A multi-scale approach for benthic habitat mapping of shallow water region using a 4 band high resolution WorldView-2 satellite imagery using object based image analysis

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Key words: worldview-2, benthic habitat mapping, object based image analysis

SUMMARY

High resolution multi-spectral satellite images had been recently used in mapping the shallow water region of the coastal environments. This helps in the monitoring and management of marine systems and coastal resources over large areas. The objective of this research is to utilized a 4 band (Red, Green, Blue, NIR) WorldView-2 satellite image to produce a benthic habitat map using object-based image analysis. The image had undergone two major steps such as pre-processing and classification.

The pre-processing comprised of several steps essential to correct the raw satellite image file for benthic habitat mapping. First, the image’s reflected radiance was calibrated and corrected from water surface and atmospheric scattering. Second, the image was georeferenced by warping it to a geometrically corrected image using ground control points with an acceptable RMSE of 0.26 m. Third, a land mask was generated using SPEAR tool’s relative water depth algorithm. Next, Hedley’s deglinting formula was applied to remove the effects of sun glint in the image. By utilizing the NIR band of the dark pixels, the deglinted image was produced. The water column correction adapted from Lyzenga was also used to remove the effects of the absorption and scattering of photons in the water. A depth invariant matrix was calculated and applied to the band pairs of good water reflectors. The water column band was stacked together with the deglinted image layers. Lastly, the deep water region and artifacts from the image were masked before proceeding to the classification.

The inputs for the multi-scale classification were the pre-processed WorldView-2 satellite image, a Digital Elevation Model, and color transformation outputs from RGB to HSV and RGB to HLS applied with PCA tool. Different segmentation algorithms were performed before the automated classification. A contrast split segmentation was performed to classify the masked region and the shallow water region. Then, a multiscale segmentation was applied using a hierarchical top to bottom scheme. Starting with a bigger scale parameter of 1000 for shallow water region, scale of 150 for reef zones and intertidal zones, and scale of 50 for the six benthic community zones (sand, corals, rocks, sparse seagrass, dense seagrass and rubbles). Different segmentation parameters such as weights, shape, and compactness for the reef zones and intertidal zones were applied to enhance the object found in each zones.

Three classifications were utilized for the WorldView-2 Image namely Nearest Neighbor, Feature Space Optimization and Classification and Regression Tree (CART) algorithms. By using the training data set, the mean layer values and their standard deviations were inputted for the bentthic classes’ object features for all of the three classifications.

Ground measurements from video tows and sampling confirmed the accurate representation of the classified benthic habitat maps. The result showed overall accuracies of 72.96%, 73.17%, and 82.15% with kappa coefficients of 0.60, 0.60 and 0.73 from nearest
neighbor, feature space optimization, and classification and regression tree algorithms respectively.
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1. Introduction

The Philippines, composed of more than 7000 islands, is supported of diverse marine ecosystems by large productive areas which provide shore protection, nutrient cycling and valuable economic goods. Considered as one of the longest coastline in the world, more than 70% of its municipalities are located in the coastal area accounting for anthropogenic activities in the coastal zones. (Philippines Environment Monitor, 2005) The coastal zone is very vulnerable to disturbances, natural phenomena, exploitation, and pollution causing threats to marine biodiversity and coastal resources. (One Ocean, 2015) With this, there is an urgent need to develop methods for mapping and establishing the geographic location, extent, and condition of marine ecosystems to monitor and manage the resources effectively. (Brown, Smith, Lawton, & Anderson, 2011)

Satellite and airborne remote sensing methods had been optimized in mapping of benthic habitats in the shallow water region. Depending on the spatial and spectral characteristics of this images, the mapping of coastal habitats such as sand bottoms, seagrass cover, and coral reef zones was enabled. Throughout the years, satellite imagery and remote sensing had been mostly used for the mapping and inventory of coastal resources (Kuchler, Jupp, Claasen, & Bour, 1986) due to time and labor intensive traditional in situ surveys that may be difficult to maintain from year to year. (Dierssen, Zimmerman, Leathers, Downes, & Davis, 2003). It was also used to evaluate the benthos, perform time series analyses and survey coral reef abundance. (Mishra, Narumalani, Rundquist, & Lawson, 2006). Aside from this, it also aids as a tool for assessment and monitoring of coastal marine systems, marine spatial planning for feature boundaries delineating habitats, resource habitat and offshore engineering. (Micallef, et al., 2012)

The objective of this research is to develop algorithms and workflow to classify benthic habitats using WorldView-2 high resolution imagery and a Digital Elevation Model (DEM) incorporating object based image analysis. The classifications used are Nearest Neighbor, Feature Space Optimization and Classification and Regression Tree algorithms.

1.1 Benthic Habitat

Anything associated with or occurring on the bottom of a body of water is termed as benthic. Benthos are referred to the animals and plants that live on or in the bottom. (National Oceanic and Atmospheric Administration, 2015)

1.2 WorldView-2

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WorldView-2 satellite imagery is a sensor launched by the Digital Globe at Vandenberg Air Force Base in California on 2009. It consists of 8 multispectral imaging bands namely: Coastal (400-450 nanometer (nm)), Blue (450-510 nm), green (510-580 nm), yellow (585-625), red (630-690 nm), red edge (705-745 nm), NIR-1 (770-895), and NIR-2 (860-900 nm) with a 2 meter (m) resolution. It collects panchromatic imagery simultaneously at 0.5 m resolution. (WorldView-2 Satellite Sensor, 2001) However, in this study, only 4 bands namely Blue, Green, Red and NIR-1 is available for the classification.

1.3 Object Based Image Analysis

Object-based image analysis has been a tool used for the classification of benthic habitat features. This method allows the segmentation of the image into group of pixels with similar spectral reflectance and/or textural characteristics into objects. These objects are assigned to classes based on their color, texture, geometry, and context based relationships. The advantage of this procedure to pixel based classification is that it outgrows the salt and pepper effect in its classification because it uses objects instead. (Lucieer, 2007). In this study, eCognition software will be used for the OBIA processing.

1.4 Multi-scale approach

For the analysis of the benthic features, the image was classified according to the benthic habitat classification scheme adapted from (Roelfsema, Phinn, Jupiter, Comley, & Albert, 2013). These levels are based on the coral reef ecosystem to define benthic habitats namely 1) Reef Zone 2) Geomorphic Zone and 3) Benthic Community Zone. The Reef Zone is the region or area of a coral reef from below the water surface at high tide, to a depth where corals no longer dominate. (Spalding, Ravilous, & Green, 2001) This separates the image objects into 3 classes namely: Land, Reef Zone, and Deep Water (> 10 m). (Neil, Phinn, & Ahmad, 2000) The second level, Geomorphic Zone, is the area on a reef with a unique set of benthic substrate structures produced by a specific combination of water, depth, wave exposure and currents. The geomorphic zone of the Philippine reef system is mainly composed of the Reef Flat Zone, Reef Crest, and the Reef Slope. (Neil, Phinn, & Ahmad, 2000) The location of the zones is mainly dependent on the reef system present in the area. In the Philippines, the reef systems are mainly fringing reefs. The benthic community zone is composed of areas of...
frequently co-occurring coral, algae, rock, rubble, and sand on reef or non-reef substrates. The benthic community is the final objects of the image classification. (Done, 1999) It is also the last level of classification with the smallest scale.

1.5 Nearest Neighbor

Nearest Neighbor classification in eCognition is based on a fuzzy classification algorithm and classified image objects have a membership to more than one class. The smaller the difference is between sample objects and the object to be classified, the higher the membership value. The greater degree of membership between the best and second best class assignment, the better the classification stability of an image object. (Definiens, 2003)

1.6 Feature Space Optimization

Feature Space Optimization is a tool that calculates an optimum feature combination based on class samples. It evaluates the Euclidean distance in feature space between the samples of all separation distance, the largest distance of the minimum distances between the least separable classes. (Definiens, 2009)

1.7 Classification and Regression Tree Algorithm

CART analysis is based on algorithms by Breiman et al. which includes the application of Gini’s diversity index as a splitting rule. Gini’s diversity index is defined as:

\[
Impurity \ (t) = \sum_{i \neq j} p(i|t)p(j|t)
\]

where \( t \) is the node in the tree, and \( p(i|t) \) is the proportion of cases \( x_n \in t \) belonging to class \( I \) (\( x \) is a measurement vector). The largest homogenous category within the data set is isolated from the remainder of the data by using the splitting rule. Subsequent nodes are then segregated in the same manner until further divisions are not possible, or the tree reaches a predetermined maximum depth. (Breiman, Friedman, Olshen, & Stone, 1984)

2 Study Area and Data Sets

Boracay, a small island of the Philippines, approximately 7 km long with a total land area of 10.32 sq km belongs to the Western Visayas Island (Region VI). It is located approximately 315 km south of Manila and 2 km off the northwest tip of Panay Island. It is under the municipality of Malay in Aklan Province. The island is popular due to its white sand beaches making it one of the world’s top destinations for relaxation, tranquility and nightlife. (Wikipedia, 2014) However, it was observed that throughout the years, the island is suffering from beach erosion and decrease of coral reefs due to increased tourism, developments and human activities. Furthermore, according to Dr. Fortes, a professor from the University of the Philippines, from 75% coral cover in 1990, it has shrunk drastically to 5-15% by 2010. (Tomioka, 2013)

There are three sets of data used in the classification of Boracay Island. The first data set is a high resolution WorldView-2 Image captured on December 18, 2013.
It contains four spectral bands namely: Blue (450 – 510 nm), Green (510-580 nm), Red (630 -690 nm), and NIR 1 (770-895 nm). This satellite imagery is obtained from the Department of Science and Technology through the DREAM Program’s Satellite-based Monitoring and Assessment of Rehabilitation in Typhoon-affected Regions (SMARTER Visayas). The second data set is a Digital Elevation Model (DEM) derived from bathymetric surveys performed by Engineer Ed Carla Mae Tomoling. The third data set is consisted of training and test areas gathered from actual field surveys in the study area. These datasets were also collected from Engr. Ed Carla Mae Tomoling from her previous works. This study is under the UP TCAGP Phil-LiDAR 2 Program Project 2: Aquatic Resource Extraction from LiDAR Surveys.

3 Methodology

There are two major steps observed in the processing of the satellite imagery: pre-processing and classification. The preprocessing involves calibration, atmospheric correction, subsetting the data, georectification, masking of land features and artifacts, deglinting, water column correction, derivation of hue, light, saturation, and value, and principal component analysis. The classification involves running a multi-scale approach for the extraction of benthic habitats using a top to bottom structure.

Due to observed factors that affect the digital numbers (DN) of the pixels of imageries, a radiometric calibration is performed based on factors such as exposure time, known values for the camera shading based on flat-field observations, dark current (output current of a detector when no energy is incident on the detector, such as when the shutter is closed), and other factors describing the unique electronics design and characteristics of an imaging system. This allows the recalculation of DNs in
radiometric units that are proportional to the brightness of a scene. (USGS, 2015) Using the ENVI 5.1 software, it automatically reads the metadata of the imagery then computes the radiance values using gains and offsets from each bands. The formula is given by:

\[ L_\lambda = Gain \times Pixel \ Value + Offset \]

The radiance values is expected to be in units of W/(m^2 * sr * µm). (Exelis, 2015) Due to the effects of the atmosphere on the visible and near-infrared radiance, spectral and spatial distribution of the radiation incident on the surface is modified. Also, deflected radiance is attenuated and scattered radiance is added to the transmitted radiance. (University of California, 2015). Using ENVI’s FLAASH, a tool that corrects wavelength in the visible through near infrared and shortwave infrared regions. The radiance image file would then be outputted into a reflectance image file. (Exelis, 2015). It is computed as follows:

\[ P_\lambda = \frac{\pi \lambda d^2}{ESUN_\lambda \sin \theta} \]

Where:
- \( L_\lambda \) = Radiance
- \( d \) = Earth-sun distance, in astronomical units
- \( ESUN_\lambda \) = Solar irradiance
- \( \theta \) = sun elevation in degrees. (Exelis, 2015)

The WorldView-2 file was subset/clipped according to the extents of the study area. After which the image was georeferenced by warping it to a geometrically corrected image of the same study area by establishing 20 ground control points with an acceptable RMSE of 0.26 m. This was necessary since the WorldView-2 image is a Basic 1B imagery which is free from any geometric corrections. (DigitalGlobe, 2014) Land masking was generated using ENVI SPEAR tool’s relative water algorithm to focus on the processing of benthic habitats. Hedley’s degl ministering formula was applied in the masked image. This algorithm exhausts the NIR band for estimating the amount of sunglint in each pixel because this assumes that the water leaving signal in this spectral region is negligible. Atmospheric correction and radiometric calibration are prerequisites for this correction because it assumes that any remaining signal after these corrections are caused by sunglint. The spectrum from the deeper water region are analyzed and used to define a linear relationship between the NIR reflectance and sungl int reflectance. (Hogrefe, 2008) The sunglint formula is given by:

\[ R’i = Ri - bi (RNIR - MNIR) \]

Where
- \( R’i \) = degl inted pixel value in band i
- \( Ri \) = pixel value in band i
- \( bi \) = regression slope
- \( RNIR \) = pixel value NIR
- \( MNIR \) = sunglint minimum pixel brightness value

Due to the effects of light attenuation, where light intensity decreases exponentially with increasing depth, the removal of the confounding influence of variable water depth is required for the mapping of benthic features. Lyzenga put forward a simple image-based...
approach to compensate for these effects. Rather than predicting the reflectance of the seabed, a depth-invariant bottom index is produced from each pair of spectral bands. However, this technique is only appropriate when there is good water clarity. A prerequisite for this correction is that all the other calibrations and corrections such as atmospheric and sun glint corrections were already applied. A measurement of depth for every pixel in the image is required as an input. (i.e. sand from the shallow water region to the deep water region) (UNESCO, 2015) The formula for this correction is given by:

\[
\text{depth-invariant matrix} = \ln(L_i) - \left[ \frac{k_j}{k_i} \ln(L_j) \right]
\]

where:

- \( L_i \) = pixel radiance in band i
- \( L_j \) = pixel radiance in band j
- \( \frac{k_i}{k_j} \) = ratio of attenuation coefficient

The depth-invariant matrix was stacked together with the deglinted bands. The artifacts and deep water region were finally masked in order to aid in the object based classification. This is the final pre-processed image file. Color transformation from RGB to HSV and HLS was also performed. Lastly, a Principal Component Analysis consisted of the deglinted RGB bands, hue, light, saturation, value and depth invariant matrix was implemented outputting a 3 band image. This is to extract the important information from the datasets to represent it as a set of new orthogonal values called principal components and to display the pattern of similarity of the observations and of the variables as points in maps. (Abdi & Williams, 2010) Thus, the inputs for the object based classification was the final pre-processed image file, DEM and 3-band PCA output.

The second major process is the multi-scale approach for the extraction of benthic habitats. The Reef Zone Classification/Level 1 Classification started with the segmentation of the image using contrast split segmentation algorithm in eCognition. It has assigned the dark pixels into masked objects then the brighter pixels into reef zone class. Using the DEM, the geomorphic zone level/Level 2 Classification was produced consisting of the reef flat, reef crest and the reef slope zones after segmenting the image in the scale of 150. Another segmentation procedure was performed using a scale of 50 but different scale parameters for the three geomorphic zones was observed to denote the properties of the benthic habitat found in each zone. Then, using the training points, the three classification algorithms were applied in the image namely: Nearest Neighbor, Feature Space Optimization and Classification and Regression Tree Algorithm. In the NN classification, all the layers and its mean and standard deviation were the inputs used for the extraction of benthic habitats. In the FSO algorithm, from a total of 16 features/layers of mean and standard deviation, 10 features were used for the classification with a maximum separation distance of 0.102. In the CART classifier, all the mean and standard deviation layers were inputted for the features. A maximum tree depth of 6, 5 for the minimum number of samples per node, and the number of cross validation folds used was 10. These three classifications produced final classification for benthic habitat zones/Level 3 Classification. Accuracy assessments were produced individually for the three classifications based from the collected points from video tows and actual ground surveys.
4 Results and Discussions

By utilizing a 4-band WorldView-2 image, a DEM, and training points, a benthic habitat map was produced using a multi-scale approach and three classification methods. The WorldView-2 image had undergone pre-processing method such as calibration, atmospheric corrections, geometric corrections, land and deep water masking, sun glint corrections, and water column corrections that are necessary before the benthic habitat extraction. Color transformations were also performed and together with the pre-processed WorldView-2 layers, a Principal Component Analysis was implemented. Using object based image analysis, a multi-scale approach was observed in the classification. Level 1 Classification produced 3 classes that delineates the boundaries of the Reef Zone, Land and Artifacts, and Deep Water. After which, a Level 2 Classification was performed from the Reef Zone class which resulted into 3 classes namely Reef Flat, Reef Crest, and Reef Slope. Finally, a Level 3 classification was produced by running three classification algorithms such as Nearest Neighbor, Feature Space Optimization and Classification and Regression Tree. Six benthic habitats were mapped in the island of Boracay namely sand, sparse seagrass, dense seagrass, sand rubbles, rocks, and corals. Accuracy assessment was run after the classification. This resulted into an overall accuracy and kappa statistic of 72.96% and 0.60 respectively for the Nearest Neighbor Classification. 73.17% and 0.60 overall accuracy and kappa statistic yielded for Feature Space Optimization. The highest overall accuracy and kappa statistic was obtained by the Classification and Regression Tree algorithm which resulted into 82.15% and 0.73 respectively. Based on the three classifications, the class that was mostly misclassified is the rock. It is misclassified with corals and rubbles. The class which was properly classified was the dense seagrass with a producer and user accuracy of 100%. After dense seagrass, the corals was classified with the best user and producer accuracy which is between 79-92% and 85-86% respectively. Mostly the coral class is misclassified with rubbles and rocks. Rubbles was also misclassified as corals. Sand was misclassified as rubbles or sparse seagrass and sparse seagrass are mostly misclassified as sand.
Figure 3: Nearest Neighbor Classification
Figure 4: Feature Space Optimization Classification
5 Conclusions and Recommendation

Object-based image analysis can be used in the extraction of benthic habitats using a four band WorldView-2 imagery by applying a multi-scale approach. Raw satellite images can be
corrected and pre-processed in order to aid in the classification of benthic habitats. Automated classifications such as Nearest Neighbor, Feature Space Optimization and Classification and Regression Tree algorithms can be used to extract the benthic habitats with overall accuracies of greater than 72%. For future studies, exhausting the texture, surface roughness and other geometrical properties of the objects may improve the classification of benthic habitats especially to the classes that are usually misclassified. (i.e. corals vs rocks vs rubbles and sand vs rubbles vs sparse seagrass) Also, analyzing and changing the values of the parameters for Classification and Regression Tree algorithm such as depth, minimum sample count, categories, and validation folds that are applicable to the benthic habitat classes can also aid in the improvement of the classification. Indices and other ratio could also aid in the discrimination of underwater features from vegetation to non-vegetation.

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**BIOGRAPHY**

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