Concept Paper:

Land Cover Mapping Fiji

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1 Introduction

End of 2011 the project proposal "***Vegetation and land cover mapping and improving food security for building resilience to a changing climate in Pacific island communities***" was accepted by USAID which is funded with USD 4.0 Million over three years. The project targets six countries: Fiji, Vanuatu, Solomon Islands, Kiribati, Tonga and Samoa.

The project document states following regarding the mapping part of the project:

Objective 1 of the projects is: "Improved understanding of present and future climate related constraints on sustainable food production in various Pacific Island agriculture ecosystems, and the adoption of innovative adaptation responses that contribute to maintaining or increasing food security.

This will be **achieved through:** "implementation of capacity building, on-farm training, and pilot demonstration activities in selected communities in each country; ***the application of GIS land-use, forestry and soil mapping techniques (including training and national capacity building activities) as a tool to guide decision making*****;** and the production of support materials and knowledge products that can support the wider application and scale-up of successful techniques across the region."

Generation of baseline data: "The SPC SOPAC Division will acquire and pre-process high resolution GIS data on land use to identify land uses in classes such as: natural forest, mangroves, agricultural land (with further sub-strata), settlement areas, bare land and water bodies. Analysis will be conducted to generate maps of land cover use. Such maps will allow the identification of the volume and location of specific agricultural products such as – for example – bread fruit and pandanus – which are critical to Pacific island food security. Comparison with historical data will be used to identify forest cover and food production changes over time and change maps generated as relevant. Present land use maps will be 'ground truthed' using field work in conjunction with national counterparts. Printed maps will be used for community and farmer engagement activities. These products will form baseline information for the development and implementation of adaptation measures."

USD 600,000 is planned for satellite image data and USD 180,000 for DEM generation of selected areas. How far funds are available for the mapping component regarding training and field visits is unclear as these funds are built in with funding of meeting, workshops and training activities for other project components.

2 Outline of Mapping at 1:10,000 Scale

During the first stakeholder meeting it was agreed that the thematic mapping of Fiji's land cover mainly forest including mangroves, agriculture pasture land and others will be conducted at 1:10,000 scale with contribution from Forestry, Agriculture and USP.

It was also agreed to start the process of ***data purchase*** for Vanua Levu and continue with the other islands after further discussion between stakeholders about form and amount of contribution to the project.

The ***image data pre-processing*** will be conducted at SOPAC through the officer financed by the project for this task.

The ***image analysis and interpretation*** will be conducted at SOPAC during the first phase and it will be discussed how far this task can be performed also at Agriculture, Forestry and other stakeholders.

The ***area analysis*** which includes merging of different thematic mappings and data type conversion will be conducted at SOPAC.

3 Image Data Purchase

There are several satellites recording bundle image data providing sub-metre resolution in the panchromatic range. There are also several image data reseller who sometimes provide more cost effective data than the satellite operator companies themselves.

The mapping requirements are:

- Sub-metre resolution in the panchromatic range,
- Coverage of the visible spectrum blue, green, red,
- Coverage of near infrared,
- Availability of bundle data,
- Position accuracy of 8 metre or better,
- Maximum 1 ½ years old.

The following chapters explain the image data and the companies which sell the data.

3.1 GeoEye

GeoEye is a satellite operated by a company with the same name GeoEye. The satellite records four different spectral and one panchromatic band, see table 3.1.

Spectral range	***Wave Length***	***Resolution***
Blue	450-520 nm	1.65 m
Green	520-600 nm	1.65 m
Red	625-695 nm	1.65 m
Near Infrared	760-900 nm	1.65 m
Panchromatic	450-900 nm	0.5 m

Table 3.1: *Image data characteristics of GeoEye satellite*

GeoEye has a position accuracy of about 5 metres and the image data is sold as bundle products. The data is marketed per square km and costs in average USD 25 per square km new collection. If archive data is offered the price is much more cost effective.

3.2 WorldView-2

WorldView-2 is a satellite which is operated by company DigitalGlobe. The satellite records in more spectral bands than other VHR satellites, however, the user has to pay extra.

Spectral range	***Wave Length***	***Resolution***
Blue	450-510 nm	1.8 m
Green	510-580 nm	1.8 m
Red	630-690 nm	1.8 m
Near Infrared	770-895 nm	1.8 m
Coastal Band (blue)	400-450 nm	1.8 m
Yellow Band	585-625 nm	1.8 m
Red Edge Band	705-745 nm	1.8 m
Near Infrared Band 2	860-1040 nm	1.8 m
Panchromatic	450-800 nm	0.5 m

Table 3.2: *Image data characteristics of WorldView-2*

WorldView-2 has a position accuracy of about 6.5 metres and the image data is sold as bundle products. The data is marketed per square km and costs in average USD 20 per square km new collection without new bands (coastal, yellow, red edge and infrared-2). If archive data is offered the price is much more cost effective.

3.3 QuickBird

Company DigitalGlobe also operates and markets the satellite QuickBird which is the first satellite with sub-metre resolution image data.

Spectral range	***Wave Length***	***Resolution***
Blue	450-520 nm	2.44 m
Green	520-600 nm	2.44 m
Red	630-690 nm	2.44 m
Near Infrared	760-900 nm	2.44 m
Panchromatic	450-900 nm	0.61 m

Table 3.3: *Image data characteristics of QuickBird satellite*

The location accuracy is about 23 m. The cost for new collect is about USD 17 per square km.

3.4 Pleiades

Company Astrium launched Pleiades recently (16th December 2011), therefore the cost of image data is not clear yet and has to be asked during the purchase preparation.

Spectral range	***Wave Length***	***Resolution***
Blue	450-530 nm	2.8 m
Green	510-590 nm	2.8 m
Red	620-700 nm	2.8 m
Near Infrared	775-915 nm	2.8 m
Panchromatic	450-820 nm	0.7 m

Table 3.4: *Image data characteristics of Pleiades*

As mentioned the cost for image data is not known yet and naturally there is little chance to purchase archive data. The location accuracy the company states with 20m.

3.5 Purchase Details

SPC-SOPAC will purchase the image data, where the copy right normally covers the country Fiji, SPC and the Pacific Disaster Center in Hawaii. Most image data in 2011 was purchased from Pacific Geomatics Ltd. a Canadian company located in Vancouver as this company offered best pricing and best service. In 2010 most image data was purchased from MDA[1] a company also located in Vancouver with good service and good pricing. For this project quotations have to be also asked from DigitalGlobe Australia and Astrium representative in Australia.

4 <u>Image Data Pre-Processing</u>

VHR multi-spectral image data is recoded (e.g. GeoEye-1) in 1.65 metre spatial resolution in four spectral bands blue, green, red and near infrared. Parallel the satellite captures a panchromatic channel with 41 cm resolution[2]. There is a way to combine both types of data and produce colour images with spatial resolution of the panchromatic channel. Normally this is carried out by the image data seller or re-seller with the one important disadvantage for Pacific Island Countries that an atmospheric correction is not possible. SOPAC saw the need and invested through GIZ assistance in atmospheric correction software and does the pan-sharpening process in house now. This allows doing an atmospheric correction before the pan-sharpening process.

[1] MDA = MacDonald, Dettwiler and Associates Ltd. Geospatial Services Inc.
[2] Downgraded to 50 cm for countries outside USA

The image data pre-processing has changed within SOPAC due to new available software handling ortho image correction and atmospheric correction of digital space borne image data and new requirements such as drought mapping base line.

The pre-processing will run in four different steps: a) geometric image correction including ortho correction, b) haze removal and atmospheric correction, c) creation of pan-sharpened image products and d) establishment of an vegetation index layer.

4.1 Geometric Image Correction

Geometric image correction squeezes the image layer into the map projection of the target area which is in Fiji the Fiji Map Grid (FMG) based on the Fiji Geodetic Datum. If FMG is used at 1:10,000 scale the normal handling assuming spheroid WGS72 without additional datum will create errors and the Fiji Geodetic Datum has to be applied. It has to be discussed if not UTM WGS84 will be the better solution.

Ortho correction is a special method within the geometric correction techniques which utilises and digital elevation model (DEM) on which it overlays the image data. Through this process the position accuracy of the satellite is activated which is based in modern imaging satellites on enhanced star tracker and GPS. By activating this information the image pixels get a location accuracy of about 5 metres which can be increased by additional Reference Image Points[3].

DEMs are available for the main islands in Fiji. For the outer islands the DEMs have to be created from the topographic map sheets at 1:50,000 scale. The DEMs then have only 1:50,000 accuracy, however, this is sufficient to activate the internal satellite position accuracy.

4.2 Haze Removal and Atmospheric Correction

Haze removal is incorporated in a software package called ATCOR and reduces the influence of haze (not clouds) over the satellite image. The software first partitions the image into a) cloud overlaid area, b) haze overlaid areas and c) clear areas. It then calculates the relation between reflection in green and in red over the clear areas and adjusts the reflectance values in the hazy areas accordingly, taking into account that haze influences reflection in red stronger than in green.

The atmospheric correction of satellite imagery over mountainous terrain removes atmospheric and topographic effects by retrieving the physical parameters of the Earth's surface from the DEM. It comprises the DEM to obtain information about surface elevation, slope, and orientation. The image data of modern satellites is recorded on different days and with different view angle and it is then patched together to one image layer. Before doing this the differences are adjusted by calculating the influence of parameters such as:

- View angle
- Terrain (mentioned above)
- Sun angle
- General land cover
- Sensor parameters
- Sensor calibration

[3] Reference Image Points (RIP) = Ground Control Points, points of known X, Y and Z coordinates which are visible in the image data. The visibility in the image data is not always the case with "normal" Ground Control Points therefore the term RIP was created for points required for image correction.

The result is a sharp and brilliant satellite images with reduced shadow effects in mountainous terrain. Image interpretation improved for the forest change detection carried out for Fiji Islands.

4.3 Production of Pan-Sharpened Image Data

Carrying out the pan-sharpening process at SOPAC has the advantage that atmospheric correction can be applied before this process as mentioned before. This also allows producing two different pan-sharpening image types a) the natural colour combination with blue, green and red channel and b) a false colour combination green, red and near infrared which provides additional contrast between different vegetation types. The colour combination is performed in four different steps:

(A) ***Conversion from RGB[4] image display into IHS*** which stands for Intensity, Hue and Saturation. Intensity is the brightness of the colour, Hue the colour frequency or wave length window and Saturation the pureness of the colour. The software converts RGB display into IHS.

(B) ***Pseudo resolution increase***, where the picture elements (pixels) of the intensity, hue and saturation channels are converted to pixels with the size of the pixels of the panchromatic channel. Instead of one pixel with 1.6 m resolution nine pixels with 50 cm resolution are available after this process where the pixels have all the same content.

(C) ***Intensity replacement*** is performed by changing the intensity channel with the panchromatic channel. By doing this the 9 pixels have different content as the panchromatic channel was recorded in 50 cm resolution.

(D) ***Back conversion from IHS to RGB*** where the resolution of the colour image is increased to the resolution of the panchromatic channel. However, any colour enhancement is limited after this process.

As mentioned above, the process will be performed with the three natural colour bands and with the false colour combination.

4.4 Establishing Vegetation Index Layer

Vegetation index layers are based on the ration between red and near infrared image layers, where the pixel value in the infrared channel is divided by the values of corresponding pixel in the red channel. This process a) decreases the contrast between sunny and shadow side of hills as a bright pixel is divided by a bright pixel on the strong illuminated hill side and a low reflection is divided by a low reflection on the shadow side; b) it increases at the same time the difference between vegetation types as the near infrared shows differences more than red which is kept in the resulting ratio.

The near infrared channel is also sensitive to plant condition as the light in near infrared is reflected from the bottom of the leave. The rays therefore have to penetrate the leave twice and the cell structure reduces the reflection as soon there is plant stress caused by biotic diseases like fungus or by insufficient water in the plant cells in cases of drought. The leaves can still look green as the visible light is not influenced that fast.

The effect of plant condition is normally overlaid by differences between the plant types. A base line vegetation index layer overlaid by new vegetation index layer recorded during plant stress shows the areas within the vegetation cover where vegetation is suffering from insufficient water supply.

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[4] RGB is the term for an image with the three layers red, green and blue whatever image channel of the sensor is attached to the three layers. In false colour combination the green channel of the sensor is displayed with the blue image layer the red with the green and the near infrared with the red image layer.

5 Purpose of Mapping and Mapping Products

The purpose is to extract thematic information out of the image data to build the mapping capacity in the corresponding departments enable create the thematic layers, update the layers and to store and maintain the digital information.

Mapping at 1:10,000 with VHR image data also create first time the map basis for operational scale. Map layers[5] will be available where forest officers or farmers who can utilise them for their work in the field as they have the necessary detail.

5.1 Thematic Map Layer Forestry Cover

At 1:10,000 scale utilising VHR image data it will be possible to separate more forest types than it is possible with image data utilised to map at 1:50,000 scale. The test for Drawa forest in Vanua Levu showed that it is possible to separate rain tree, shrub, casuarina, mahogany and pine/bamboo. More strata will be separated during the interpretation process.

The thematic map layer "Forest Cover" will be available as vector layer and as raster layer. The interpretation will be done in relation to 10 x 10 km map sections of the current topographic map sheet (1:50,000 scale). The production of a raster layer is essential to combine the layer with other layers such as soil, slope, aspect and political boundaries such as province or tikina.

Two officers from Forestry will be trained and will be able to carry out all steps of image interpretation and production of digital map layer including the area analysis in attached database.

The image data will be available as pan-sharpened image in natural colour and pan-sharpened image in false colour infrared combination.

A further product for forestry use will be a vegetation index layer which a) helps during the interpretation and delineation process and b) will be a base line for possible drought stress analysis of vegetation at a later stage.

5.2 Thematic Layer Agriculture

Like for Forestry at 1:10,000 scale utilising VHR image data it will be possible to separate more agriculture types than it is possible with image data utilised to map at 1:50,000 scale which was 10m resolution ALOS image data. It is currently unclear how many different agricultural crop types and pasture land types can be separated.

The thematic map layer "Agriculture and Pasture Cover" will be available as vector layer and as raster layer. The interpretation will be done in relation to 10 x 10 km map sections of the current topographic map sheet (1:50,000 scale). The Agriculture/Forestry boundary will be discussed with Forestry. The production of a raster layer is essential to combine the layer with other layers such as soil, slope, aspect and political boundaries such as province or tikina.

Three officers from Agriculture will be trained and will be able to carry out all steps of image interpretation and production of digital map layer including the area analysis in attached database.

The image data will be available as pan-sharpened image in natural colour and pan-sharpened image in false colour infrared combination. It is possible that a different image enhancement will be used than prepared for forestry.

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[5] Map layer is the digital content of one thematic such as forestry or agriculture. Overlaid with infrastructure layers like roads or river system they form a digital map which can be transferred to a GPS unit or laptop computer for field work. It also can be printed as physical map. However, it will not be possible to *print* maps for complete Fiji at 1:10,000 scale.

Also for Agriculture the vegetation index layer will be utilised during the interpretation and delineation process and will stored as base line for possible drought stress analysis of agriculture vegetation at a later stage.

5.3 Coconut Palm Layer

It will be the first time that image data is available in geometric accurate projection enabling to map the coconut resource stratified into dense, semi dens and scattered coconut palm. The delineation only needs the pan-sharpened image data in natural colour.

It is expected that the corresponding part of the Agriculture Department will carry out the delineation under SOPAC supervision. For outer islands the interpretation might be assisted by the Department of Energy.

5.4 Mangrove Layer

Fiji's mangrove resources were never completely mapped at 1:10,000 scale. All three layers 1) the pan-sharpened natural colour, 2) the pan-sharpened false colour infrared layer and 3) the vegetation index layer have to be included in the delineation process.

It is possible that an additional image stretch (image enhancement) is necessary to enable the delineation of different mangrove species associations within the mangrove cover.

5.5 Pine Plantation Layer

During mapping tasks at 1:50,000 scale pine plantations were mapped as legal boundaries regardless of the actual cover with pine and other trees. At 1:10,000 scale it would be technically possible to map the left gallery forest within the pine plantation areas, which is of ecological importance. Further details of Fiji Pine leased areas could be mapped if FPL would be part of the team.

5.6 Hardwood Plantation Areas

During mapping tasks at 1:50,000 scale mahogany plantations were mapped as legal boundaries regardless of the actual cover with mahogany or natural forest. At 1:10,000 scale it would be technically possible to map the coverage with mahogany as far as the mahogany trees have grown through the canopy of the natural forest. Further details of Fiji Hardwood leased areas could be mapped if Fiji Hardwood would be part of the team.

5.7 Topographic Map features

Topographic map sheet coverage for Fiji does not exist yet. It is unclear how far features such as creeks, track and small roads can be interpreted with the image data. It is possible that it is necessary to produce a new enhanced panchromatic layer from the bundle data.

It is not the purpose of the project to produce a topographic map, however, with the support of Fiji Lands Department this could be investigated or carried out. The layers produced would be:

- Road network
- River system
- Coast line
- Settlement area
- Other infrastructure such as railway lines or airport runways

6 Image Data Analysis and Interpretation

The image interpretation will be performed as visual interpretation and on-screen delineation in GIS environment as digitising is more user friendly using GIS software than image analysis software. The area analysis will be performed for every 10 x 10 km map section in raster data environment and exported to Access as relational database.

6.1 Image Analysis and Delineation

The interpreter toggles between the three image backdrops a) natural colour, b) false colour infrared c) vegetation index and delineates which have to be loaded into GIS.

It is expected that one interpreter will delineated in average the area of one 10 x 10 km map section per day, where he concentrates on his thematic only. This means the forest stratification is performed by a forester, the agriculture and pasture stratification by an agriculture specialist, the mangrove by somebody from Environment, etc. The boundaries between forestry and agriculture or forestry and mangrove areas have to be agreed between the interpreters.

For every 10 x 10 km section a standardised description has to be stored in a database explaining a) which image data set was utilised (there might be different enhancements from the same data and there image patches recorded in at different point in time), b) the main finding, c) problems and uncertainties during the interpretation caused by clouds and unclear image parts.

If a 10 x 10 km section is finished by all interpreters it has to be ensured that the connection to the four neighbouring map section is seamless, which sometimes requires re-interpretation.

6.2 Data Storage and Conversion

The interpretation has to be stored for every section as own file in vector environment. Then the vector data has to be converted to raster file format and stored again. If changes are necessary after field visits a new version of vector and raster layer will be stored without overwriting the old version.

During the interpretation process an interpretation key will be established and permanently updated, where reference areas will be marked in the field. These areas will be used to establish spectral signatures of different vegetation types which might lead into semi-automated image analysis at a later stage.

6.3 Area Analysis

Image analysis software has tools which allow a fast cover type analysis where the pixels of each vegetation type are counted and knowing the area coverage of each pixel with the counted number of pixels for each 10 x 10 km map section the total area of each land cover class is known as well.

The 10 x 10 km map sections are the smallest interpretation unit which are sustainable and output has to be referenced at stage to these areas, where area analysis in relation to province, district and tikina will be discussed at a later stage.

7 Area Analysis for Province District and Tikina

So far province, district and tikina boundaries do not exist at 1:10,000 scale level. It will create inaccurate areas if the boundaries created at 1:50,000 will be utilised at 1:10,000 scale. Once if this 1:10,000 scale data is available it can be converted to raster data sets allowing an easy and fast overlay over the vegetation layer. In image analysis software the 10 x 10 km map sections covering one political unit have to be joined and as next step overlaid over the political unit where the process clips all pixel outside the political area unit and counts the pixels for each class covering the province, district or tikina. These are all semi-automated and therefore fast processes.