	CARE	No response	
2	2.9	MLMUPC	Aerial Photo	2001	Rattanakiri	Unkown	Unknown	CARE	No response	
2	2.10	MRC	Aerial Photo	2002	Phnom Penh	5,000	Colour	MRC	No response	
2	2.11	MRC	Aerial Photo	2002	Phnom Penh	8,000	Colour	MRC	No response	

2	2.12	MLMUPC	Aerial Photo	2004	Chhbar Mon	10,000	Colour	MLMUPC	No response	
2	2.13	MLMUPC	Aerial Photo	2004	Svay Pao	10,000	Colour	MLMUPC	No response	
2	2.14	MLMUPC	Aerial Photo	2004	Kandal	20,000	Colour	MLMUPC	No response	
2	2.15	MLMUPC	Aerial Photo	2004	Siem Reap	20,000	Colour	MLMUPC	No response	
2	2.16	MLMUPC	Aerial Photo	2004	Kampong Speu	25,000	Colour	MLMUPC	No response	
2	2.17	MLMUPC	Aerial Photo	2004	Central Cambodia	40,000	Pan	MLMUPC	No response	
2	2.18	MLMUPC	Aerial Photo	2004	Eastern Cambodia	40,000	Pan	MLMUPC	No response	
2	2.19	MLMUPC	Aerial Photo	2004	Eastern Cambodia	40,000	Pan	MLMUPC	No response	
2	2.20	MLMUPC	Aerial Photo	2004	Stung Chinit	40,000	Pan	MLMUPC	No response	
2	2.21	MOWRAM	Aerial Photo	2005	Stung Chinit	10,000	Colour	MOWRAM	No response	
2	2.22	MOWRAM	Aerial Photo	2005	Tonle Sap	15,000	Colour	MOWRAM	No response	
2	2.23	MoE	Aerial Photo	2005	Tonle Sap	25,000	Colour	MoE	No response	
2	2.24	MLMUPC	Aerial Photo	2005	Central Cambodia	40,000	Pan	MLMUPC	No response	
2	2.25	MLMUPC	Aerial Photo	2005	Central Cambodia	40,000	Pan	MLMUPC	No response	
2	2.26	MLMUPC	Aerial Photo	2005	Central Cambodia	40,000	Pan	MLMUPC	No response	
2	2.27	MLMUPC	Aerial Photo	2005	Central Cambodia	40,000	Pan	MLMUPC	No response	
3	3.1	GeoEye	GeoEye-1	2013	5 Provincial Towns	0.5m	Multispectral	Held by GIZ	No response	Single (1-5 users)
3	3.2	GeoEye	GeoEye-1	2008	Virachey NP & Kratie	0.5m	Multispectral	Held by Indochine Mining	Yes	Single (1-5 users)
3	3.3	GeoEye	GeoEye-1	2010	Mondulkiri	0.5m	Multispectral	Held by Renaissance Minerals	Yes	Single (1-5 users)
3	3.4	GeoEye	GeoEye-1	2009	Botum Sakor NP, Koh Kong	0.5m	Multispectral	Held by Wildlife Alliance	No response	Single (1-5 users)
4	4.1	Astrium	SPOT5	2003	Scattered	10m & 2.5m	Multi + Pan	MOE	No response	Single (1 user)
4	4.2	Astrium	SPOT5	2004-2006	Scattered	2.5m	Natural Color	Supplied to FAO	Not Applicable	Multi (All Govt.)

4	4.3	JAXA	Aster	2005	Scattered	15m, 30m, 60m	Multispectral	MOE	No response	Single
4	4.4	ESA	LISSIII	2006	Most of Country	23.5m	Multispectral	MOE	No response	Single
4	4.5	JAXA	AVNIR-2	2010	Whole country	10m	Multispectral	FA	No response	Single
4	4.6	JAXA	PRISM	2010	Scattered	2.5m	Pan	FA	No response	Single
4	4.7	JAXA	Palsar	2010	Scattered	20m	Radar	FA	No response	Single
5	5.1	Astrium	SPOT5	2002-2004	Scattered	10m & 2.5m	Multi + Pan	MJMUPC	No response	Single
5	5.2	RapidEye	RapidEye	2011	BTB/REP/PURSAT/KG Thom	6.5m	Multispectral	Held by Fintrac	No response	Single
5	5.3	RapidEye	RapidEye	2012	Bokor NP	6.5m	Multispectral	Held by FFI	No response	Single
5	5.4	RapidEye	RapidEye	2011	Lumphat WS	6.5m	Multispectral	Held by Koo & Sobota	Yes	Single
5	5.5	RapidEye	RapidEye	2011	Parts of Pursat	6.5m	Multispectral	Held by GERES	Yes	Single
5	5.6	MDA	Radarsat	2000	Whole country	Unkown	Radar	Held by MRC	No response	Single
5	5.7	JAXA	JERS	1997	Kampong Chhnang	Unkown	Radar	Held by MRC	No response	Single
5	5.8	DMCII	UK-DMC2	2011	Rattanakiri	22m	Multispectral	Held by FAO	Yes	Single
5	5.9	ESA	ES2 (Radar)	2007	Eastern Cambodia	30m	Radar	Held by WCS	Yes	Single
5	5.10	ESA	IRS	1998-2001	Eastern Cambodia	Unkown	Pan	Held by WCS	Yes	Single

Table 3: Summary of Satellite Data in Cambodia

3.2.5 Category 5 Data Summary

Category 5 data is classified as satellite data with a general data license agreement does not allow for additional users, and the license holder is NOT a participant in UN-REDD (MoE, FA etc). This data would be difficult or impossible to obtain without paying an additional license fee (if allowed by the operator) and with the agreement of the licensee. These data are listed in Table 3 and in Annex 7.

4 Data Quality Assessment of Catalog

4.1 Spatial Coverage

Generally speaking, it is desirable to cover all forested areas with imagery from the same sensor, particularly when national level assessments are being undertaken. This will allow for consistent and repeatable methodologies to be developed for all areas. It is noted that "REDD+ monitoring needs to cover all forest areas and the same area needs to be monitored for each reporting period." (GOFC-Gold, 2012).

As shown in Figure 3, forested areas in Cambodia, including those in protected areas are located all over the country and account for 57% of the land area in 2010 (RGC, 2011). In terms of complete national coverage, by far the most accessible and available data is the Landsat series of satellites. Although a large amount of Landsat is available for download, it is preferable to use the Landsat GLS dataset (1990, 2000, 2005 and 2010) which are pre-processed to a higher level than the regular Landsat images. Other significant holdings with national coverage also exist from the ALOS sensor (2010), LISSII (2006-2007) and aerial photography (1993 and 2002-2004). These are generally held by Cambodian government agencies and are detailed in the Annexes of this report and index files accompanying this report.

Apart from data covering the whole country, imagery covering smaller areas should also be considered, particularly high or very high resolution imagery. This imagery can be quite useful in supporting the analysis of medium resolution imagery such as Landsat, for example to visually identify forest characteristics such as canopy cover, leaf on/off in deciduous forest and verification of mapping results. VHR imagery is also useful to verify forest characteristics of very remote or inaccessible areas. The available high and VHR imagery holdings are detailed in the Annexes of this report and index files accompanying this report.

One final consideration in relation to spatial coverage is the footprint area of a satellite sensor. Most medium resolution sensors such as Landsat, ALOS, LISS have a fixed swath. For example Landsat has a swath of 185km, while UK-DMC-2 has a swath of 600km. All things being equal, it is sometimes preferable to use data with a larger swath, as this can reduce the amount of image processing work and also provide a temporally consistent snapshot within the footprint.

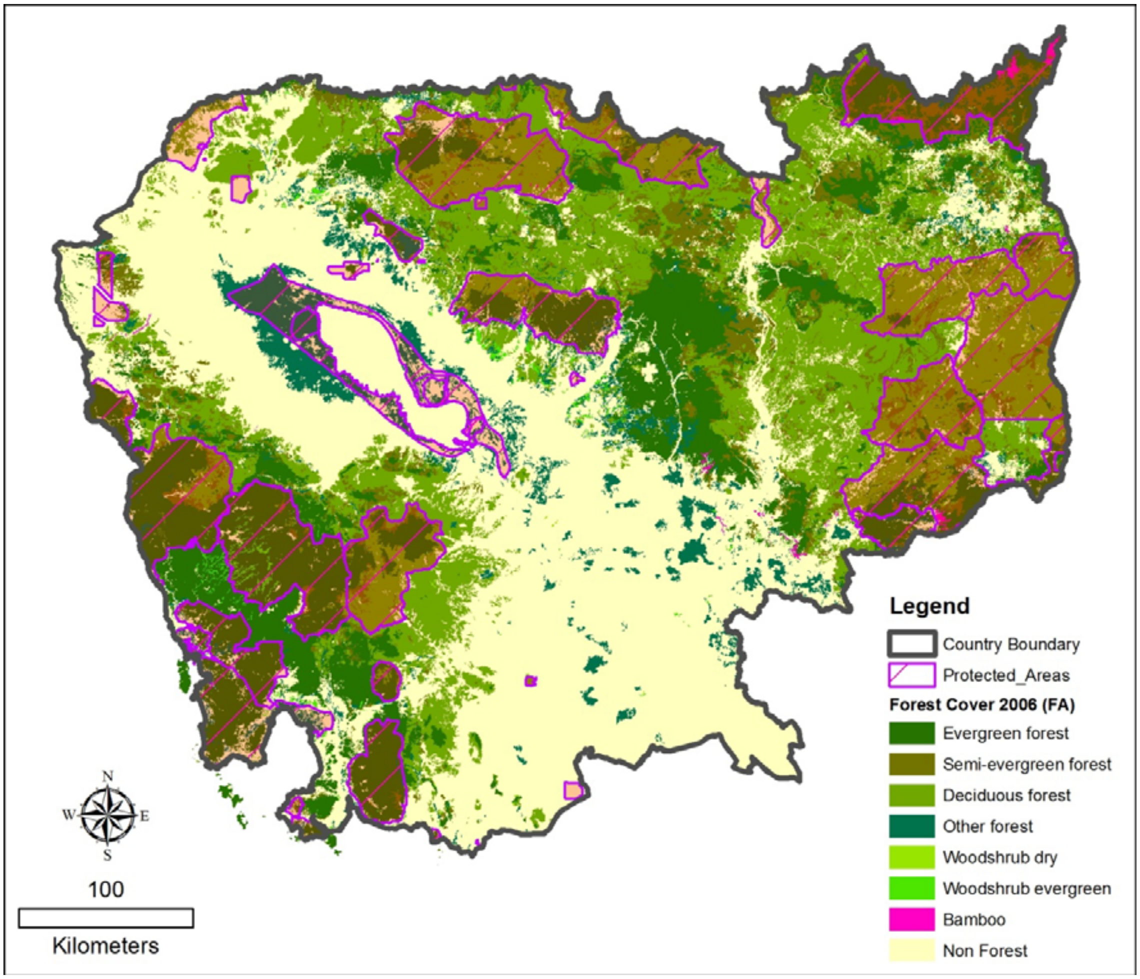

Figure 3: Forest Cover 2006 in Cambodia Source: Forestry Administration

4.2 Temporal Coverage

Temporal coverage has several main aspects; (a) the availability of historical data suitable for REDD+ mapping and (b) the availability of data within the same year and season and (b) the availability of data from the same period with in a season e.g. early dry season, late dry season. In the case of deciduous forest, it may be desirable to have imagery from the early part of the dry season so that canopy cover can be more accurately assessed. If available, early AND late dry season imagery will also help to identify the degree of deciduousness where forest is comprised of evergreen and deciduous species.

From a historical perspective, Annex 1 provides a full list of the launch history of most common optical satellites. Since REDD+ could require historical mapping as far back as 1990 and add various intervals in between, Landsat is probably the most suitable for historical analysis. However, between 2002 and 2013, Landsat 7 imagery was affected by the "SLC-off" problem causing strips of data to be missing. Though this was partly mitigated by the ongoing, though patchy coverage of Landsat 5. Additionally, "gap filling" of SLC-off Landsat 7 is possible and some products such as the Global Land Survey (GLS) have already been gap filled. This generally results in images that have only 1-10% missing.

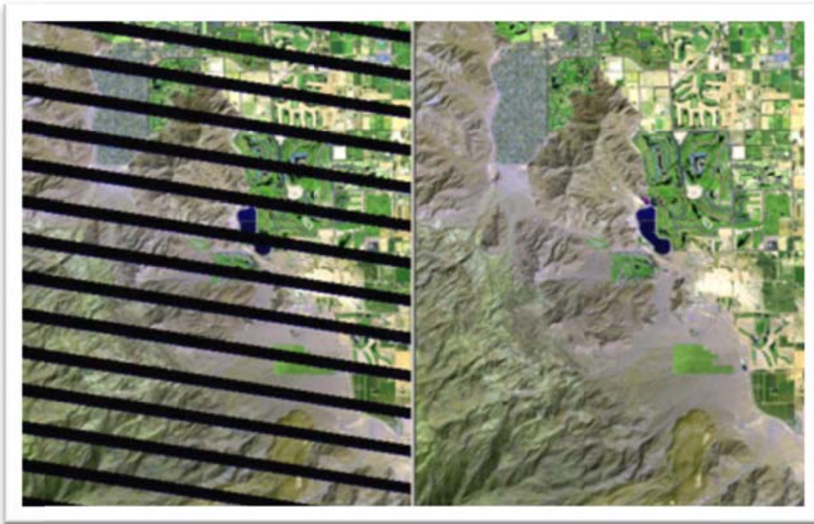

Figure 4: Landsat 7 imagery in SLC-off mode (left) and Gap filled (right)

In terms of the 2010 GLS data for Cambodia, most of the scenes are in fact from Landsat 5 as can be seen in Figure 5 below. Due to the overlap with adjacent scenes, most Landsat 7 scenes have 100% coverage (no data missing). One scene, 125-51 has a 1 pixel gap missing for 10km, but that is very minor. Overall, the 2010 GLS data is suitable for use without augmentation with other imagery.

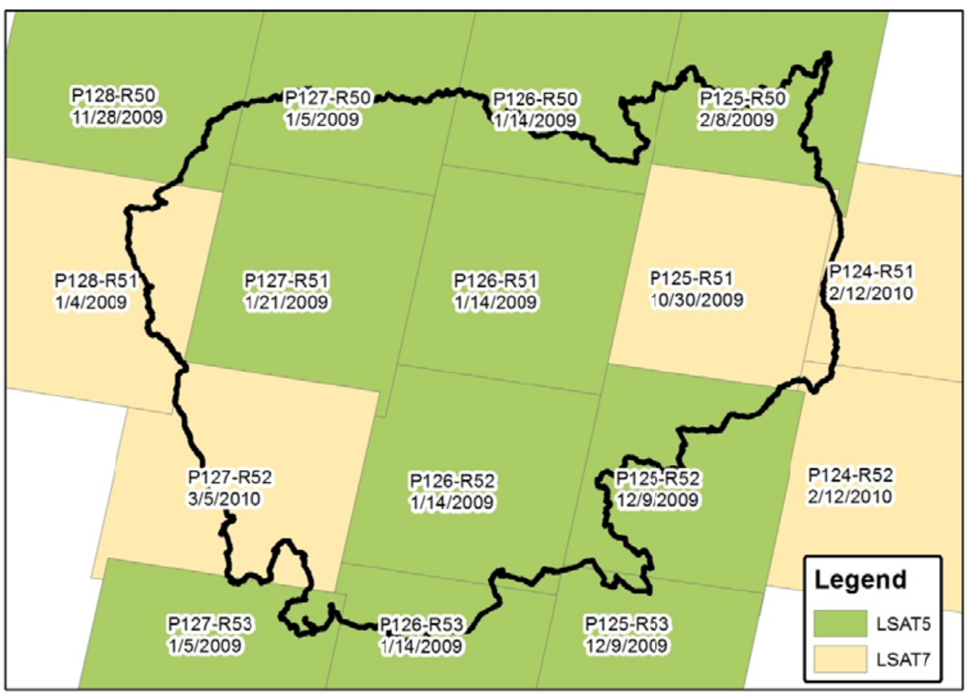

Figure 5: GLS2010 Landsat imagery indicating satellite source

Most older, medium resolution sensors, including Landsat 7 will only overpass the same location every few weeks, which will sometimes mean that the images taken in a particular dry season contain too much cloud. In these cases, the optimal image for a particular location may have to be selected from another year. This is acceptable provided that image is not too far from the target year and that calculation of the rate of change takes into account differing image dates.

For example, as shown in Figure 6 below, the difference between the oldest and newest image in the GLS2005 dataset is around 2 years. These images have been selected to minimize cloud cover to support the GLS mapping effort in 2005 and represent the best available Landsat images from around that year.

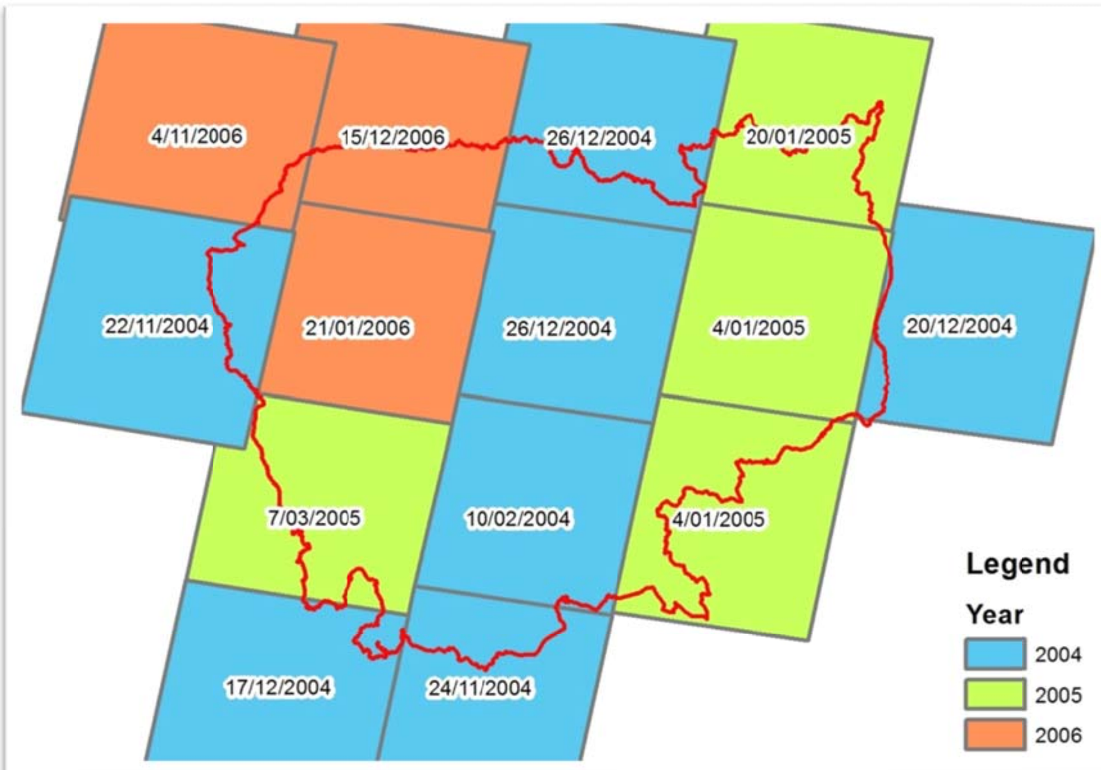

Figure 6: Dates of Landsat Images from the GLS2005 Dataset

The importance of having data within the same period of a season is related to factors such as deciduous trees being "leaf-on" or "leaf-off" and the presence of seasonal grasses. These factors can have an impact on mapping methodologies, which many need to be adapted to account for such effects. Of course, trade-offs may be necessary where there is limited choice in available imagery e.g. it might be preferable to choose and image that has low cloud cover but from a different part of the dry season compared to other images.

As noted in the GOFC-Gold Sourcebook (GOFC-Gold, 2012), “During the selection of the scenes to use in any assessment, seasonality of climate has to be considered: in situations where seasonal forest types (i.e. a distinct dry season where trees may drop their leaves) exist more than one scene should be used. Inter-annual variability has to be considered based on climatic variability.” In Cambodia, there is a distinct dry season that approximately runs from the end November to the end of May. This is the period that needs to be focused on in terms of accurately mapping of deciduous and mixed deciduous forest types. These forest types are found throughout the country, but tend to be more prevalent in the north and north east of the country (see Figure 3). In terms of selecting imagery, it would be ideal to have one image from the early dry season and one from the mid to late dry season. Some fieldwork would probably be required to understand when trees drop their leaves in different parts of the country.

The dry season is also the time when fire activity is greatest, related to land clearing as well as burning of seasonal grasses. According to the GOFC-Gold Sourcebook (GOFC-Gold, 2012), "A high temporal resolution of satellite imagery is not only important for the monitoring of the full extent of unplanned selective logging but also for mapping burned areas. The rapid vegetation re-growth on areas affected by fire can hinder the detection of burned areas". To support mapping of fire affected areas, use should be made of the MODIS Active Fire and Burned Area Products, available at http://modis-fire.umd.edu/

4.3 Cloud Cover

As indicated in Figure 7 below, Cambodia has a distinct dry season and for around three months of the year (Dec-Mar), the cloud cover percentage is on average 40-50%. Crucially during this period, there are often spells over very low cloud cover <10% over some areas.

For satellite remote sensing, cloud cover is probably the single most important factor when selecting suitable satellite imagery. The main objective is to acquire imagery with the lowest cloud cover for a particular area and a given time period. Generally speaking, the historical Landsat archives allow for complete country coverage with very low cloud cover (<10%). In cases where cloud is present, supplemental images are available for no additional cost.

Other quasi-commercial satellite systems like ALOS may also be restricted in terms of the availability of low cloud imagery. Quasi-commercial in this sense means that the satellite cannot be tasked to acquire areas and the user has to take a "wait and see" approach. In these cases, users will generally have to make compromises in quality and age of imagery. This is also an important consideration for monitoring, as discussed in a later section.

Most commercial satellite systems such as GeoEye, RapidEye, SPOT etc can be tasked to acquire imagery during a particular window e.g. December to March. The user can normally specify the amount of acceptable cloud cover. e.g. < 20%, < 10%, though often the cost is higher if a lower cloud cover percentage is specified. The success of acquiring imagery with acceptably low cloud cover often depends on the capabilities of the sensor in terms of coverage, ability to be pointed at target areas, frequency of overpass and demands placed the system by other users. For example, older generation satellites such as SPOT5 have a much lower chance of successful acquisition than do newer generation satellites such as RapidEye and SPOT6/7.

Aerial photography datasets are generally cloud free, as this is often a stipulation of the contracts under which the photography is acquired. However, as noted in a later section, most aerial photography available in Cambodia is black and white and therefore not suitable as a primary data source for forest cover mapping, especially where semi-automated approaches are used. This is due to the lack of colour or infra-red information that would allow the separation of cover types based on color tone or leaf chlorophyll.

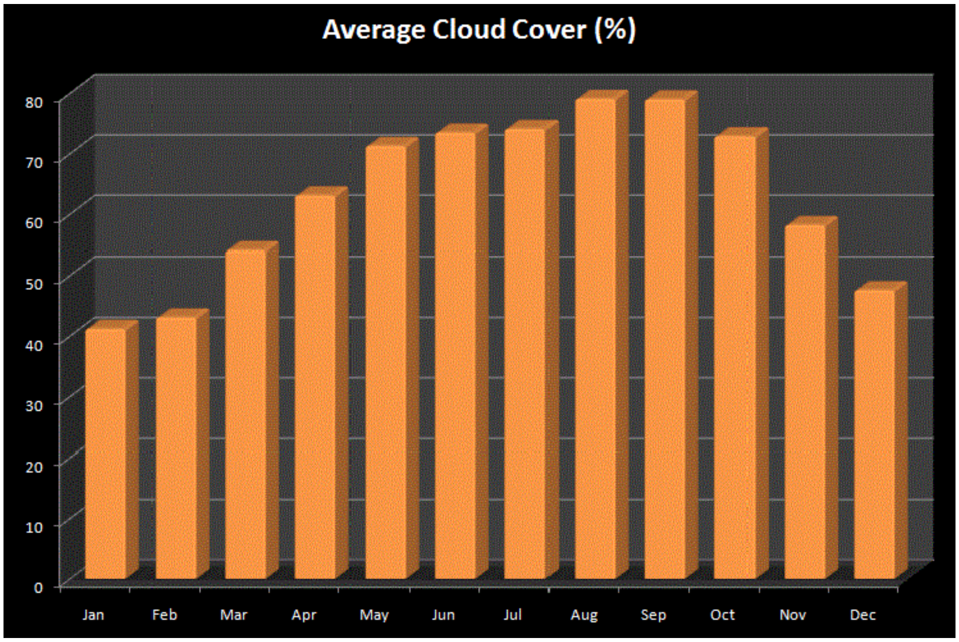

Figure 7: Cloud cover by Month over Cambodia, derived from weather satellite observations

4.4 Spatial and Spectral Resolution

4.4.1 Spatial Resolution

When it comes to spatial resolution, a trade off generally needs to be made between resolution and cost for national mapping. Using the Very High Resolution (VHR) data (0.5m) for wall to wall coverage is difficult and would result in an overwhelming volume of data for processing and very high cost. In this context, the use of VHR is best applied to support the interpretation of high resolution or medium resolution data by using it as "ground truthing" data to support the analysis. Use of VHR data is particularly useful in areas that are difficult to access in order to train classifiers and verify the outputs.

For wall-to-wall monitoring of changes in forest cover from 1990 to the present time, Landsat type (20-30m) imagery is generally considered to be acceptable. As noted in GOFC-Gold (GOFC-Gold, 2012), "In summary, Landsat-type data around year 1990, 2000, 2005 and 2010 will be the most suitable to assess historical rates and patterns of deforestation. This is not just for reasons of spatial and spectral resolution, but also for other reasons outlines in other sections of this report."

Although given fairly brief attention in the GOFC-Gold Sourcebook, the concept of a benchmark forest cover map is crucial if "up-front" stratification is being considered. Based on GOFC-Gold (GOFC-Gold, 2012), such a baseline map should be < 5 years old, which would leave two possibilities in the Cambodia context; (a) to user forest cover maps from the Forestry Administration from 2010 or (b) produce a benchmark map as part of the national REDD activities. Figure 8 below gives an example of the limitations of existing forest cover maps from the RGC, particularly in the context of stratification by carbon stocks. In any case, one needs to consider whether the classification scheme is sufficiently detailed to allow stratification by carbon stocks. In particular, the issue of selective logging and degradation is often not directly represented in the existing forest cover maps, but can have a significant impact on GHG emissions.

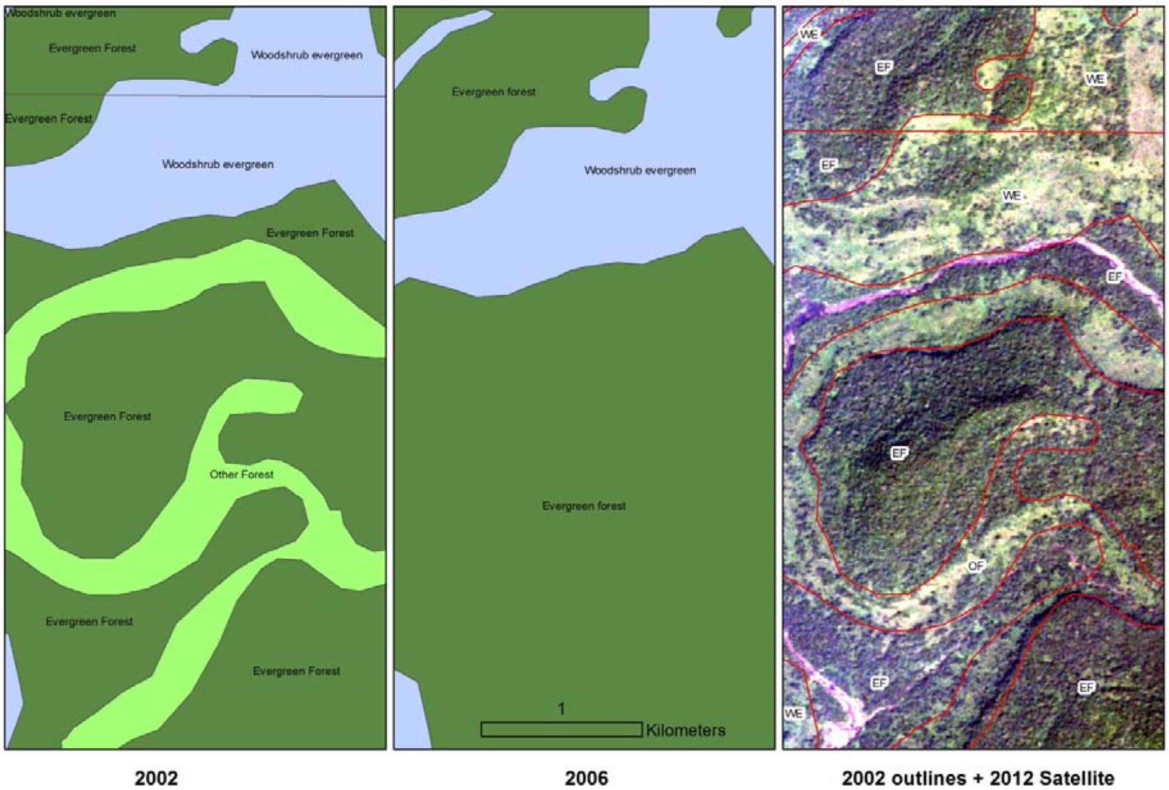

Figure 8: Example of re-classification of "Other Forest" to "Evergreen Forest" in 2006. The polygon is a mosaic of trees and shrubland with a lower density than the neighboring evergreen forest.

From Aruna's own experience, there is a significant benefit in using high resolution imagery (2.5-10m) such as RapidEye, SPOT or ALOS for baseline mapping. The main reason is that degradation by selective logging and shifting cultivation leads to highly heterogeneous landscapes that require more site-specific information to map accurately. Another reason is that canopy structure can be more readily represented with smaller pixels, which is important in discerning the forest/non-forest cut-off in relation to canopy cover. Using high resolution imagery allows the interpreter to better segment imagery, train the classifier and verify the results. Generally speaking, there is a benefit to using 5m imagery over 10m imagery as the canopy structure can be more readily represented with smaller pixels. This will become particularly important in discerning the forest/non-forest cut-off in relation to canopy cover. See Figure 9 below.

Figure 9: 10m ALOS/AVNIR-2 (Left) and 5m RapidEye (Right). Note that it is easier to discern areas of low canopy woodland in the image on the right.

4.4.2 Spectral Resolution

In terms of spectral resolution, it is highly desirable to have imagery with bands in both the visible and near infra-red spectrum. An infra-red channel allows mapping of differences in chlorophyll and the calculation of indices such as NDVI. For example, Spectral Mixture Analysis (SMA) a technique for mapping mixtures of different land cover types, especially degraded areas, "...requires at least four spectral bands placed in spectral regions that contrast the end-members spectral signatures" (GOFC-Gold, 2012). Most satellite imagery comes with an infra-red channel, the exception being some VHR imagery which is sometimes delivered with visible bands only.

The mid-infrared channels in Landsat imagery are also useful, particularly where canopy cover is less as it allows mapping of information such as soil moisture and by extension, the associated forest ecosystem. These channels should be included in any automated classification work. It should be noted that some of the imagery identified by this project is panchromatic or pan-sharpened natural color (no Infra-red channel). This imagery is less suited for automated classification, but is still of some use for training and verification.

Some HR and VHR sensors also come with narrow spectrum bands that allow mapping of specific phenomena. Studies by Bindel, M., et. Al. (2011) and Shuster, C., Förster, M. and Kleinschmit, B., (2012) have shown that the inclusion of a red-edge channels in automated classification can lead to higher classification accuracy. However, the improvements can be for some classes in some forest types, so "across the board" improvements are not necessarily to be expected. Red edge information is often used to detect differences caused by factors such as stress and the impact on chlorophyll so might have some utility in more accurately mapping deciduous or semi-deciduous forests in the dry season on Cambodia. Further investigation into this issue is recommended

Sensor	Band Name	Spectrum	Application
RapidEye	Red Edge	690 – 730 nm	More sensitive mapping of Chlorophyll
World View-2	Yellow Band	585 - 625 nm	Used to identify "yellowness" characteristics of targets, important for vegetation applications.
World View-2	Red Edge Band	705 - 745 nm	Aids in the analysis of vegetative condition. Directly related to plant health revealed through chlorophyll production.

Table 4: Examples of some narrow image bands and their specific benefits to vegetation mapping

4.5 Image Registration

Image registration is vitally important for projects where multiple dates and imagery sources are involved. A mis-registration of even one pixel can cause false change to be detected. The process of image registration involves taking the raw imagery and ortho-rectifying using ground control points, satellite rational function coefficients and a Digital Elevation Model (DEM). The use of rational function coefficients, supplied by the satellite operator will mean that a more rigorous correction can be calculated, with fewer ground control points.

Most satellite operators offer imagery at various levels of processing from un-corrected to fully ortho-rectified. Furthermore, each operator has different production processes, software and Ground Control Point (GCP) databases, meaning that the accuracy of the supplied product will vary. The most significant source of difference is whether the operator has used highly accurate ground control points, especially for HR and VHR imagery. For Cambodia, these GCPs are often not available to commercial satellite operators, so it is preferable to obtain the unprocessed data and process it with GCPs collected in the field or from other local sources. Any ortho-rectification done in country should use image processing software that support rational function modeling, ground control points and a DEM.

The general exception to this statement is the Landsat collection, most of which has been ortho-rectified to the same standard to produce their L1T product, which can be used without further processing. In fact, further processing would be fairly difficult, since this imagery already has a sub-pixel accuracy (< 30m).

4.6 Synthetic Aperture Radar Imagery

For a variety of reasons, most of the focus on baseline and historical mapping for REDD is focused on optical satellite sensors. This is and continues to be a suitable approach, particularly in a country like Cambodia, where cloud free or near cloud free conditions are encountered in the dry season. However there is a growing interest and focus on Synthetic Aperture Radar Imagery for forest monitoring. To quote from the GOFC-Gold Sourcebook (GOFC-Gold, 2012):

“Optical mid-resolution data have been the primary tool for deforestation monitoring. Other, newer, types of sensors, e.g. Radar (ERS1/2 SAR, JERS-1, ENVISAT-ASAR and ALOS PALSAR) and Lidar, are potentially useful and appropriate. Radar, in particular, alleviates the substantial limitations of optical data in persistently cloudy parts of the tropics. Data from Lidar and Radar have been demonstrated to be useful in project studies, but so far, they are not widely used operationally for forest monitoring over large areas. Over the next five years or so, the utility of radar may be enhanced depending on data acquisition, access and scientific developments."

Although numerous SAR systems are currently active (see Table 5), the GOFC-GOLD Sourcebook (GOFC-Gold, 2012) gives considerable attention to ALOS/PALSAR. This is due to a number of factors, particularly the sensor a having longer wavelength L-Band sensor (allowing deeper penetration into forest canopies) and also a collection strategy that aims to collect wall to wall coverage at least once a year for all of the world's land masses. Although the ALOS program is designed to continue to last "at least 10 years" the first satellite, ALOS-1 suffered a malfunction in March 2011. The second satellite ALOS-2 is scheduled for launch in 2013 which should provide continuity for future forest cover monitoring needs.

One final comment on SAR imagery is that it often requires specialized software to process and analyze and also a high level of specialization by the person(s) conducting the analysis. Such software and skills are often lacking in developing countries, including Cambodia compared to more traditional analyses tools and methods based on optical imagery.

Current Satellites/sensors	Nation (s)	Period of Operation	Band	Polarization	Spatial Resolution (m)	Orbital Repeat (days)
ERS-1	Europe	1991-2000	C	Single (VV)	26	3-176
JERS-1	Japan	1992-1998	L	Single (HH)	18	44
ERS-2	Europe	1995-	C	Single (VV)	26	35
RADARSAT 1	Canada	1995-	C	Single (HH)	8-100	3-24
Envisat/ASAR	Europe	2002-	C	Single, Dual	30-1000	35
ALOS/PALSAR	Japan	2006-	L	Single, Dual, Quad	10-100	46
RADARSAT 2	Canada	2007-	C	Single, Dual, Quad	3-100	24
TerraSAR-X	Germany	2007-	X	Single, Dual, Quad	1-16	11
COSMO- SkyMed	Italy	2007-	X	Single, Dual Interferometric	1-100	16

Table 5: Summary of current and planned spaceborne synthetic aperture radar (SAR) sensors and their characteristics. Source: GOFC-Gold Sourcebook (GOFC-Gold, 2012)

4.7 Forest Definition Aspects

For estimation of deforestation, it is of course important to first define forest vs. non-forest, something that each country is required to define through their Designated National Authority (DNA). According to the GOFC-Gold Sourcebook (GOFC-Gold, 2012):

"For the purpose of the Kyoto Protocol, Parties should select a single value of crown area, tree height and area to define forests within their national boundaries. Selection must be from within the following ranges, with the understanding that young stands that have not yet reached the necessary cover or height are included as forest:

- Minimum forest area: 0.05 to 1 ha
- Potential to reach a minimum height at maturity *in situ* of 2-5 m
- Minimum tree crown cover (or equivalent stocking level): 10 to 30 % "

In terms of the satellite imagery being able to support this, the general premise is that any analysis can adapt to different tree crown cover and minimum forest area thresholds. In order to support any mapping process, it is of course necessary to confirm by conducting fieldwork and/or examining VHR imagery that the appropriate tree crown cover threshold is being mapping.

Ideally, a decision on the definition of forest would be agreed prior to any mapping commencing, but in practice this may not be possible as it is not a straightforward decision to make. Nonetheless, mapping activities can certainly start ahead of a decision on forest decision being finalized, perhaps with a working definition, though of course this may mean that the mapping of some classes needs to be revised at a later point in time.

5 Forest Degradation

One of the most challenging technical aspects of forest carbon assessment for REDD is monitoring of degradation with the resultant reduction in carbon stocks. Direct detection can consist of either 1) identifying and mapping forest canopy damage (gaps and clearings) or 2) mapping the combined i.e., integrated are of forest canopy damage, intact forest and regeneration patches. The former approach would rely more heavily on fine (<5m) imagery, while the latter approach would require medium (10-60m) imagery and would also require field sample measurements (GOFC-Gold, 2012). In cases of low intensity or selective logging, it is noted that high resolution such as RapidEye is required due to the minor visible damage of unplanned selective logging (GOFC-Gold, 2012). Due to a daily overpass frequency, RapdiEye has also been demonstrated to address the requirement for frequent (at least annual) monitoring (Franke et al., 2012).

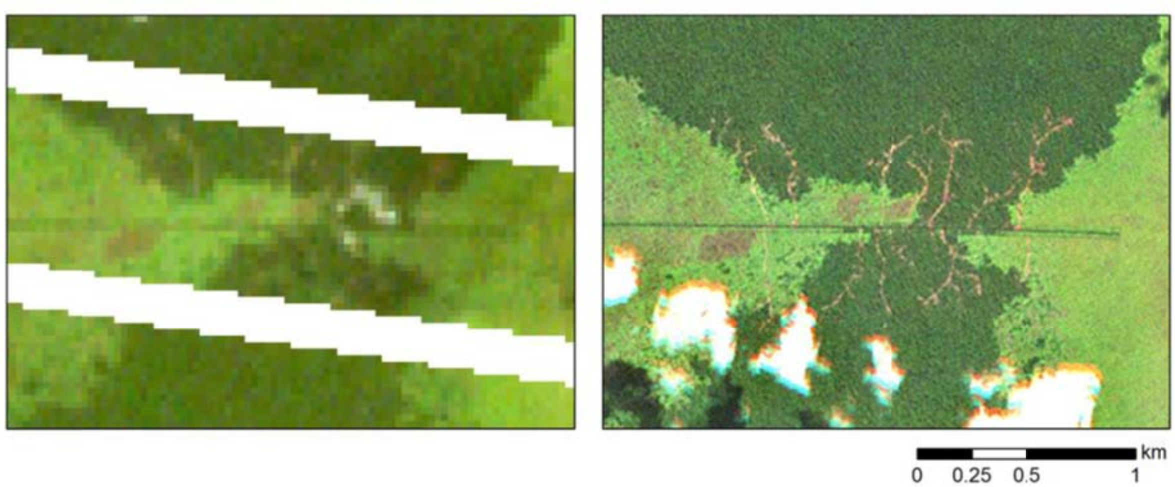

Figure 10: True color Landsat (left) and RapidEye (right) scenes acquired on 22 May 2009 within an unplanned selectively logged peat swamp forest in Central Kalimantan on Borneo. Source (GOFC-Gold, 2012)

In Aruna's own experience, we have successfully demonstrated to the World Bank SUFORD project that RapidEyeor similar resolution imagery is very well suited to mapping the combined area of forest damage in Laos. In fact, Aruna were able to successfully identify individual trees that were cut within these logging areas using visual interpretation. Further work with object-oriented image classification techniques and Spectral Mixture Analysis (SMA) is recommended to investigate the degree to which RapidEye imagery is suited to directly mapping forest canopy damage.

In Cambodia, although formal timber concessions were cancelled in 2002, there is considered to be widespread illegal or quasi-legal sourcing of timber for both the domestic market and for export (Blackett, 2008). These activities are likely to be highly dispersed and at relatively low intensity given the often illegal nature of these activities, therefore high resolution imagery is likely to be required if direct detection is to be successful.

The issue of forest degradation (the second 'D' in 'REDD') is critical for Cambodia. Forest degradation takes a number of forms, ranging from selective logging to damage from local people collecting firewood, structural timber for housing and non-timber forest product s (NTFP). A significant form in terms of removal of forest carbon stock is that of selective logging. Large mature trees comprise a large percentage of the forest carbon stocks within mature forest, their removal affects carbon stocks, but the change is much more difficult to detect because the surrounding trees remain in place. Lower resolution imagery such as Landsat will not be able to detect selective logging, whereas High resolution imagery could provide assistance in detection. The detection of degradation will be necessary to properly account for changes in carbon stocks over time. This issue is well understood in Lao PDR and Vietnam, both of whom have selected High resolution imagery as the basis for their Benchmark Forest Maps and are either using or expect to use it for ongoing monitoring on an annual or semi-annual basis. Given the benefits of compatibility with neighbouring countries for implementation of REDD, this is another consideration to select a higher quality and resolution basis for the Benchmark Forest Map and for ongoing monitoring.

6 Assessment of Possible Additional Data

In summary and generally speaking, there exists good quality historical imagery (mostly Landsat) and complete coverage of ALOS in 2010 that would be suitable for baseline mapping at the national level. Although the Landsat imagery is freely accessible, ALOS data is under license, which might mean it cannot be used outside of FA without paying additional license fees to the satellite operator (JAXA).

As previously noted, mapping of medium resolution imagery such as Landsat and ALOS requires a certain amount of field verification and checks against VHR satellite imagery, particularly in remote areas. Focusing on the 2010 ALOS baseline imagery, it is noted that some 2.5m Panchromatic PRISM data has already been acquired over some parts of the country, though not widely spread.

Considering the use of even higher resolution imagery (0.5 – 1m), one of the constraints is the availability of data for the target year (2010). Figure 11 below shows available imagery for the period 01-Dec-2009 to 30-Jan-2011.

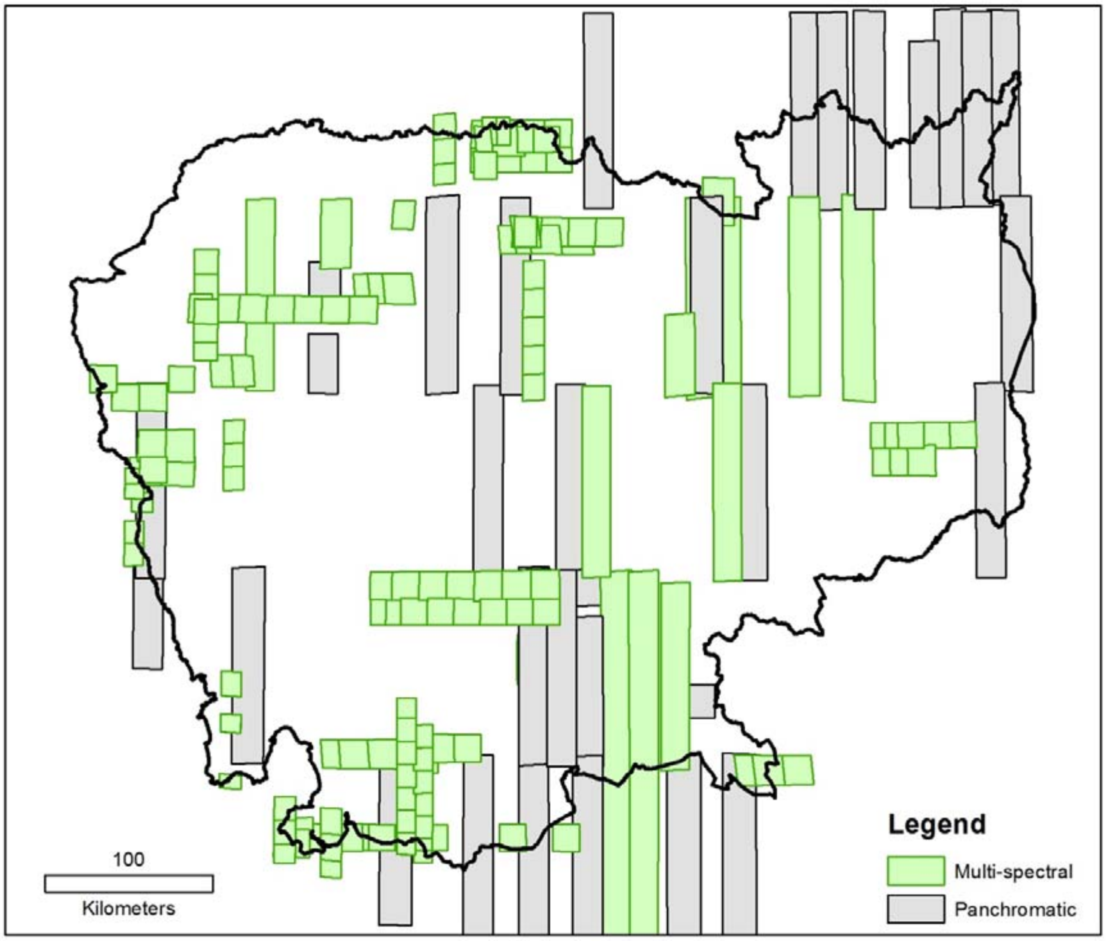

Figure 11: Coverage of VHR Imagery in Cambodia, 2010

As can be seen the figure above, there exists quite considerable VHR satellite imagery in the year 2010, though much of it is panchromatic. Nonetheless, panchromatic imagery is still useful in calculating canopy cover. This imagery comes from five different satellites, all of which are now owned by Digital Globe (Quickbird, WorldView-1, WorldView-2, IKONOS, and GeoEye-1). The imagery can be ordered in small blocks, with the minimum order being 25 sq km.

In terms of cost of acquiring this data, commercial pricing for ortho-ready (not yet ortho-rectified) imagery is as follows;

- $14/sq km x 25 sq km = $350

So for example, if one wanted to acquire archive imagery for 30 sites, the total cost would be $10,500.

Table 6 and Figure 12**Error! Reference source not found.** below show commercial pricing for archive imagery some common commercial satellite sensors. The main purposes of these figures is to illustrate the sharp increase in price as resolution decreases and the trade-offs that might need to be made in cost vs. coverage. For wall to wall cover for monitoring purposes, it needs to be considered whether the cost of very high resolution is prohibitive or not (notwithstanding that it would not be practically possible to cover the entire country within a single imaging season). For example, RapidEye imagery, which has already been noted to be well suited in terms of spatial resolution and temporal frequency would cost; 181,000 (country area) x $1.28 (single user license) = $231,680

Archive Price	Resolution (m)	Price	Area	$/km2
SPOT4 XS, 20m	20	$ 2,100	3500	$ 0.60
SPOT5 XS, 10m	10	$ 3,050	3500	$ 0.87
TH-1, 10m	10	$ 1,725	3500	$ 0.49
ALOS, 10m	10	$ 248	3500	$ 0.07
SPOT5 Color, 5m	5	$ 6,150	3500	$ 1.76
RapidEye, 6.5m	6.5			$ 1.28
SPOT5 Color, 2.5m	2.5	$ 8,800	3500	$ 2.51
SPOT6, 1.5m	1.5			$ 4.94
VHR, > 6 months old	0.5			$ 14.00

Table 6: Commercial Pricing for archive imagery some common sensors (single user license)

For further reference, a list of commercial satellite companies and the satellites they operate are listed below.

No	Company Name	Satellites
1	Astrium	Spot4, Spot5, Pleiades, FORMOSAT-2, DEMIOS-1, TerraSAR-X,
2	RapidEye	RapidEye Constellation (5)
3	Digital Globe	Quickbird, WorldView-1, WorldView-2, GeoEye-1, IKONOS
4	GISTDA	Theos
5	Indian Space Research Organization	11 operational satellites
6	JAXA	ALOS (Non-operational)
7	USGS	Aster
8	European Space Agency	ERS-1 (non-operational), ERS-2
9	Canadian Space Agency	Radarsat-1, Radarsat-2

Table 7: List of Commercial Satellite Operators and Systems Relevant to Forestry Applications

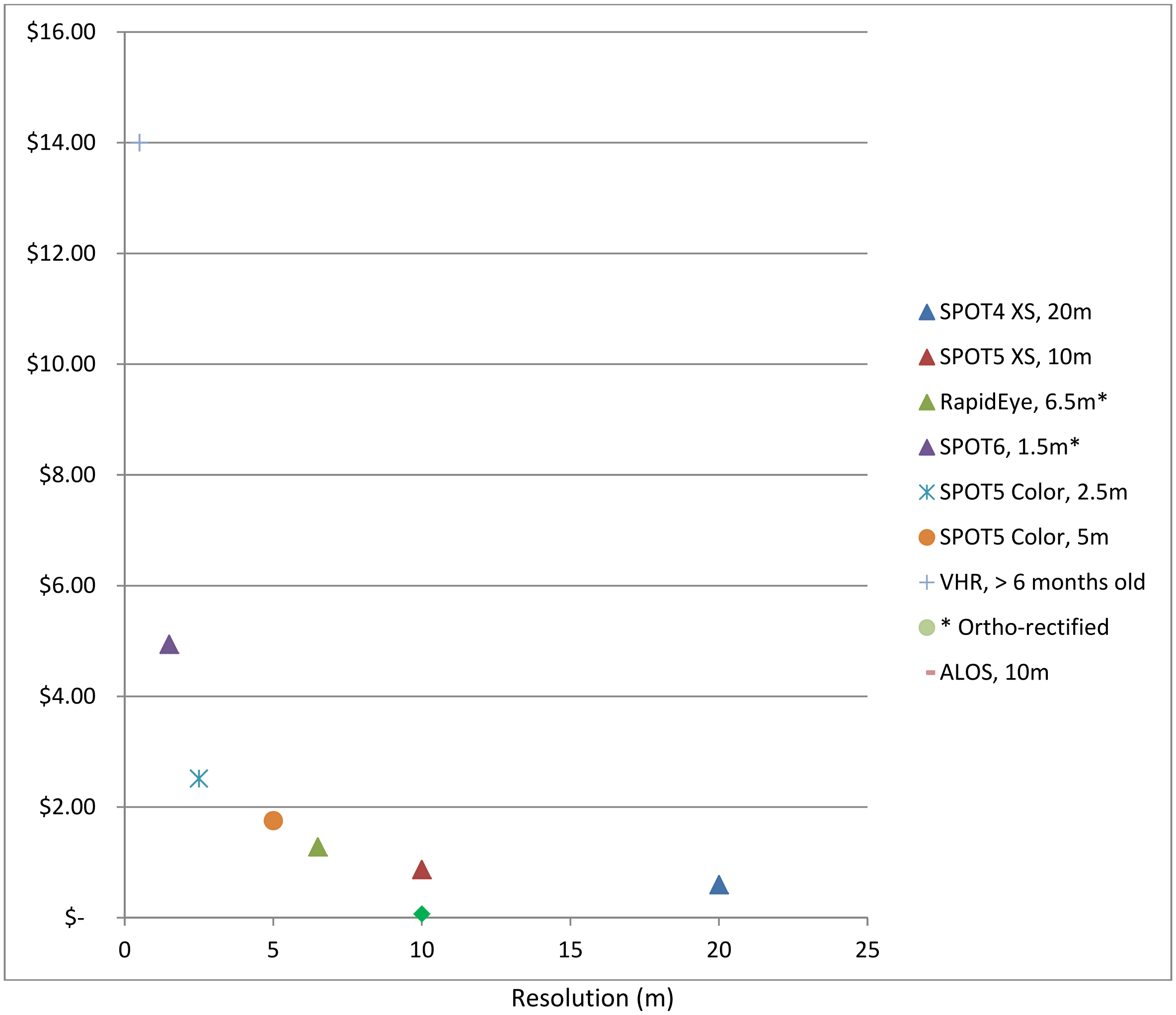

Figure 12: Graph of commercial pricing for archive imagery (USD per sq km)

Apart from new acquisitions, some commercial companies allow licenses to be upgraded from single user to multi-user if a fee is paid. The fees vary from company to company and may depend on the number of additional users added to the license. For example the RapidEye pricing structure for additional users is as follows;

Single User License	0% uplift
Multi-user License (2 – 5 users)	30% uplift
Enterprise User License (6 – 10 users)	50% uplift
Expanded License	custom quote
Government Licenses	custom quote

Normally, license upgrades need the agreement of the original licensee. The list of organizations which hold RapidEye imagery is provided in Table 3 and the maps are provided in Annex 7.

7 Key Recommendations

The establishment of the National Forest Monitoring System requires the compilation of all available and accessible aerial photography and satellite imagery. "Available" in this context refers to imagery that is freely accessible or has already been purchased by an organization. "Accessible" in this context, means that the data is freely accessible or the particular license conditions allow access by the institution with the mandate for implementing the Satellite Forest Monitoring System. Early efforts should concentrate on obtaining as much of the readily accessible data as possible.

Additionally, there exist vast holdings of satellite imagery by commercial providers and the capacity for collection of new images is similarly large and growing by these commercial providers. In terms of obtaining data that may incur a license upgrade by the existing holder or outright purchase, more attention needs to be given as to the benefit provided by acquiring such imagery and whether the investment is justified. Such decisions hinge on the intended use of the imagery e.g. wall-to-wall coverage or for verification of lower resolution data and the desired level of accuracy and detail in the mapping.

These recommendations pertain to the acquisition of data as a starting point for UN-REDD activities in Cambodia.

Recommendation 1. Check the positioning accuracy of all imagery obtained to determine if the imagery meets the accuracy standard at the scale of intended use. If necessary, apply additional corrections to align with existing image data. Having imagery with consistent geo-referencing is fundamental for monitoring activities.

Recommendation 2. Identify additional Landsat imagery in the main archive (http://earthexplorer.usgs.gov/) to assist in the accurate mapping of deciduous forest areas. Existing GLS data may not always be from an ideal time of year for some areas. Download and ortho-rectify the imagery to match the Landsat GLS data.

Recommendation 3. A decision needs to be made as to what imagery should be used for monitoring going forward. In situations of selective logging and low intensity degradation that is found in Cambodia, GOFC-Gold (GOFC-Gold, 2012) indicates Landsat-type imagery not suitable. RapidEye imagery, though costly, is being used successfully in Laos, partly because it is one of the few sensors that has the capacity to provide coverage of large areas within a single season.

Recommendation 4. Obtain or seek to obtain, aerial photo and satellite image data identified in this report, respecting the relevant license conditions. Suggested approaches by data Category are as follows;

Category 1 data. Most Category 1 data has been acquired and delivered with this report. However, some datasets were not obtained in time and the organizations who hold them should be contacted to request that data be shared with UN-REDD. These datasets are identified in Table 3.

Category 2 data. This includes all of the aerial photography held by the various agencies of the Cambodian government. Obtaining agreement is likely to be a lengthy process and may involve some costs. It is recommend that the agency responsible for the satellite land monitoring system and the UN-REDD programme first attempt to obtain all data without charge, but if this is unsuccessful to identify priority areas and datasets and negotiate to obtain those from the relevant agency.

Category 3 data. Since some of these datasets are of urban or cropping areas, it is recommend that datasets of interest to UN-REDD and the organization holding that data be contacted, seeking inclusion in the existing license agreement. It is likely that the license holder is not fully aware of the license conditions and these should be clearly communicated to them.

Category 4 data. This includes data held under a single user license agreement, but by an agency that is participating in UN-REDD and for which the license is relevant for access for that purpose. It is recommend that these agencies be contacted within the context of the existing formal agreements with the FAO, seeking to obtain these data for the purposes of UN-REDD.

Category 5 data. This is data that can only be obtained by commercial purchase, including upgrading of existing licensing from a single to multi-user license. It is recommend that the UN-REDD identify priority datasets and weigh the cost-benefit of obtaining the data, either by upgrade or outright purchase. License upgrades are less costly than outright purchase, typically in the order of 30-50% of the original purchase price. License upgrades would usually require the agreement of the existing license holder.

Recommendation 5. Establish procedures and standard operating procedures (SOPs) to obtain, process and incorporate satellite imagery from free sources. These sources include USGS (Landsat, MODIS) and ESA (Sentinel). This will ensure that data products are on hand in the required format and standard for possible mapping and analysis activities.

Recommendation 6. Establish links with organizations or agencies that have ongoing programs to acquire commercial satellite imagery and seek to obtain access to the data at no cost (if allowed by the license) or by paying a license uplift fee. Decisions on whether to acquire particular datasets can be made on a case by case basis.

Recommendation 7. Consider “background tasking” of commercial satellites in years when national forest cover mapping in planned. Some satellite operators will direct any spare capacity they have to an area of interest but without an obligation to purchase the imagery. In particular, it might be considered to background task the DEIMOS or DMC satellites to acquire imagery in the dry season as a possible compliment to Landsat imagery. If any gaps in coverage of Landsat imagery exist in a given year, then they can be filled with this imagery.

Recommendation 8. Establish a data portal website listing free data available from the National Forest Monitoring System and data held by others but subject to license conditions. Ideally index maps would be provided to allow visitors to assess the coverage and quality of the data. Such a portal will foster data exchange between parties involved in mapping from satellite imagery and provide access to those who may not have the tools and knowledge to acquire and process data themselves.

8 References

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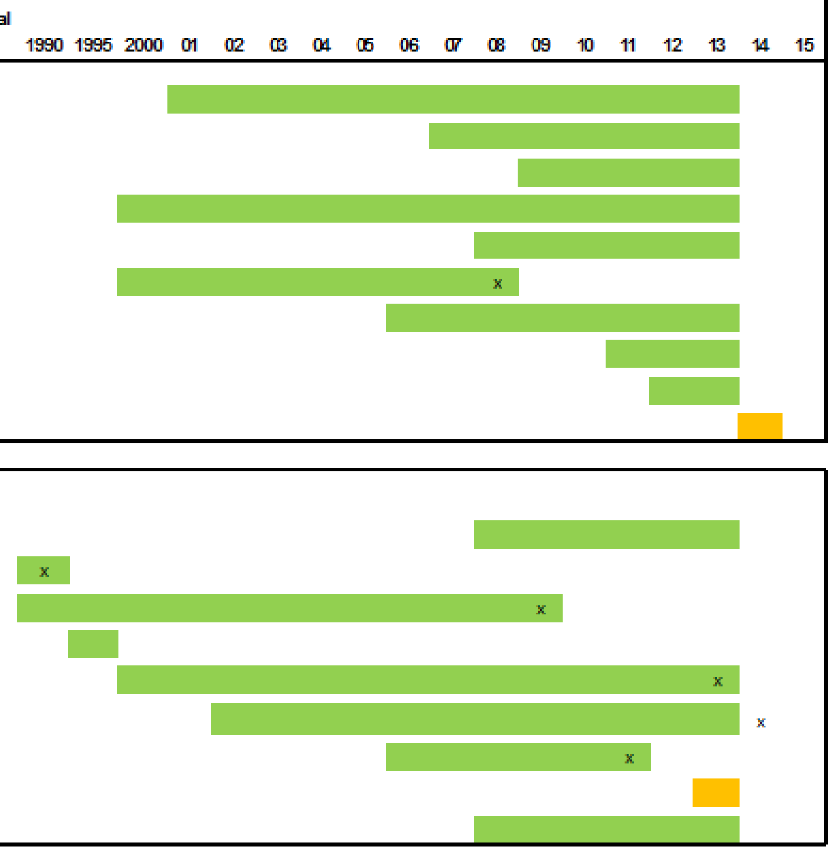
Annex 1 - List of Common Optical Satellite Imaging Sensors

	Launch	Ended	Panchromatic Resolution	Multi-Spectral Resolution
Very High Resolution				
Quickbird	18-Oct-01	Active	0.6m	2.4m
WV-1	17-Sep-07	Active	0.5m	NA
WV-2	8-Oct-09	Active	0.5m	1.8m
IKONOS	24-Sep-99	Active	1m	1m
GeoEye-1	6-Sep-08	Active	0.5m	0.5m
Kompsat-1	21-Dec-99	6-Jan-08	NA	6.6m
Kompsat-2	28-Jul-06	Active	1m	5m
Pléiades 1 & 2	17-Dec-11	Active	0.75m	?
SPOT6	9-Sep-12	Active	1.5m	8m
SPOT7	Planned	NA	1.5m	8m
High Resolution				
RapidEye	29-Aug-08	Active	NA	6.5m
SPOT1	22-Feb-86	31-Dec-90	10m	20m
SPOT2	22-Jan-90	1-Jul-09	10m	20m
SPOT3	26-Sep-93	14-Nov-97	10m	20m
SPOT4	24-Mar-98	11-Jan-13	10m	20m
SPOT5	4-May-02	Active[3]	2.5m	10m
ALOS-1	24-Jan-06	22-Apr-11	2.5m	10m
ALOS -2	Planned	NA	1-3m and 3-10m	
THAICHOTE	1-Oct-08	Active	2m	15m



Medium Resolution				
Landsat 5	1-Mar-84	Active[1]	NA	30m
Landsat 7	15-Apr-99	Active[2]	15m	30m
Landsat 8	11-Feb-13	Active	15m	30m
DEIMOS-1	29-Jul-09	Active	NA	22m
RESOURCESAT-1	17-Oct-03	Active	5.8m	23.5m
RESOURCESAT-2	20-Apr-11	Active	5.8m	23.5m & 56m
UK-DMC2	29-Jul-09	Active	NA	22 & 32m
Aster	18-Dec-99	Active	NA	15m,30m,90m

1 - On 26-Nov-2005, Lansat 5 began to suffer power problems and imaging is now sporadic
2 - On 31-May-2003, Landsat 7 suffered a failure of the scan line corrector (SLC) and image since that date contains missing data
3 - Expected to be retired in 2014

Annex 2 - List of Organizations identified under the present project.

Organization	Contact Name	Email 1	Status	Contact Name 2	8.1.1.1 Email 2
WCS	Phien Sayon	psayon@wcs.org	Check with data provided	Tom Clements	tclements@wcs.org
GERES	Sovann PREY	s.prey@geres.eu	Responded affirmative, sent shape template	Mathieu Ruillet	m.ruillet@geres.eu
PACT	Julien Brewster	jbrewster@pactworld.org	Check with data provided		
Conservation International	Bunra Seng	b.seng@conservation.org	Check with data provided	Tracy Farrell	tfarrell@conservation.org
WWF	Keavuth Huy	keavuth.huy@wwfgreatermekong.org	Check with data provided	Thibault Ledecq	thibault.ledecq@wwfgreatermekong.org
FFI	Matthew Maltby	Matthew.Maltby@fauna-flora.org	Check with data provided	Yeang Donal	yeangdonal@gmail.com
Save Cambodia's Wildlife	Sina Brod	sina@cambodiaswildlife.org	Emailed	Rebeca Sandoval	
Winrock/LEAF	Dr. Sarah M. Walker	SWalker@winrock.org	Emailed	Chris Kopp	CKopp@winrock.org
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Wildlife Alliance	Mr Romica Grosu	romicagrosu@gmail.com	Emailed	Suwanna Gauntlett	suwanna@online.com.kh
Mekong River Commission	Mr. Heng Suthy		Emailed		mrcs@mrcmekong.org
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JAFTA					
Birdlife		vorsak@birdlifecambodia.org	Emailed		
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independent consultant	David Aswell	ashwell@online.com.kh	No data (confirmed)		
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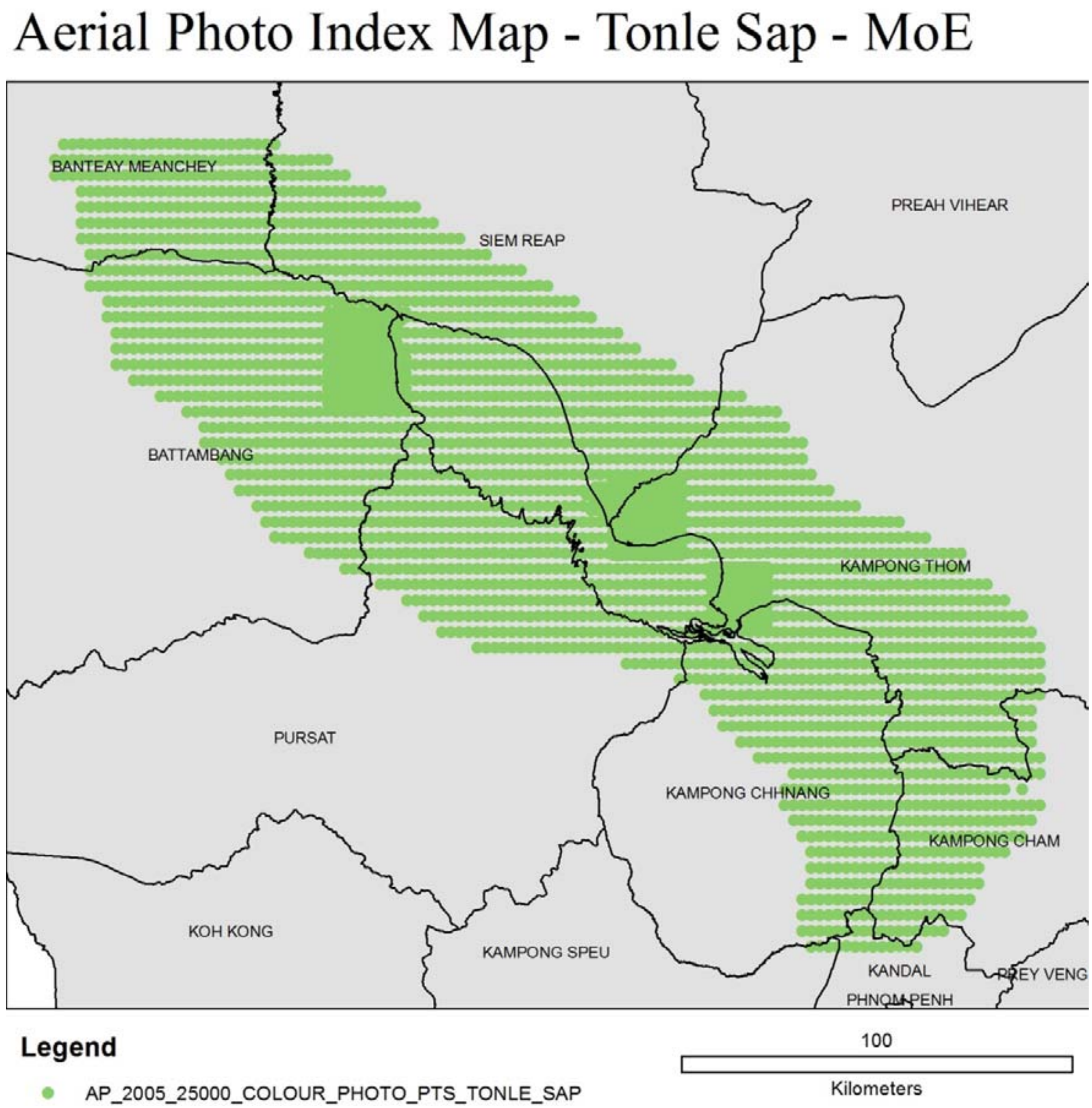
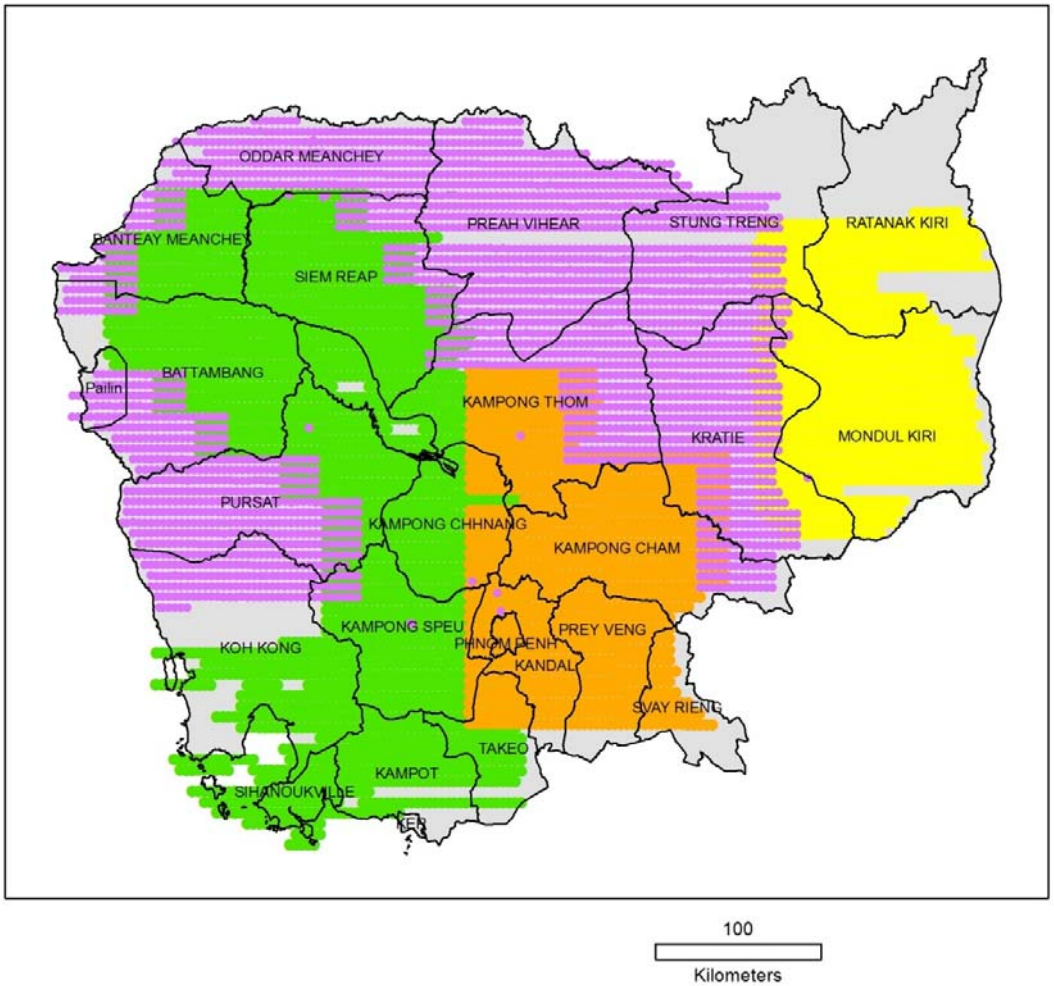
EC	Koen Everaert	Koen.EVERAERT@eeas.europa.eu	Emailed		
AFD	Moung Sideth	muongs@afd.fr	Emailed		
USAid	Brad Arsenault	barsenault@usaid.gov	No data (confirmed)		mkim@usaid.gov
Private Sector					
Indochine Mining	Ross Hill	rhill@indochinemining.com	Responded affrimative		
Renaissance Minerals	Jon Poulsen	Jon.Poulsen@rnscambodia.com	Responded affirmative, will compile		
Angkor Gold	John-Paul Dau	jp@angkorgold.ca	Emailed		

Sakari Resources	Darragh O'connor	doconnor@pttapm.com	Emailed		
Egogen	Valerie Sobotta	valerie@koosolaw.com	Responded affrimative		
Finnmap	Teemu jantunen	teemu.jantunen@finnmap.com	No data (confirmed)		
Satellite Companies					
SPOT Asia	Mr Foo Weng Kee		Responded, cannot provide		
Digital Globe/GeoEye	Ms Yvonne Uu		Responded, cannot provide		
GISTDA	Chinta	chinta@userservice.gistda.or.th	Emailed		
Restec	Mr Kuwahara Katsuya	kuwahara.katsuya@restec.or.jp	Emailed		

Annex 3 – Aerial Photo Coverage Maps (Category 2 Data)



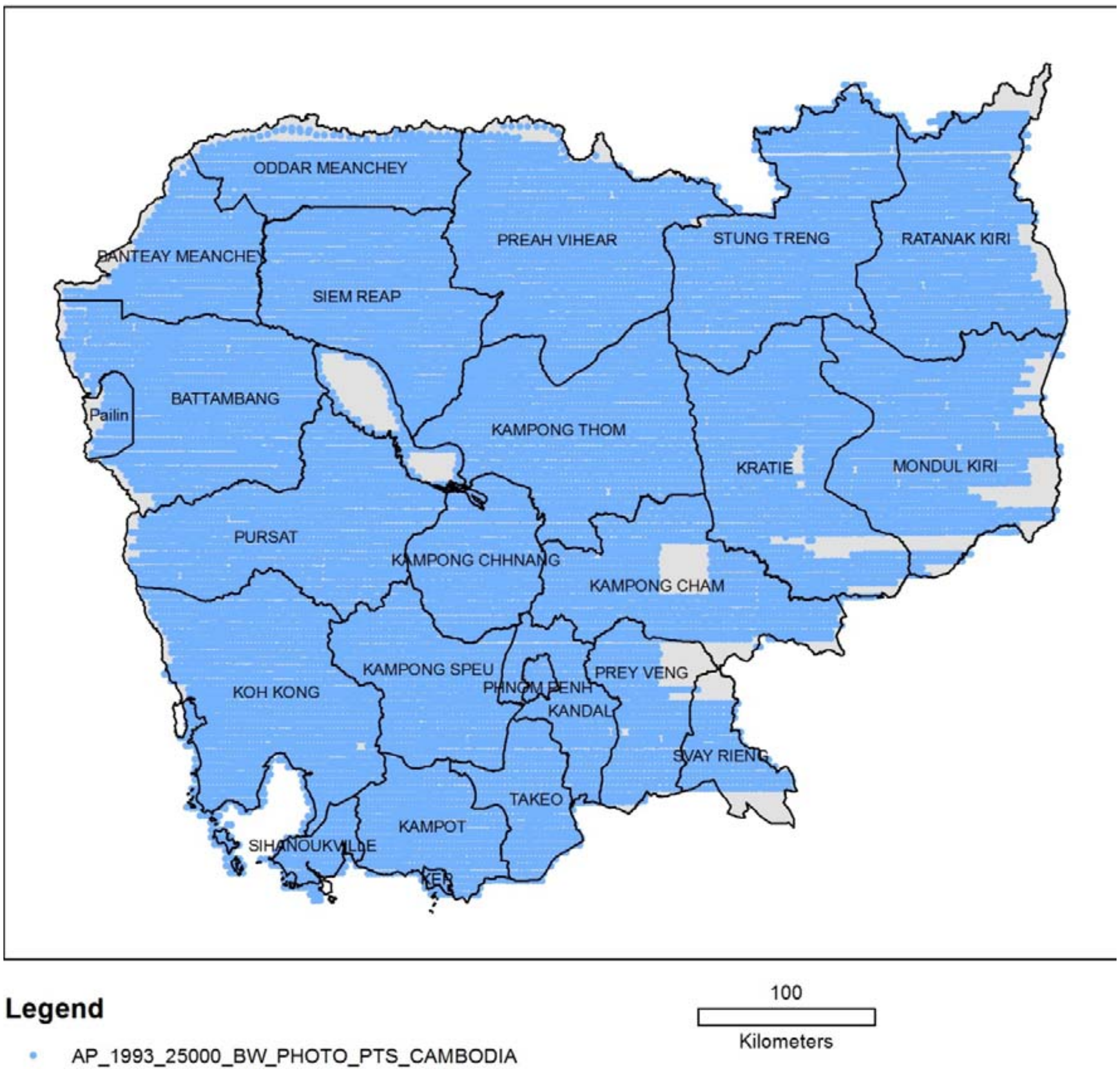
Aerial Photo Index Map - 1:40,000 - MLMUPC



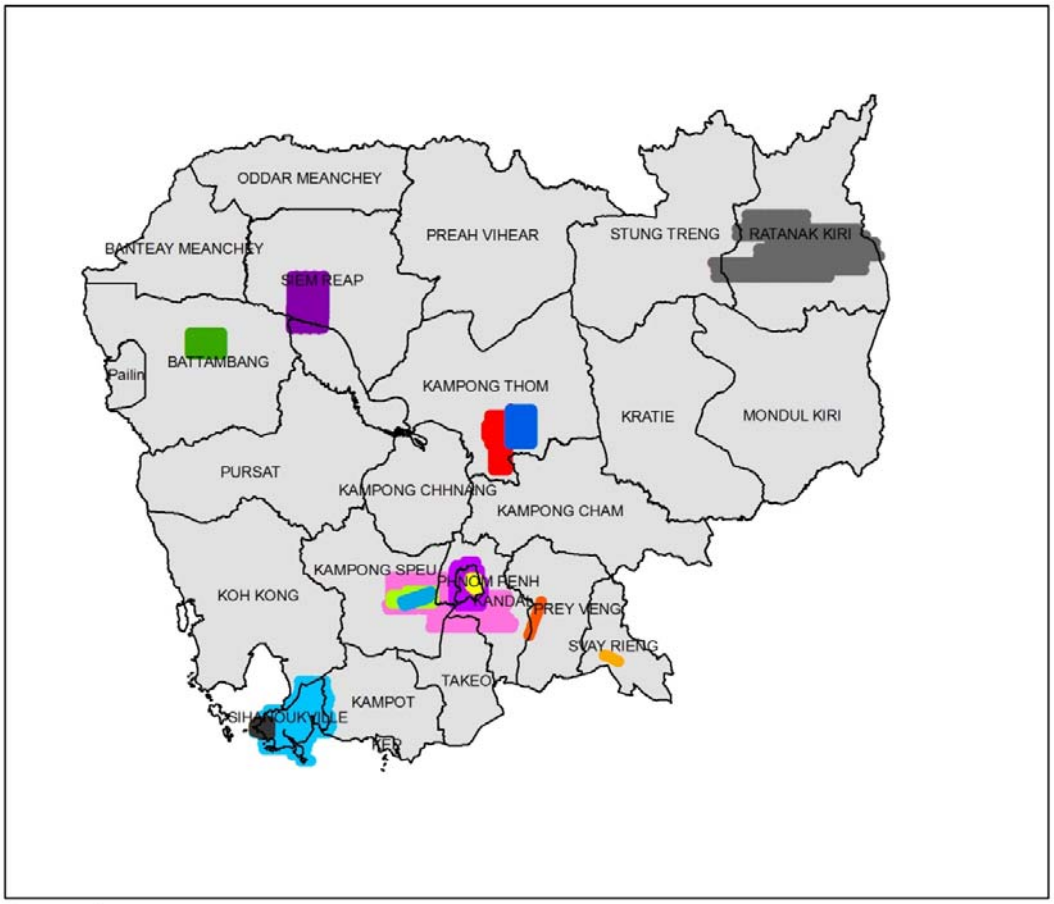
Legend

- AP_2001_40000_BW_PHOTO_PTS_JICA
- AP_2004_40000_BW_PHOTO_PTS_CENTRAL_CAMBODIA_MLMUPC
- AP_2004_40000_BW_PHOTO_PTS_EASTERN_CAMBODIA_MLMUPC
- AP_2005_40000_BW_PHOTO_PTS_CCDP

Aerial Photo Index Map - 1:25,000 - MLMUPC



Aerial Photo Index Map - Various - 2001 - 2005



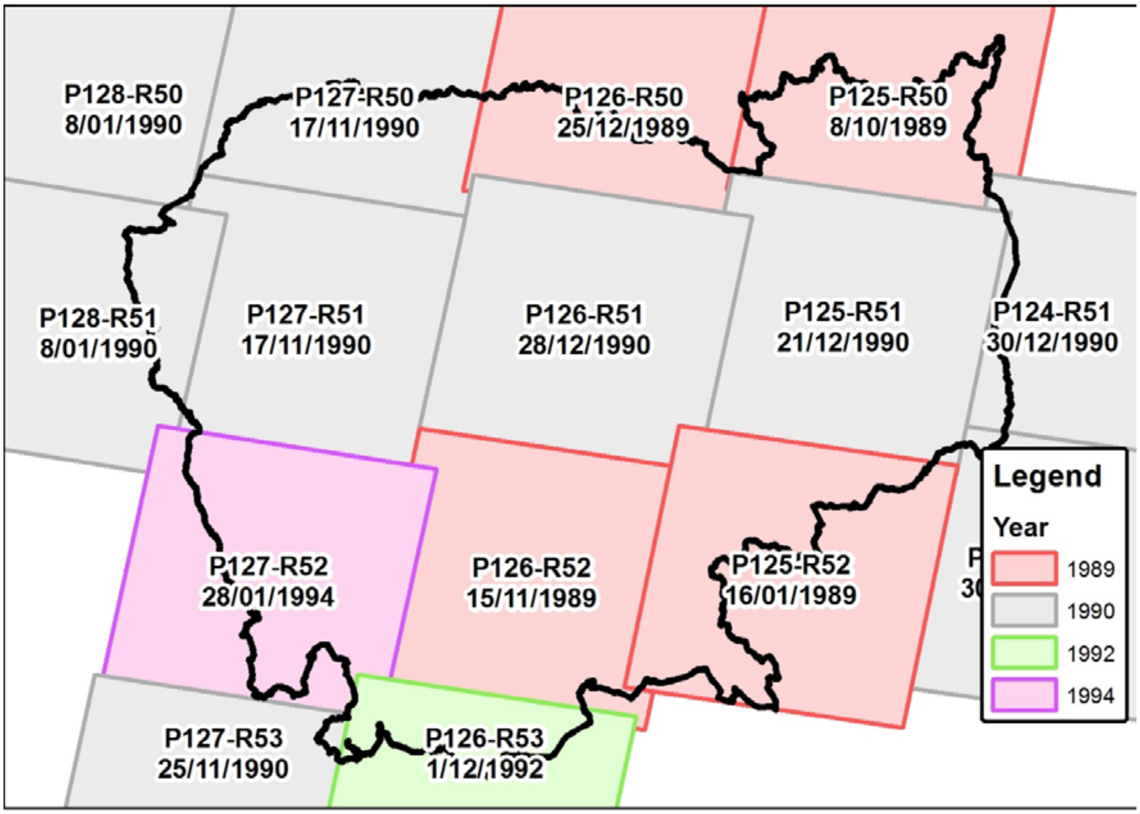
Legend

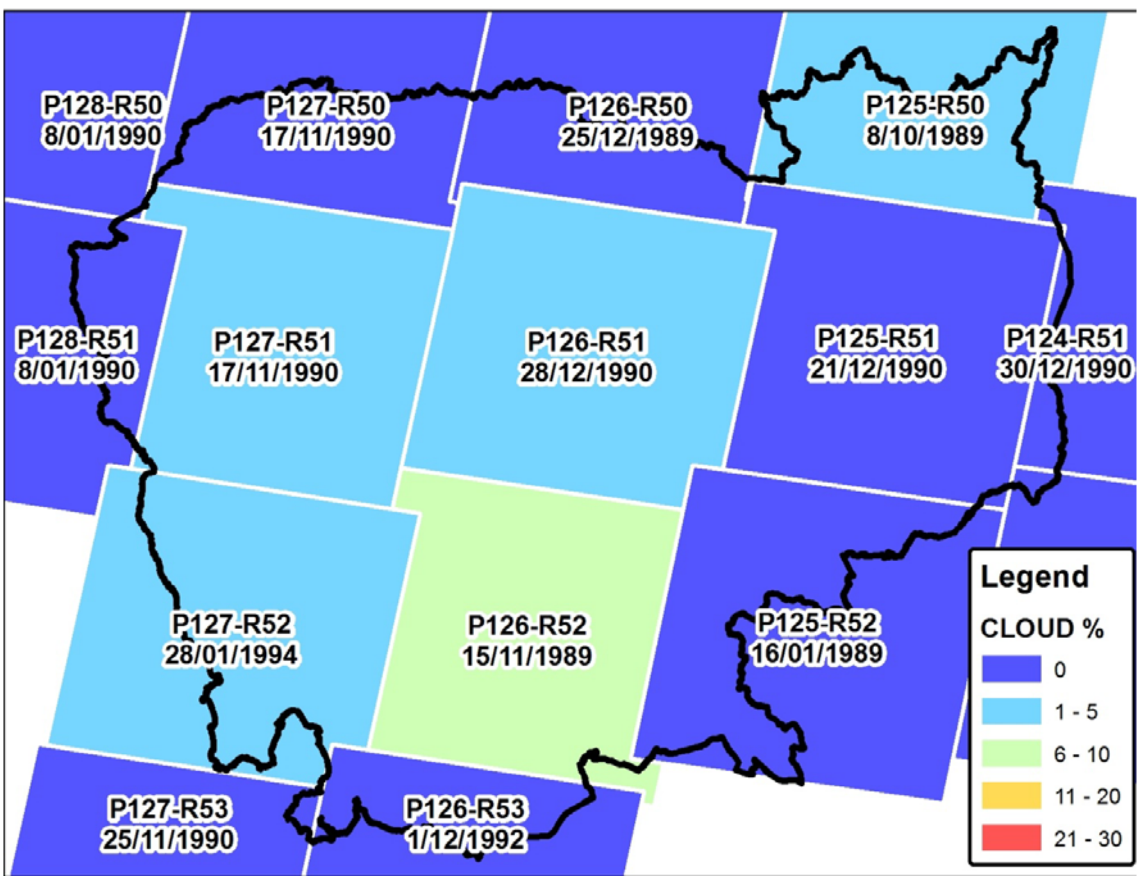
- AP_2001_15000_BW_PHOTO_PTS_SVAY_RIENG_CCDP
- AP_2001_25000_BW_PHOTO_PTS_PREY_VENG_CCDP
- AP_2001_8000_COLOUR_PHOTO_PTS_SIHANOUKVILLE_MRC
- AP_2001_25000_BW_PHOTO_PTS_SIHANOUKVILLE_CCDP
- AP_2001_SCALE_XXX_PHOTO_PTS_Rattanakiri_CARE_NGO
- AP_2002_5000_COLOUR_PHOTO_PTS_PHNOM_PENH_MRC
- AP_2002_8000_COLOUR_PHOTO_PTS_PHNOM_PENH_MRC
- AP_2004_25000_COLOUR_PHOTO_PTS_KG_SPEU_MLMUPC
- AP_2004_10000_COLOUR_PHOTO_PTS_CHHBAR_MON_MLMUPC
- AP_2004_10000_COLOUR_PHOTO_PTS_SVAY_PAO_MLMUPC
- AP_2004_20000_COLOUR_PHOTO_PTS_KANDAL_MLMUPC
- AP_2004_20000_COLOUR_PHOTO_PTS_SIEM_REAP_MLMUPC
- AP_2005_10000_COLOUR_PHOTO_PTS_STUNG_CHINIT_MOWRAM
- AP_2005_15000_COLOUR_PHOTO_PTS_STUNG_CHINIT_MOWRAM

100
Kilometers

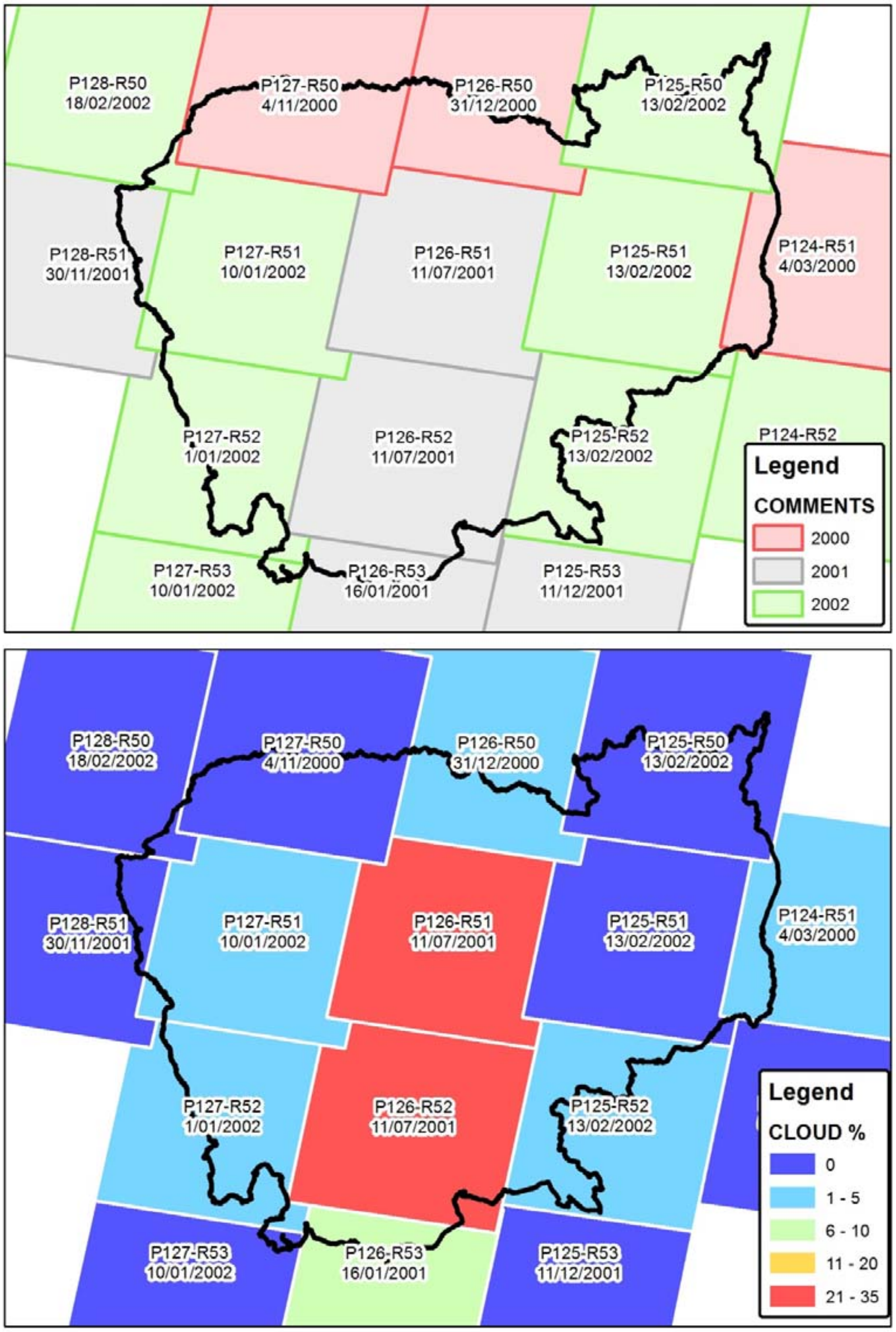
Annex 4 – Category 1 Satellite Image Coverage Maps

Landsat - Global Land Survey (GLS) 1990

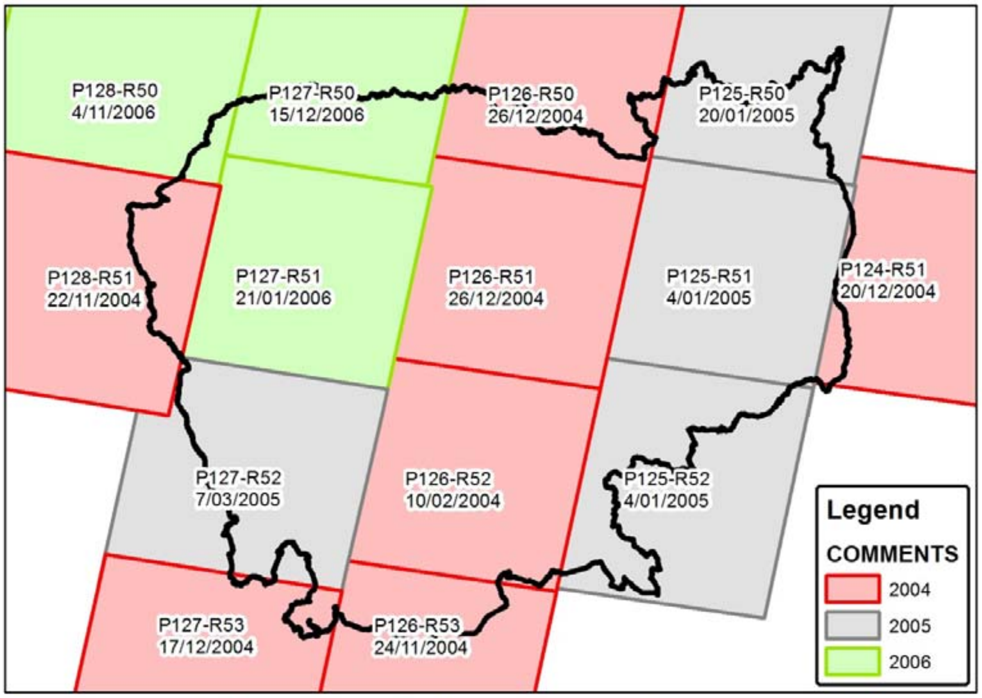


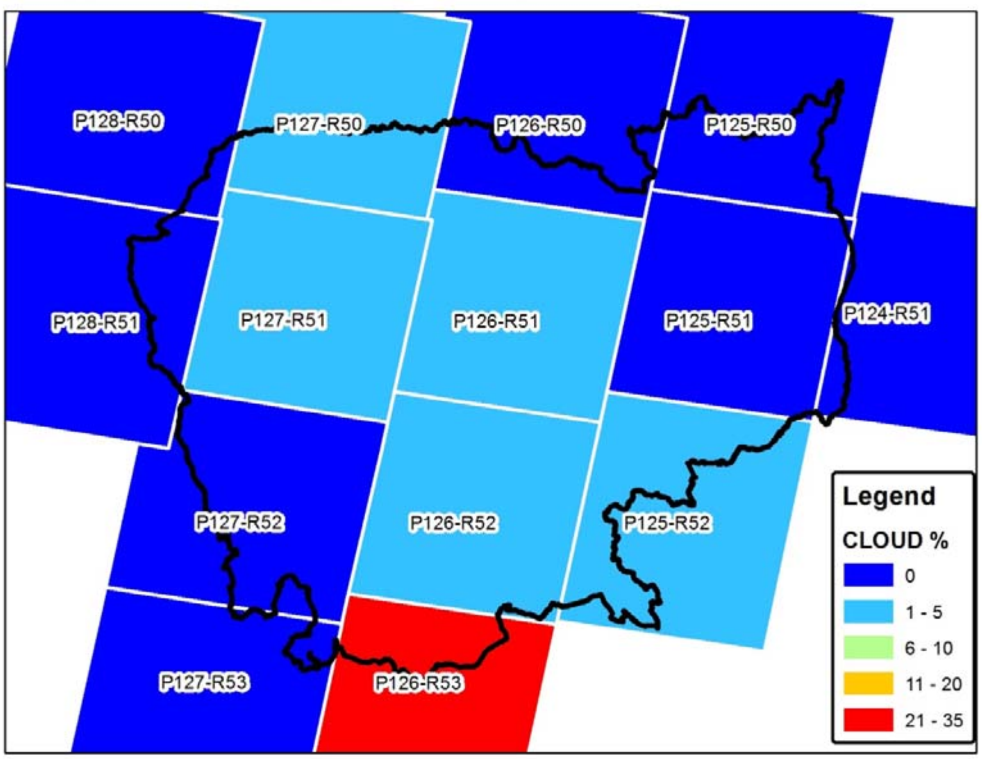


Landsat - Global Land Survey (GLS) 2000

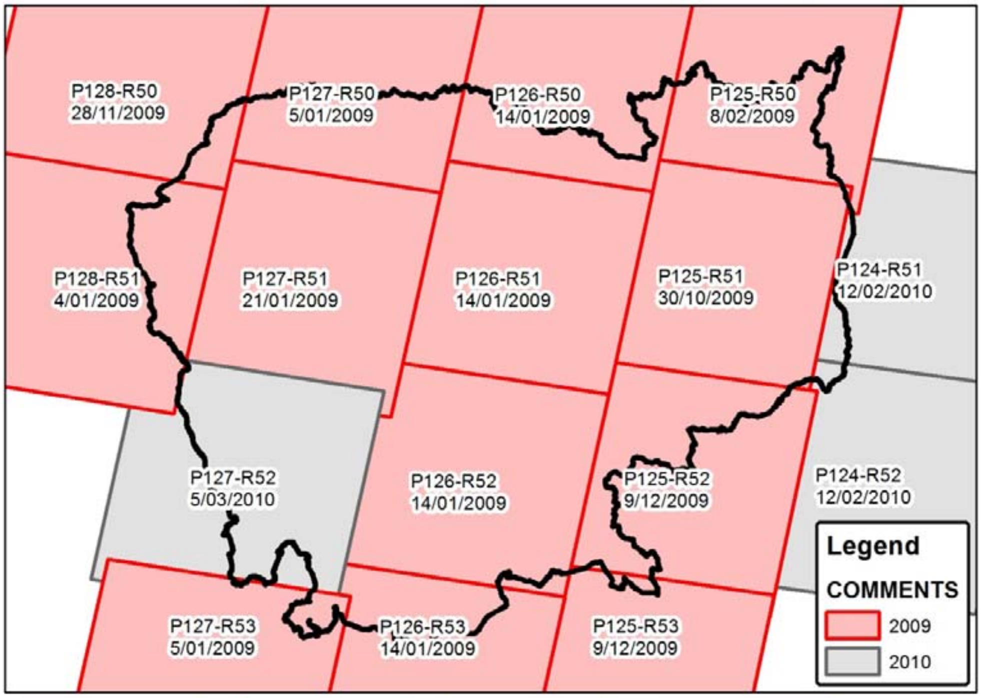


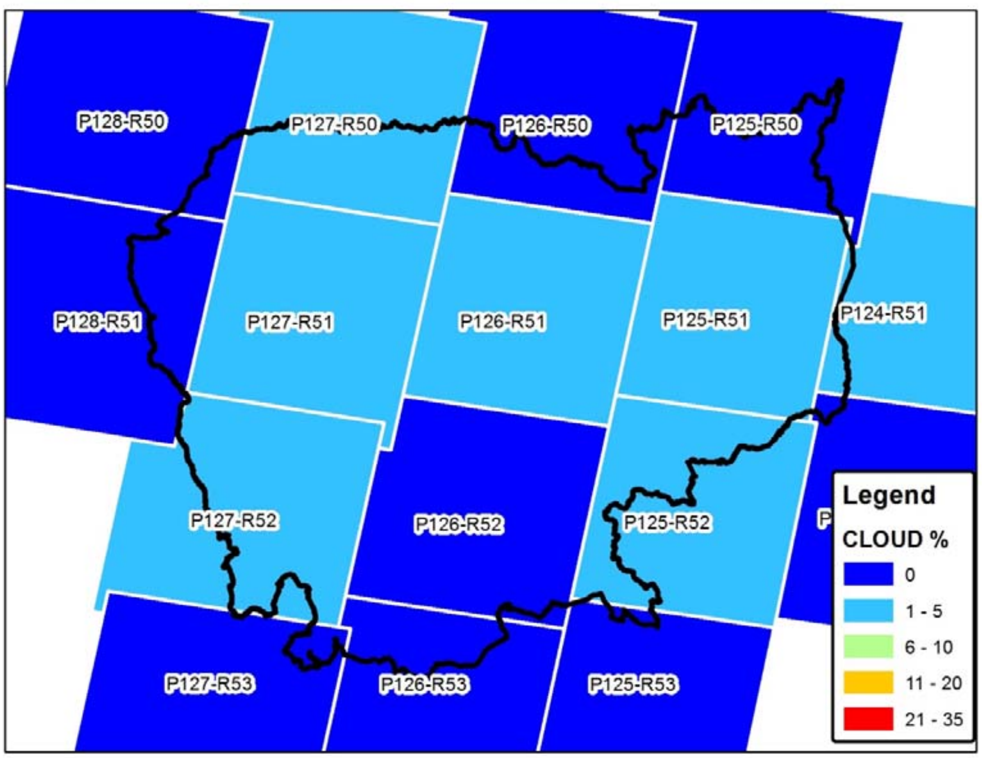
Landsat - Global Land Survey (GLS) 2005



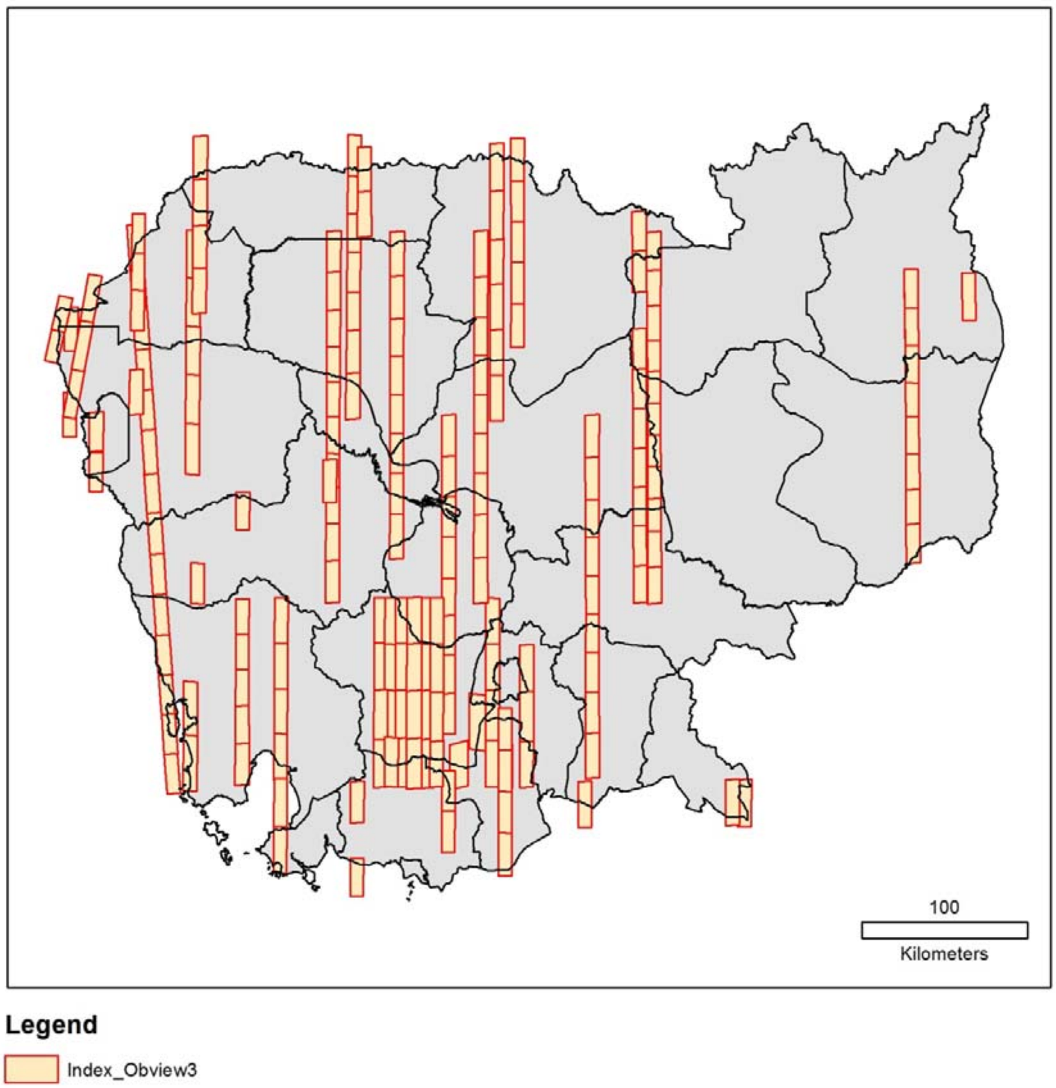


Landsat - Global Land Survey (GLS) 2010



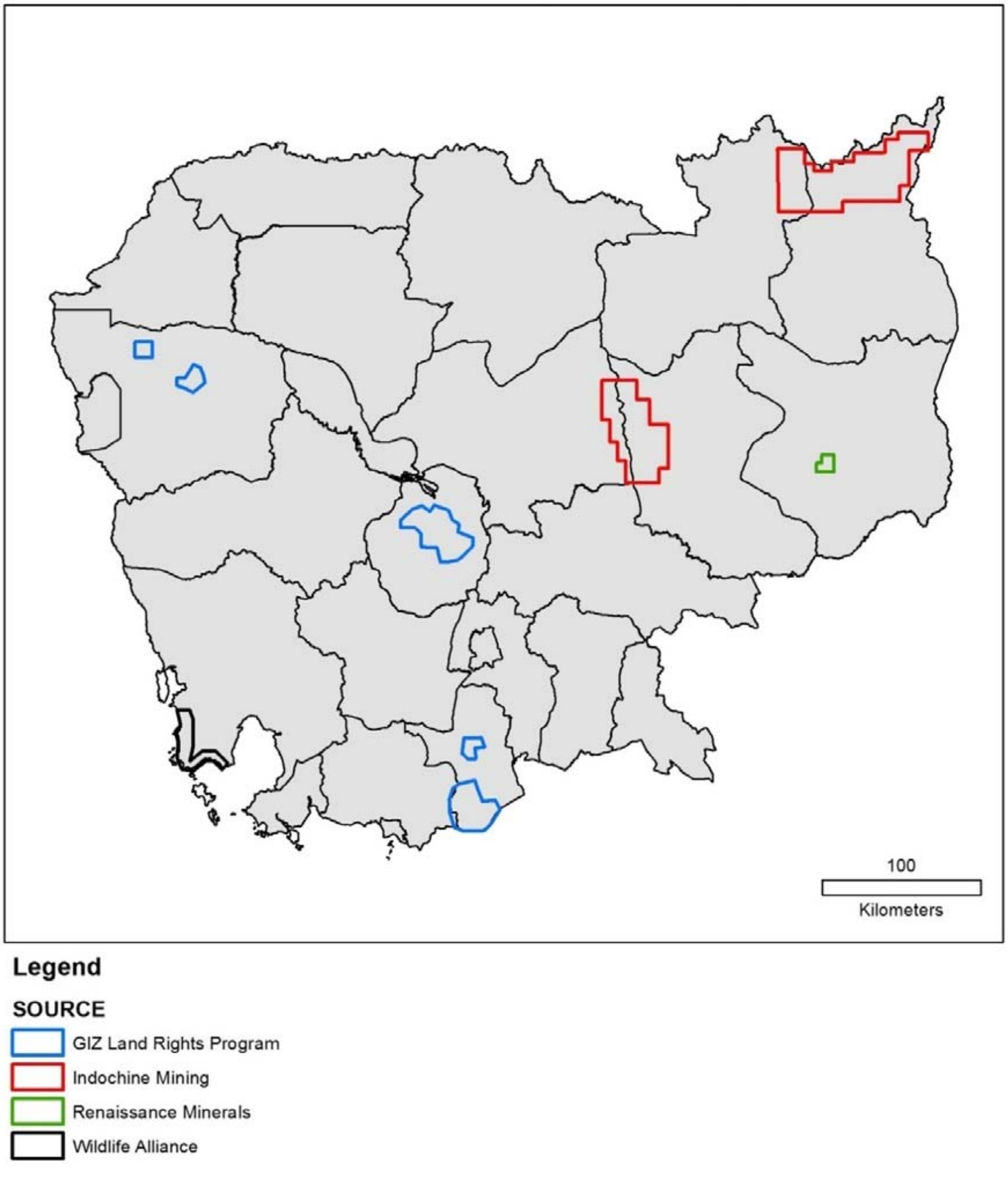


Satellite Index Map - Orbview-3

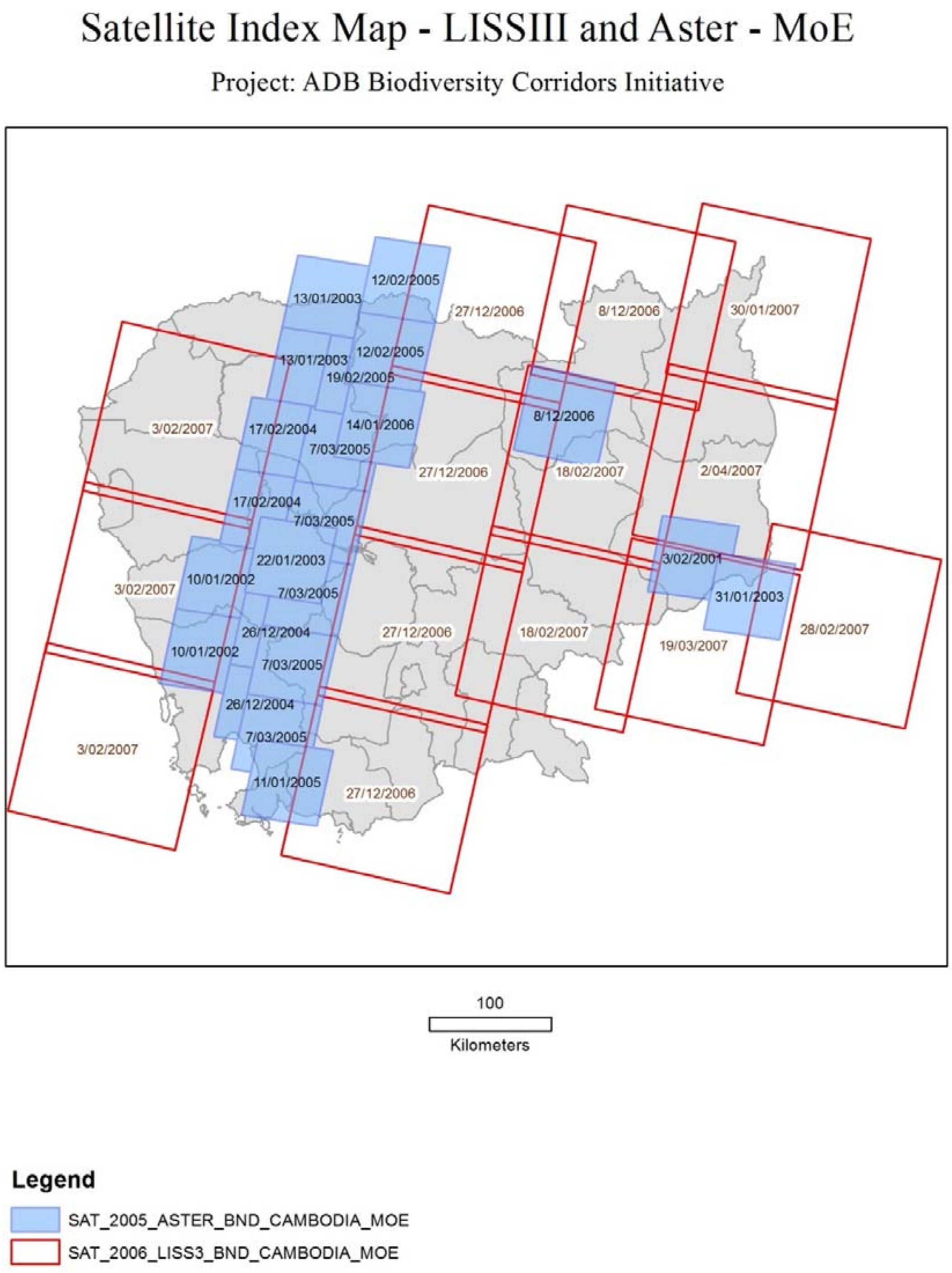


Annex 5 – Category 3 Satellite Image Coverage Maps

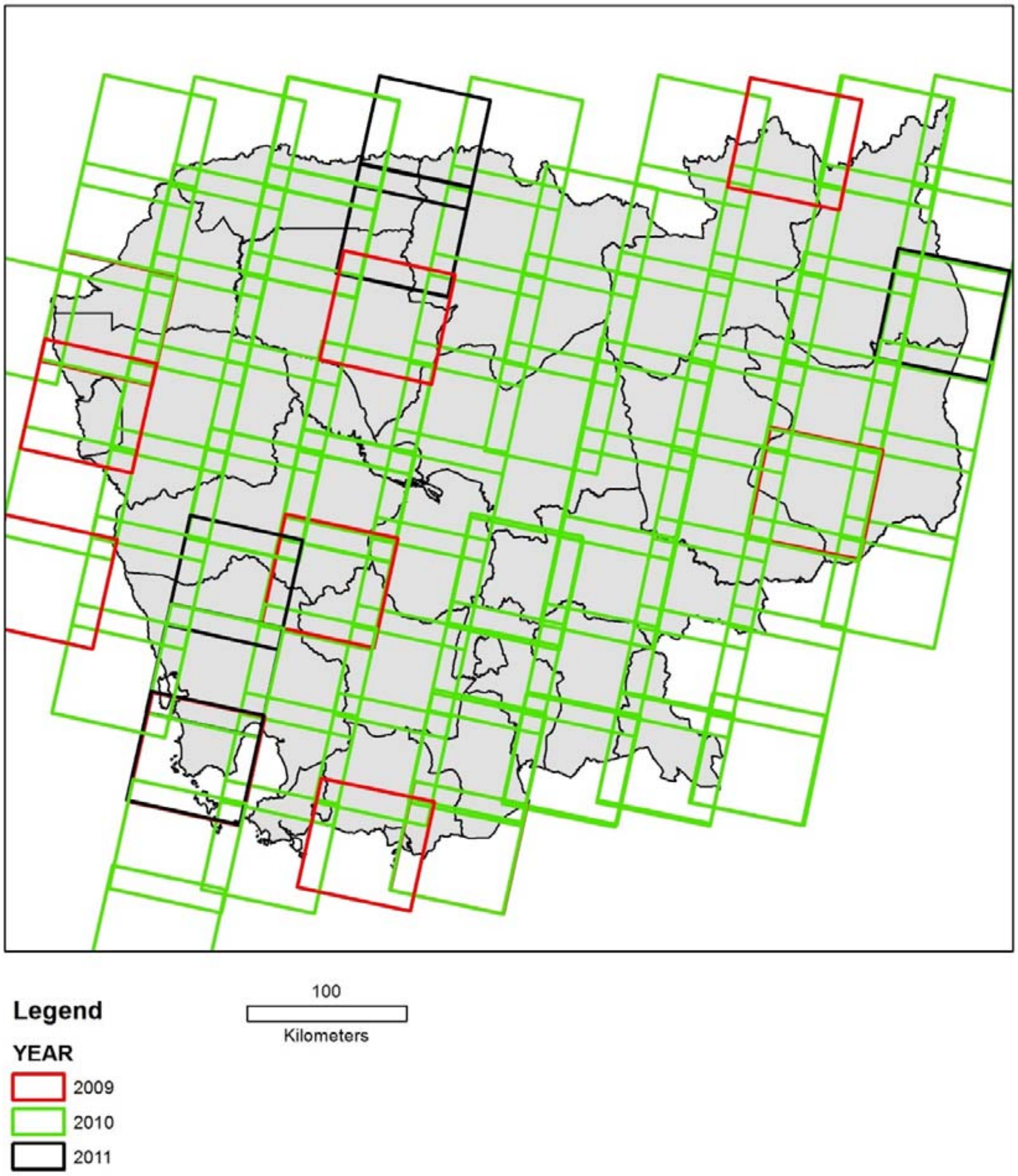
Satellite Index Map - GeoEye-1



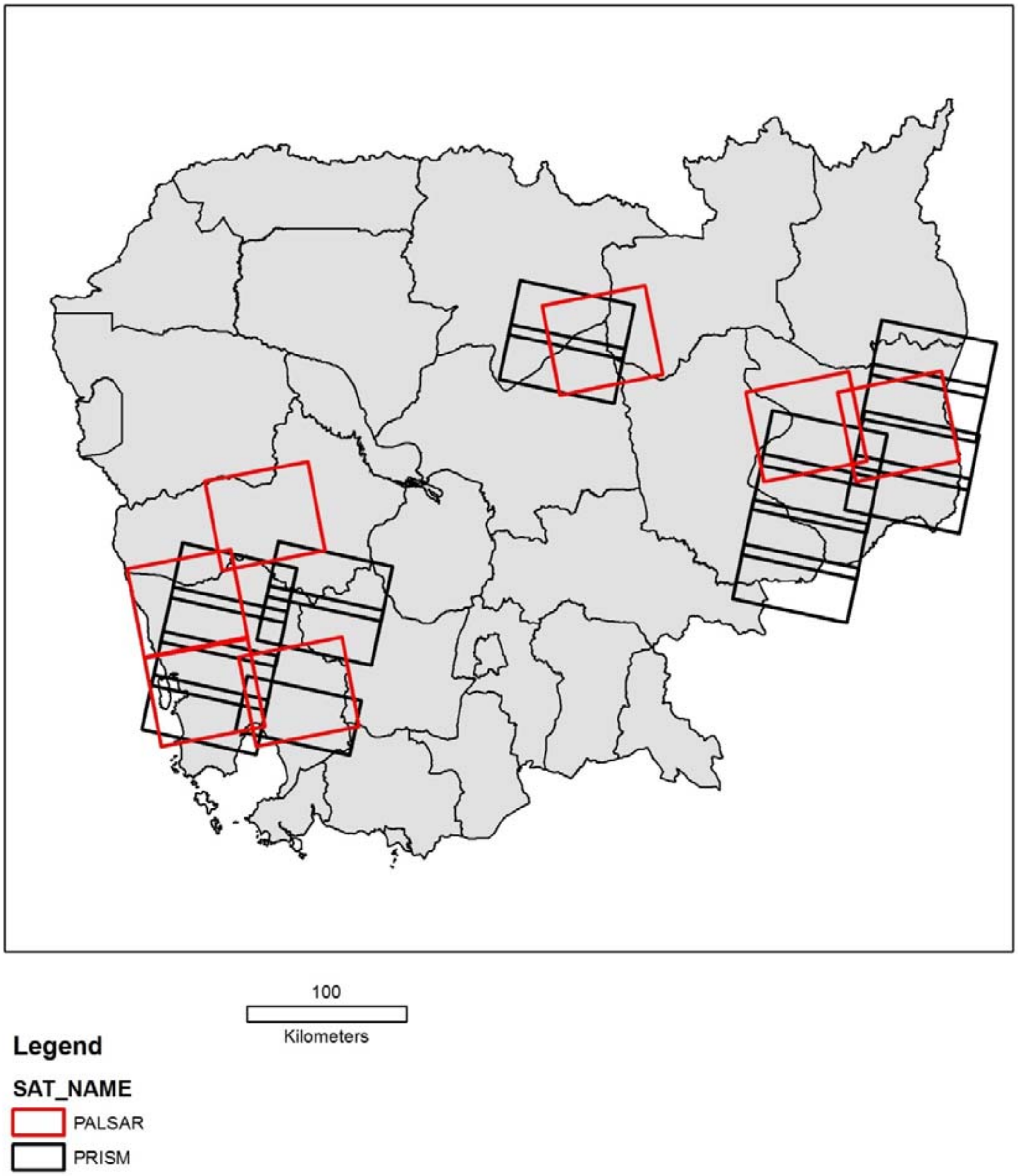
Annex 6 – Category 4 Satellite Image Coverage Maps



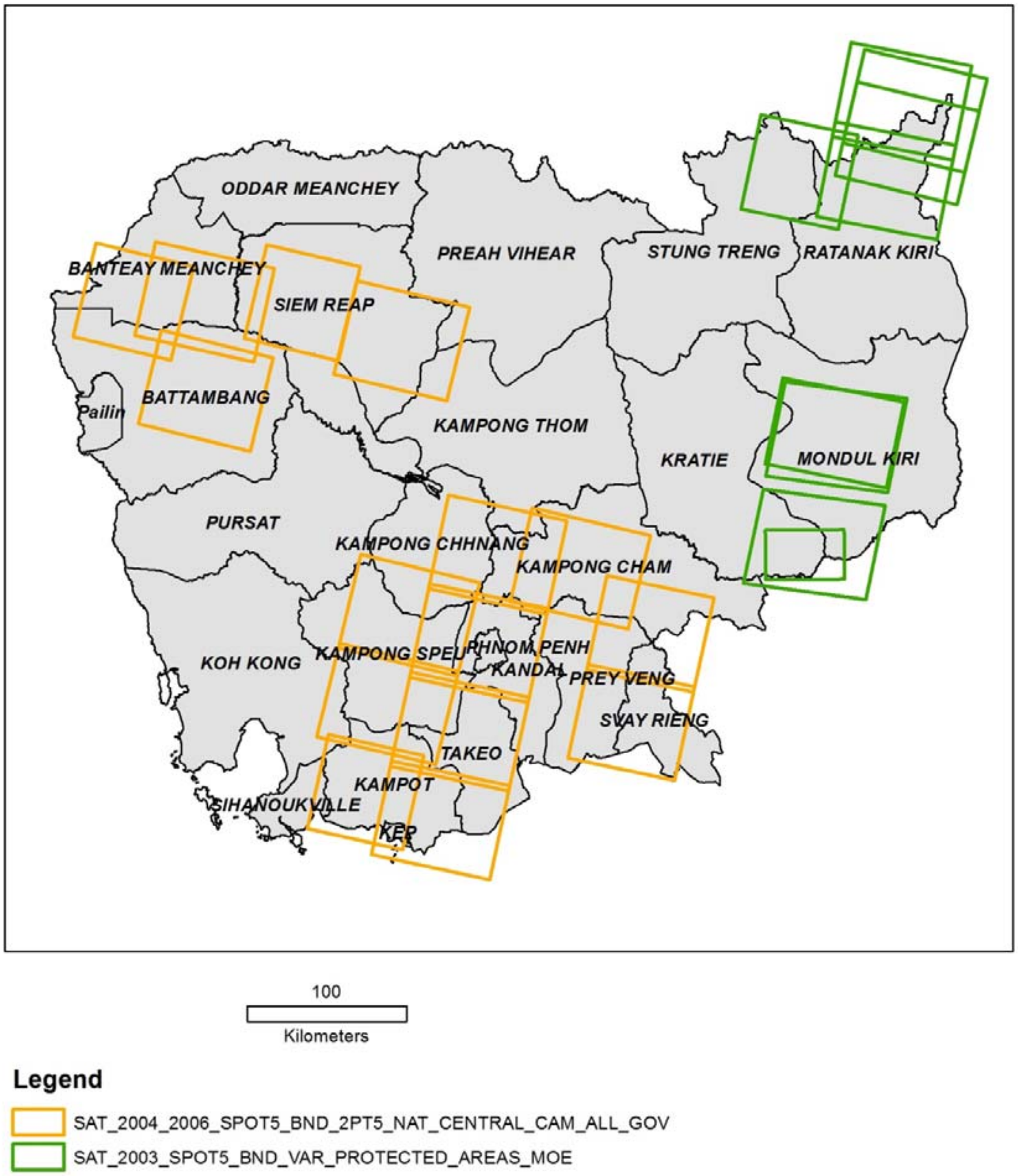
Satellite Index Map - ALOS AVNIR-2



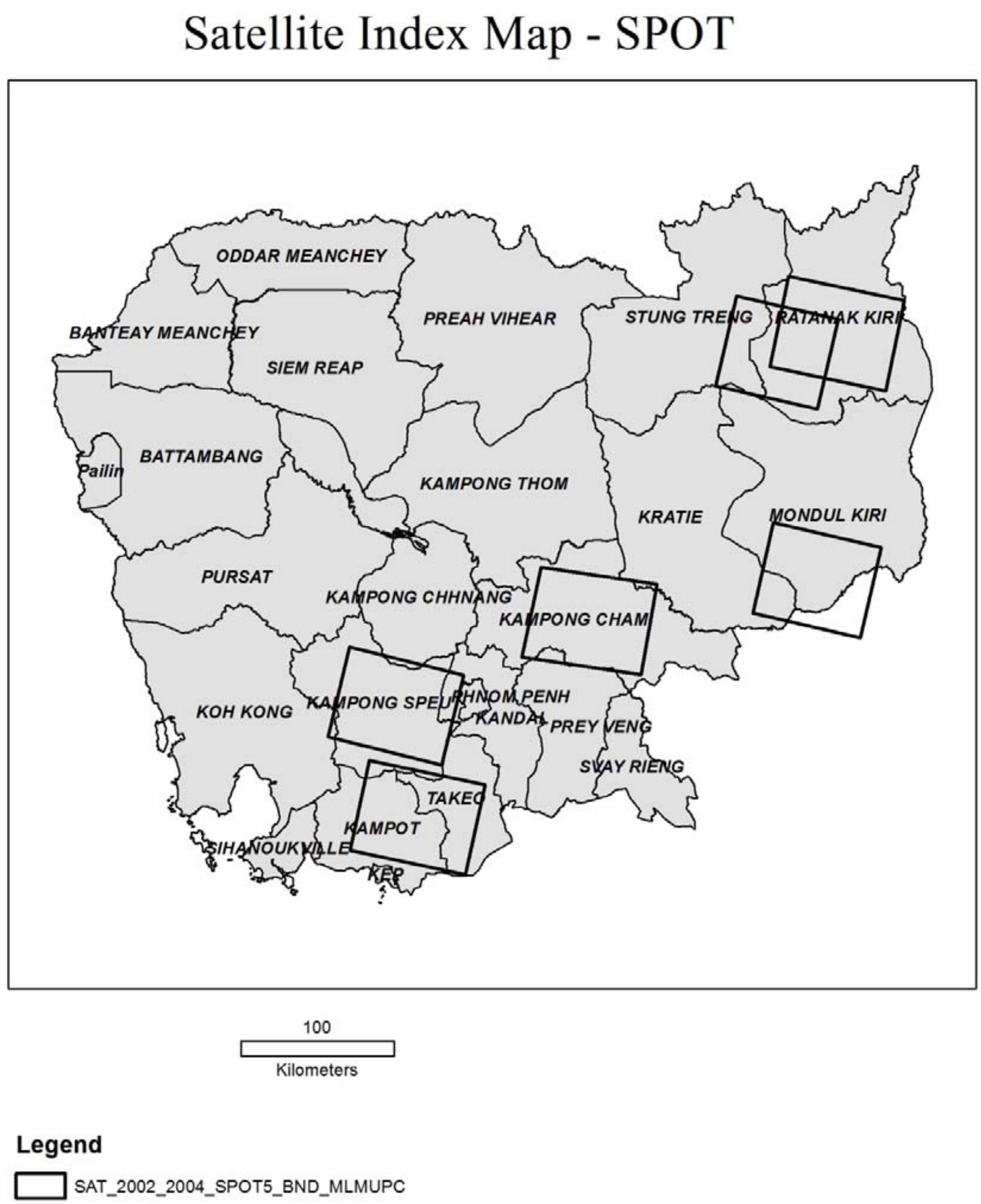
Satellite Index Map - ALOS PRISM & Palsar



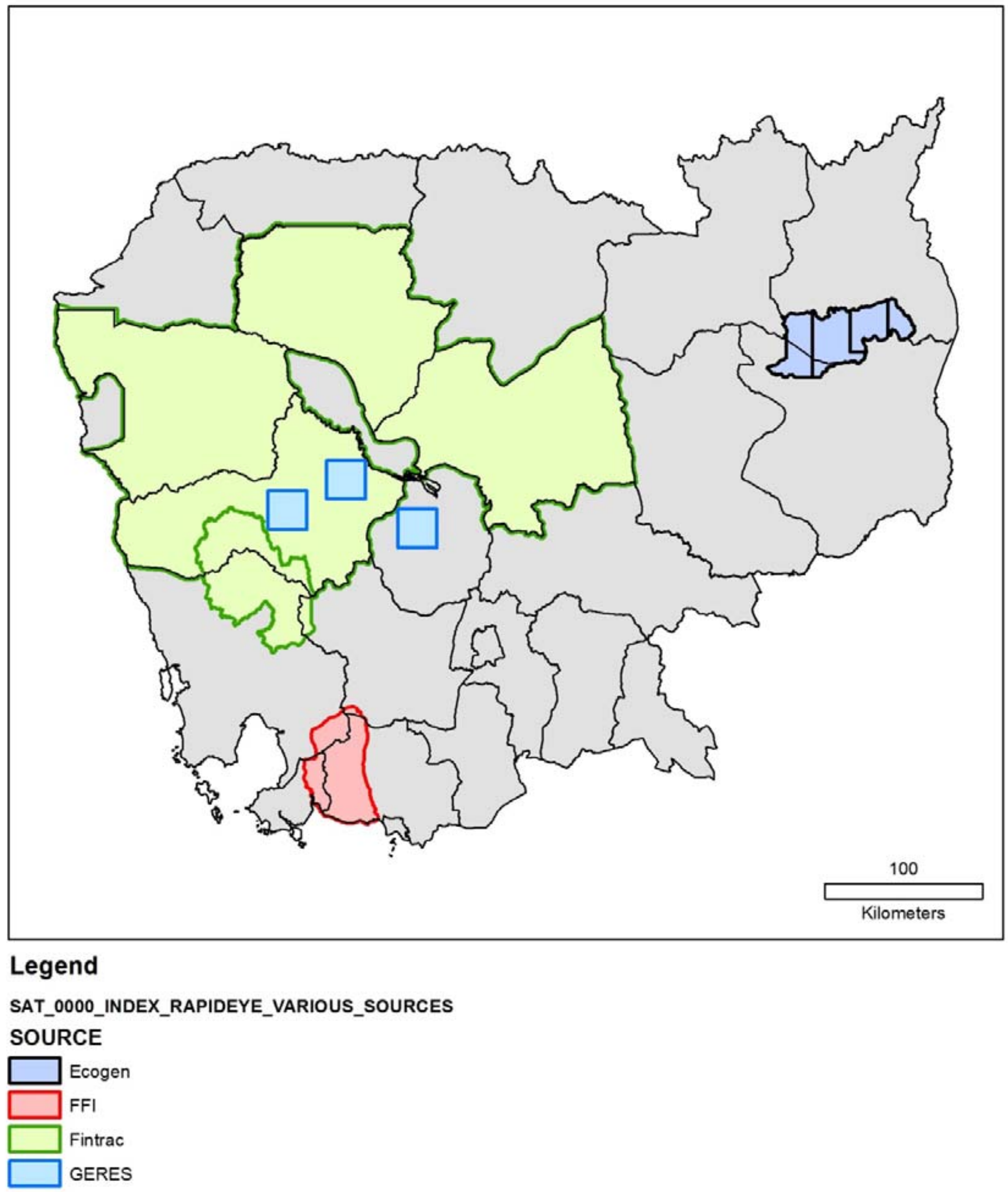
Satellite Index Map - SPOT



Annex 7 – Category 5 Satellite Image Coverage Maps



Satellite Index Map - RapidEye



Satellite Index Map - DMC - FAO