EXPLORING THE CAPABILITIES OF COMBINING THE SENTINEL-2 MSI DATA AND HIGH RESOLUTION GOOGLE EARTH IMAGE FOR MAPPING MANGROVE SPECIES

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ABSTRACT:

Knowledge gained about the mangrove species mapping is essential to understand mangrove species development and to better estimate their ecological service value. Spectral bands and spatial resolution of remote sensing data are two important factors for accurate discrimination of mangrove species. In this study, mangrove species classification in Shenzhen Bay, China was performed by using Sentinel 2 (S2) Multi Spectral Instrument (MSI) data and Google Earth (GE) high resolution imagery as data sources and their suitability in mapping mangrove forest at a species level was examined. In the classification feature groups, the spectral bands were from the S2 MSI data and the textural features were based on GE imagery. The SVM classifier was used in mangrove species classification processing with eight groups of features, which were based on different S2 spectral bands and different GE spatial resolution textural features. The highest overall accuracy of our mapping results was 78.57% and the Kappa coefficient was 0.74, which indicated great potential of using the combination of S2 MSI and GE imagery for distinguishing and mapping mangrove species.

1. INTRODUCTION

Mangrove ecosystems dominate the coastal wetlands of tropical and subtropical regions throughout the world. They provide various ecological and economical ecosystem services contributing to coastal erosion protection, water filtration, provision of areas for fish and shrimp breeding, provision of building material and medicinal ingredients, and the attraction of tourists, amongst many other factors1.

Mangrove species mapping is imperative to understand their vegetation dynamics better, such as succession, deforestation, stand density and health conditions, as well as further understanding the ecological services they provide (Giri et al., 2015, Rogers et al., 2017). Optical data is the main data source for mangrove species mapping. With the availability of high spectral and high spatial resolution remote sensing images, it is feasible to digitally mapping mangrove forests to the species level (Kuenzer 2011, Heumann 2011). To overcome the poor spectral resolution limitation, the spatial textural features have been exploited in mangrove species mapping, and got promising mapping results (Xin et al., 2009, Roslani et al., 2014).

In recent studies, Worldview constellation, which can produce images with high spectral and spatial resolution, has been selected as the data source for this study (Wang et al., 2015, Valderrama-Landeros et al., 2018, Zhang et al., 2018). As the Worldview constellation satellite images include consideration of ideal spectral (Red-edge region and NIR bands) and spatial resolution (0.5m panchromatic band), they can accurately discriminate mangrove species. While the use of Worldview constellation imagery has gained considerable attention, the limitations of high purchase cost and small swath size hamper continuous or large geographic coverage application.

Sentinel is a new mission developed by the European Space Agency specifically for the operational needs of the Copernicus programme. S2 MSI data offers 13 multispectral bands, of which four traditional bands (red/green/blue/NIR) have a spatial resolution of 10-m and three bands are 20-m resolution red-edge bands designed for vegetation detection, but does not acquire a classic high resolution panchromatic band. Some researchers have suggested using S2 data for mangrove monitoring. Valderrama-Landeros et al (2018) assessed the accuracy of mangrove species mapping using different remote sensing data. Results indicated that S2 was ranked second among the four data sources (i.e., Landsat 8, SPOT-5, S2, and Worldview-2). Wang et al. (2018) evaluated the performance of S2, Landsat 8 and Pleiades-1 in mapping mangrove species. Results showed that the performance of S2 was worse than Pleiades-1 imagery, but better than Landsat 8 data.

The high spatial resolution Google Earth (GE) images, as a free and open data source, have provided great supports for the traditional land use/cover mapping (Hu et al., 2013, Aher et al., 2014). In the field of mangrove species mapping, GE images are rarely used as a direct data source. This might be due to that, GE images are only available in RGB bands, but feature no red-edge/NIR channels which are commonly used for classifying vegetation.

This study aims to validate the suitability of combining S2 MSI data and high resolution GE imagery in mangrove forest mapping at species level. To meet the objective, the Futian Mangrove Nature Reserve in Shenzhen, China was selected as the case study. In the classification procedure, the spectral

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features were from the S2 MSI data and the textural features were extracted from GE imagery.

2. MATERIALS AND METHODS

2.1 Study Areas

This study focused on the Futian Mangrove Nature Reserve in Shenzhen, Guangdong Province, China (Fig. 1). The Futian Mangrove Nature Reserve was officially created in 1984. It is centred at latitude 22 29’ N and longitude 113 58’ E, and covers an area of 367 ha. It is the only nature reserves that located in the urban area and the smallest one in China.

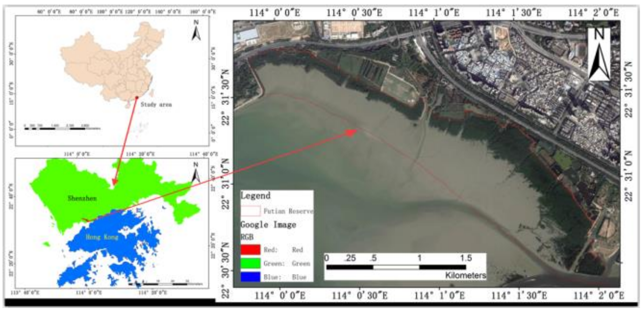


Figure 1. Location map of the study area

2.2 Main Mangrove Species and Samples

The mangrove vegetation typically found in this region includes Kandelia obovata, Avicennia marina, Aegiceras corniculatum, Acanthus ilicifolius, Sonneratia caseolaris and Sonneratia apetala

The field works were conducted in the Futian Reserve in December 2014. A differential GPS coordinated in the UTM system was used to match the geographical location between field survey data and image pixel data. A total of 361 mangrove reference points were selected, as shown in Table 1. Due to the special growth environment of mangroves (inter-tidal mudflats inundated by periodic seawater) and their dense forests, it is very difficult for people to enter mangrove forests for extensive field surveying and sampling. And as the area of Futian Reserve is very small, the narrowest point of mangrove forest is just 100m, and the widest point is just 400m. 361 mangrove samples are almost the most samples we can get in the study area.

Two other types, water and mudflat were added into the classification system. For convenience, coded names were given for each of the mangrove species. To validate the results in this paper, the reference samples were split into two sets of disjoint training and validation samples.

Mangrove Species	Coded name	Training samples	Validating samples	Total
Sonneratia caseolaris	SC	21	45	66
Sonneratia apetala	SA	13	17	30
Acanthus ilicifolius	AI	21	46	67
Avicennia marina	AM	22	42	64
Kandelia obovata	KO	23	46	69
Aegiceras corniculatum	AC	23	42	65
Total		123	238	361
Water	WT	20	36	56
Mudflat	MD	21	35	56

Table 1 Number of training and validating samples

2.3 Data Collection and Pre-processing

The multi-source remote sensing data used in this study were S2 MSI imagery and GE imagery.

One S2 MSI image (Level-1C) was acquired on 25 Jan. 2017 and was downloaded from the European Space Agency’s Sentinel Scientific Data Hub. The S2 MSI image has 13 spectral bands in the visible, NIR, and SWIR wavelength region with spatial resolution of 10-60m (Table 2). All the 13 bands were resampled to 10 m using the Sentinel Application Platform (SNAP) v6.0. Then using the sen2cor plugin v2.4.0 which is an inbuilt algorithm available on the SNAP, the S2 image was processed reflectance image from Top-Of-Atmosphere (TOA) Level 1C, to Bottom-Of-Atmosphere (BOA) Level 2A.

High resolution (0.55m) GE image (acquired on 12 January 2017) was extracted directly from Google Earth using Google Satellite Map Downloader v7.45. The GE data has three spectral bans (red, green and blue). As one of the objectives of this study is to assess the performance of texture features with various spatial resolutions, the 0.55m GE data was resampled to 0,5m, 1m, 2m, and 4m. For convenience, the five GE images were named GE0.5, GE1, GE2, and GE4 respectively.

Finally, the S2 imagery was geo-referenced based on the 0.5m GE image with the accuracy of less than 0.5 pixel.

Sentinel 2 MSI 25th Jan. 2017			
Band name	Band number	Bandwidth (nm)	Spatial resolution (m)
Coastal	B1	430-457	60
Blue	B2	448-546	10
Green	B3	538-583	10
Red	B4	646-684	10
Red-Edge1	B5	694-713	20
Red-Edge2	B6	731-749	20
Red-Edge3	B7	769-797	20
NIR	B8	763-908	10
Vegetation Red Edge	B8A	848-881	20
Water- vapour	B9	932-958	60
SWIR Cirrus	B10	1336-1411	60
SWIR1	B11	1542-1685	20
SWIR2	B12	2081-2323	20

Table 2 The characteristics of Sentinel 2 MSI data

2.4 Texture Feature Extraction

The introduction of texture features has been widely proven to be an effective method of improve the accuracy of classification for remote sensing imagery. As textural features can reflect the local spatial changes of intensity or brightness, they have been shown to be valuable for mangrove species classification (Wang et al., 2015, Zhang et al., 2018, Wang et al., 2018).

In this study, the texture features of the Grey-Level Co-Occurrence Matrix (GLCM) were extracted based on the GE red band. According to GLCM analysis carried out by J Alberto et al.(2012), the texture variables derived from the red band of optical remote sensing data are the best explanatory variables for vegetation attributes15. In the Texture category, only four texture features based on the GLCM were considered among the 14 originally proposed by Haralick et al. due to the strong correlation frequently reported between many of the features. The four selected features were contrast, entropy, correlation, and homogeneity.

The window size of textural features is important to the mapping results, as an undersized window will fail to fully exploit the textural arrangement of the objects of interest, whereas an oversized window will result in blurring of the object boundaries8. Empirically, we applied a 19×19 window to calculate the GLCM texture features for GE0.5 data, and 17×17, 13×13, 9×9 window for GE1, GE2, GE4 respectively.
For comparison, the four textural features of S2 were also extracted based on the 10m resolution red band with 3×3 window.

2.5 SVM classifier

We used the support vector machine (SVM) classifiers to conduct mangrove species classifications. SVM is a machine-learning technique that is well adapted to solving non-linear, high dimensional space classifications. Different from traditional classification approaches, SVM classifier identifies the boundary between classes in n-dimensional spectral-space rather that assigning points to a class based on mean values. SVM creates a hyperplane through n-dimensional spectral-space that separates classes based on a user defined kernel function and parameters that are optimized using machine-learning to maximize the margin from the closest point to the hyperplane.

2.6 Accuracy Assessment

Accuracy assessment was conducted using confusion matrix. The overall accuracy (OA), user's accuracy (UA), producer's accuracy (PA), and the Kappa coefficient of the classification results of the six mangrove species were generated using all the testing samples described in Table 1.

3. RESULTS

3.1 Mangrove Species Classification

In this study, the S2 and GE data were designed in eight different features groups. The abbreviations and detailed information of the features groups are shown in Table 3. The S2 10m bands are the four 10m resolution bands of Sentinel 2 that are Blue, Green, Red, and NIR. The S2 20m bands are the six 20m solution bands of Sentinel 2, that are Red-Edge1, Red-Edge2, Red-Edge3, Vegetation Red Edge, SWIR1, and SWIR2. Type subheadings flush with the left margin in bold upper case and lower case letters. Subheadings are on a separate line between two single blank lines.

The resultant mangrove species maps of the Futian Mangrove Reserve based on the eight feature groups are shown in Fig. 2 to Fig. 9.

Sentinel 2 MSI 25th Jan. 2017			
No.	Abbreviation	Spectral Bands	Textural features
1	S2_10	S2 10m bands	-
2	S2_10 &20	S2 10m and 20m bands	-
3	S2+T10	S2 10m and 20m bands	Based on 10m S2 red band
4	GE+T0.5	GE RGB bands	Based on 0.5m GE red band
5	S2+T0.5	S2 10m and 20m bands	Based on 0.5m GE red band
6	S2+T1	S2 10m and 20m bands	Based on 1m GE red band
7	S2+T2	S2 10m and 20m bands	Based on 2m GE red band
8	S2+T4	S2 10m and 20m bands	Based on 4m GE red band

Table 3 Detailed information of the eight features groups

As reported by the previous studies, mangrove species are likely to grow within their own niches (Vaiphasa et al., 2006), and thus causes strip-like patterns (Jia et al., 2014). According to our field survey, the distributions of mangrove species in Futian Reserve are consistent with this characteristic. Using visual overview, besides the results of GE+T0.5 (Figure 2), the other seven thematic maps portrayed the similar mangrove species distribution and showed clearly zonations.

To compare the mangrove species classification results based on different feature groups, three regions of interest (ROI) I, II, and III were selected based on the functional zoning of Futian Reserve.

ROI 1 is located in the experimental zone. Besides the results of GE+T0.5, the other seven classification results all showed that SC and KO were the dominant species. According to the knowledge from field survey and Futian Reserve materials, we found that in Figure 3 and Figure 4, feature groups S2_10 and S2_10&20 underestimated KO, and in Figure 5, Figure 8 and Figure 9, feature groups S2+T10, S2+T2, and S2+T4 overestimated SA. In fact, there is hardly any SA in ROI 1.

ROI 2 is located in the core zone. KO, AC, and SC are the three dominated mangrove species, and are zonal distributed from landward to seaward. GE+T0.5 was the only one feature group of which the classification result did not show this distribution pattern. For feature groups S2_10 (Figure 3), S2_10&20 (Figure 4), and S2+T10 (Figure 5), the AI and AM were overestimated.

ROI 3 is located on the side of Shenzhen River estuary. SC and SA are the two dominated mangrove species. SC is distributed on the fringe of mangrove forests. The classification result of

GE+T0.5 was completely wrong. For feature groups S2_10 (Figure 3) and S2_10&20 (Figure 4), the SC at the edge was underestimated.

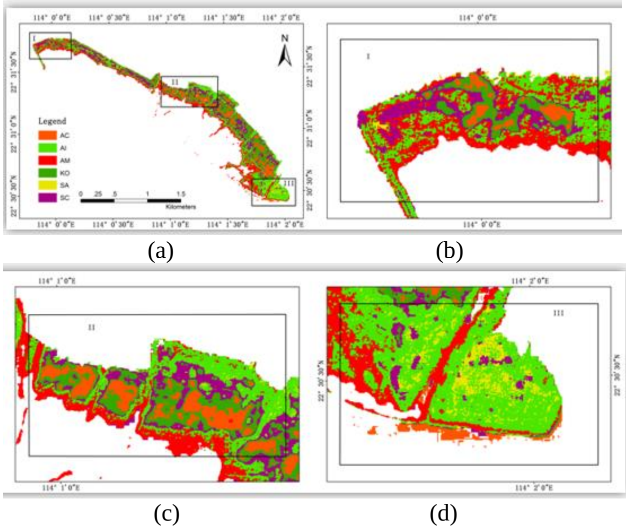


Figure 2. Mangrove species classification results based on feature group GE+T0.5, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3

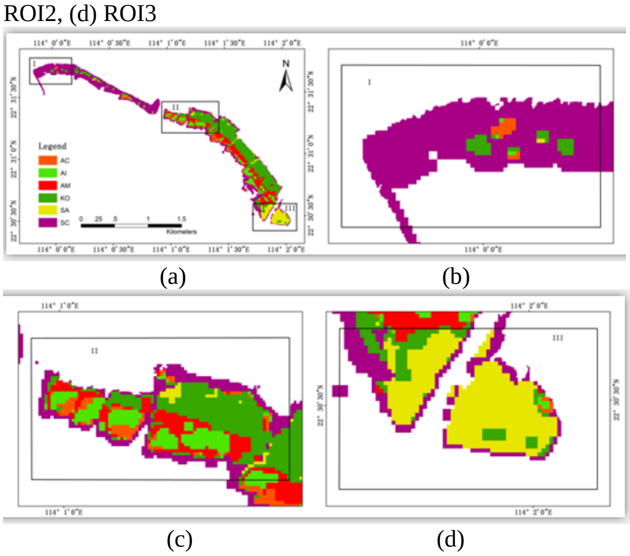


Figure 3. Mangrove species classification results based on feature group S2_10, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3

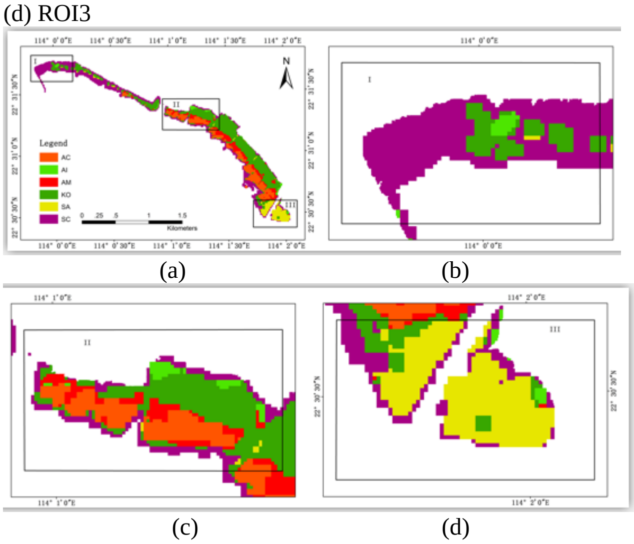


Figure 4. Mangrove species classification results based on feature group S2_10&20, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3

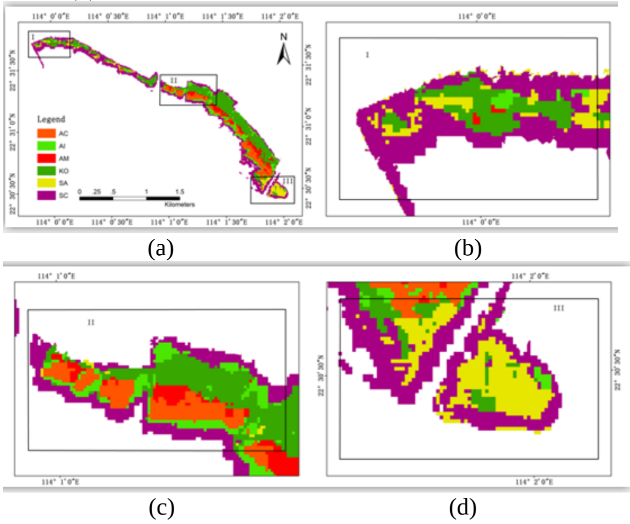


Figure 5. Mangrove species classification results based on feature group S2+T10, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3

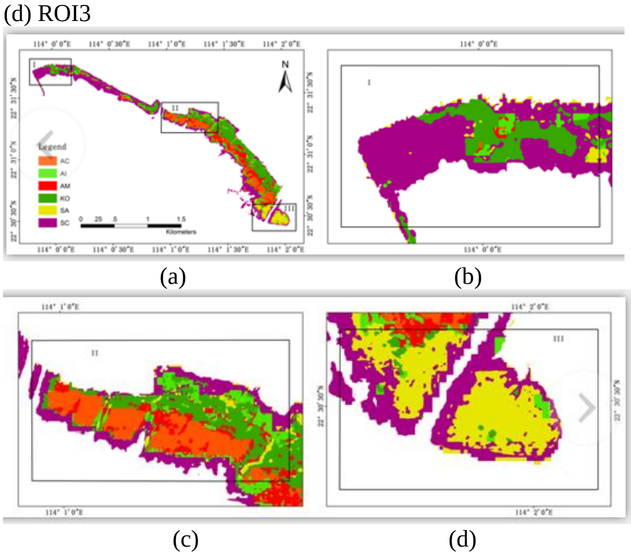


Figure 6. Mangrove species classification results based on feature group S2+T0.5, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3

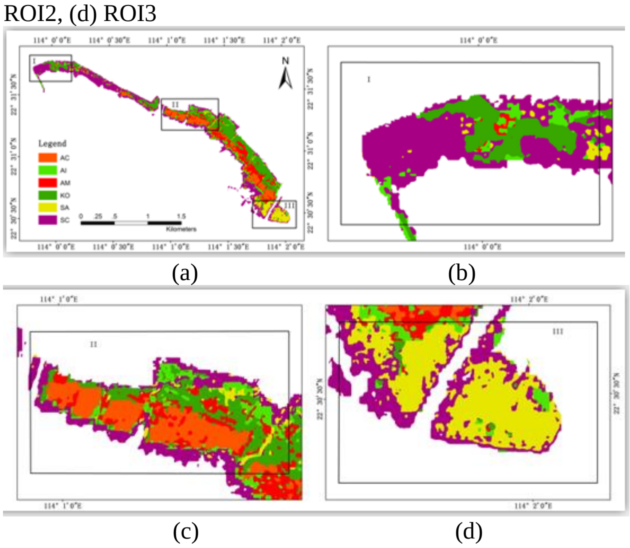
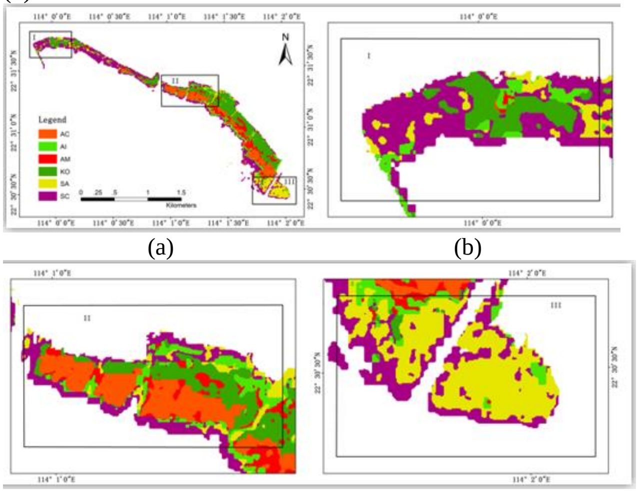
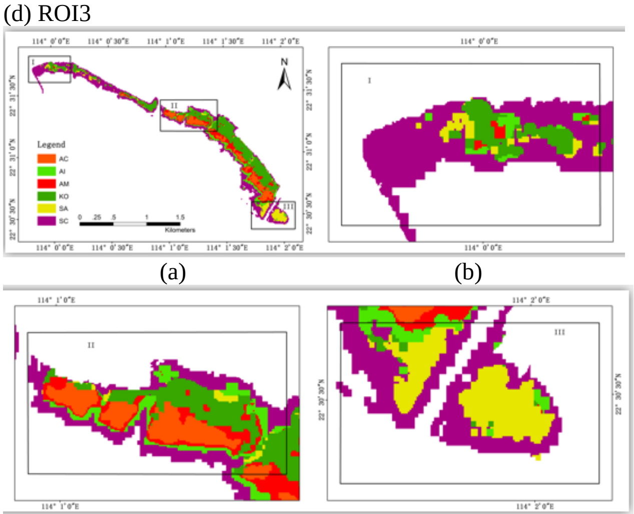


Figure 7. Mangrove species classification results based on feature group S2+T1, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3



(a) (b) (c) (d)

Figure 8. Mangrove species classification results based on feature group S2+T2, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3



(a) (b) (c) (d)

Figure 9. Mangrove species classification results based on feature group S2+T4, (a) whole study area, (b) ROI1, (c) ROI2, (d) ROI3

3.2 Accuracy Assessment

The classification accuracy of the mangrove species based on different feature groups is shown in Table 4. Consistent with the results discussed in Section 3.1, the lowest accuracy came from GE+0.5T, of which the overall accuracy was just 43.15%.

No.		1	2	3	4
Feature Group		S2_10	S2_10&20	S2+T10	GE+T0.5
Overall Accuracy		53.78%	71.42%	72.13%	43.15%
Kappa Coefficient		0.44	0.65	0.65	0.35
AC	PA	9.52%	95.24%	83.34%	15.32%
	UA	22.22%	88.89%	84.76%	26.43%
AI	PA	32.61%	56.52%	76.09%	45.31%
	UA	25.42%	52.00%	59.32%	27.76%
AM	PA	33.33%	23.81%	40.12%	47.62%
	UA	37.84%	43.48%	70.13%	29.65%
KO	PA	91.03%	91.30%	93.48%	60.15%
	UA	75.00%	76.36%	85.12%	63.21%
SA	PA	82.35%	94.12%	64.71%	52.97%
	UA	70.00%	66.67%	61.11%	67.59%
SC	PA	86.67%	80.00%	77.78%	35.82%
	UA	81.25%	87.80%	74.62%	43.68%
No.		5	6	7	8
Feature Group		S2+T0.5	S2+T1	S2+T2	S2+T4
Overall Accuracy		77.73%	78.57%	77.05%	73.10%
Kappa Coefficient		0.73	0.74	0.72	0.67
AC	85.71%	85.71%	80.95%	83.33%	15.32%
	87.80%	87.80%	91.89%	89.74%	26.43%
AI	78.26%	78.26%	80.43%	76.09%	45.31%
	63.16%	66.67%	62.71%	64.81%	27.76%
AM	38.10%	45.24%	33.33%	38.10%	47.62%
	55.17%	59.38%	46.67%	57.14%	29.65%
KO	95.65%	95.65%	95.65%	91.30%	60.15%
	89.80%	91.67%	88.00%	91.30%	63.21%
SA	76.47%	70.59%	76.47%	64.71%	52.97%
	76.47%	75.00%	72.22%	61.11%	67.59%
SC	88.89%	88.89%	86.67%	77.78%	35.82%
	88.89%	85.11%	88.64%	67.31%	43.68%

Table 4 Accuracy descriptive statistics of mangrove species based on different feature groups

Overall accuracy of mangrove species maps based on exclusively S2 data reached the values of 53.78% and 71.42%, when feature groups S2_10, and S2_10&20 were used. Compared the results of S2_10 with S2_10&20, with the addition of S2 20m red edge and SWIR bands, the producer's and user's accuracies of the six mangrove species were increased, and the AC was increased most noticeably, from 9.52% and 22.22% to 95.24% and 88.29%. For feature group S2_10&20, the accuracies of AI and AM were less than 60%. These two mangrove species were not identified as easily when using only spectral features.

When the texture features of S2 10m red band were introduced in the S2_10&20 feature groups, the overall accuracy was slightly improved from 71.42% to 72.13%, which indicated that the contribution of 10m textural features was little.

Mangrove species mapping results based on the combination of S2 spectral bands and GE texture features had higher accuracies than mapping results based exclusively on S2 data. Particularly, the highest accuracy was reached when feature group S2+T1 was used (overall accuracy 78.57%, Kappa coefficient 0.74), followed by feature groups S2+T0.5 (overall accuracy 77.73%, kappa coefficient 0.73), S2+T2 (overall accuracy 77.05%, kappa coefficient 0.72), and S2+T4 (overall accuracy 73.10%, kappa coefficient 0.67). By comparison with the feature group S2+T10, the overall accuracies of S2+T1, S2+T0.5, S2+T2, and S2+T4 increased by 6.44%, 5.6%, 4.92%, and 0.97%, respectively. There was not significant difference among the mapping accuracies of S2+T0.5, S2+T1, and S2+T2. This is consistent with the mapping results shown in Figures 6-8.

4. DISCUSSIONS

4.1 The Potential of Combination of S2 and GE Images for Mangrove Species Classification

Knowledge gained about the mangrove species mapping is essential to understand mangrove species development and to better estimate their ecological service value. From the perspective of mangrove managers, ecologists, and geographers, cost-effective remote sensing data, which is suitable for continuous and large geographic coverage application, is very important.

One objective of this study was to perform mangrove species classification in Shenzhen Bay, China by using Sentinel 2 MSI data and Google Earth high resolution imagery as data sources and to examine their suitability in mapping mangrove forest at a species level. The classification results show that in general, the combination of S2 and GE data can achieve an overall accuracy of 78.57% and Kappa coefficient 0.74 (feature group S2+T1). Moreover, the distribution of individual mangrove species is basically consistent with the official records. This suggests the great potentials of combining the freely available S2 and GE imagery in mangrove species mapping.

The advantage of combining S2 and GE images can be further demonstrated by comparison with the classification results when S2 and GE images were used alone. Compared to the feature group GE+T0.5 (only GE image was used), the combination of S2 and GE images improved the overall accuracy from 43.15% to 78.57%, while the kappa coefficient from 0.35 to 0.74. Although GE image has high resolution, its classification results were very poor due to the lack of key spectral bands. Compared to the feature group S2_10&20 (only S2 spectral bands were used), the introduction of GE texture features (feature group S2+T1) improved the overall accuracy from 71.42% to 78.57%, while kappa coefficient from 0.65 to 0.74. The textural features based on S2 image were also tested with S2 spectral bands (feature group S2+T10), however, the contribution of 10m resolution textural features was very small, with just 0.71% improvement of overall accuracy.

In general, the S2 MSI data and high resolution GE data are highly complementary in mangrove species classification. In consideration of the high price of data sources which can provide high resolution band and multi-spectral bands simultaneously (such as WorldView constellation), the combination of two freely-available data sources can be regarded as a viable alterative.

4.2 Contributions of S2 Spectral Bands with Different Resolution

As shown in Table 3, the eight feature groups based on S2 and GE imagery have different discrimination capacities for mangrove species mapping, which are attributed to two main factors: 1) spectral bands selection of S2 data, and 2) spatial resolution of GE imagery.

In this study, the 13 S2 bands (Table 2) were divided to 3 groups based on their resolution, 10m, 20m, and 60m. Besides feature group GE+T0.5, feature group S2_10 (including only 10m bands) performed worst among the seven feature groups, with OA 53.78%, kappa coefficient 0.44. Previous studies (Wang et al., 2018, Wang et al., 2004) confirmed that the use of high resolution IKONOS, QuickBird and Pléiades-1 data, which have spectral bands similar to Sentinel 2 10m bands, can effectively map mangrove species with high accuracies. Our results showed that when the spatial resolution was degraded to medium resolution (10-100m), the coarse spatial resolution decreased the capability of Red, Green, Blue, and NIR bands for mangrove species mapping greatly.

S2 20m bands include four red edge and two SWIR bands. Previous studies (Wang et al., 2018, Wang et al., 2004) showed that red edge and SWIR bands were more important than NIR and visible bands in mangrove species classification. Our results were consistent with their conclusions. As shown in Table 3, when the 20m bands were included in the feature group (S2_10&20), OA was greatly improved from 53.78% to 71.42% (kappa coefficient from 0.44 to 0.65).

S2 60m bands include coastal aerosol, water vapour and SWIR/Cirrus bands. The three bands contributed little to improve the mapping accuracy. When the 60m bands were included in the feature group (S2_all), OA decreased a bit from 71.42% to 71.01% instead. Due to the limited space, the thematic map and accuracy assessment of feature group S2_all were not included in this study. As the contribution of the three S2 60m bands was quite limited, they were not included in the features groups with both spectral bands and textural features.

4.3 Optimal Textural Features Resolution

The use of high resolution textural features (around 1m) can effectively improve the results of mangrove species mapping, as described in previous studies (Wang et al., 2015, Wang et al., 2018). The same conclusion can be reached in this study. When the texture features based on 0.5m GE imagery were included in feature group (S2+T0.5), OA was improved from 71.42% to 77.73%.

The higher the spatial resolution of remote sensing data, the more detail it contains, but at the same time the larger computation it brings. One of the objective of this study was to analyze the influence of GE spatial resolution on the mangrove species mapping accuracy. To our knowledge, this has not been discussed in previous studies. In Section 2.5, the texture features were extracted based on five levels of GE imagery with different spatial resolutions. When the spatial resolution of GE imagery was 4m and 8m (corresponding to feature groups S2+T4 and S2+T8 respectively), the overall accuracies were 73.52% and 73.10% respectively, which were a little bit higher than that of mapping results without texture features (feature group S2_10&20, OA 71.42%). Due to the limited space, the thematic map and accuracy assessment of feature group S2+T8 were not included in this study. When the spatial resolution of GE imagery was 2m, 1m, and 0.5m (corresponding to feature groups S2+T2, S2+T1, and S2+T0.5), OA was improved to around 78%, and there was not significant difference among these three mapping results. When the spatial resolution of texture features was higher than 2m, the increase of spatial resolution could not improve classification accuracy significantly with respect to mangrove species mapping. Based on the above results and discussions, taking both computation amount and classification accuracy into account, the optimal spatial resolution for GE imagery texture features extraction is 2m.

4.4 Future Works

This study presented the preliminary results for the evaluation of GE and S2 in mangrove species classification. There are still several issues to be explored in the future. Firstly, in this study, the texture features were extracted based on window box with fixed size. The main drawback of this approach is that the mangrove forests, which were at the edge of different communities or smaller than the window size, might be misclassified. Object-oriented classification is a promising way to overcome this drawback. The textural features will be extracted based on the mangrove communities oriented objects. Secondly, SVM classifier is a traditional classification method. In the future, some new and advanced classifiers, such as Random Forest and Rotation Forest (Zhang et al., 2018, Wang et al., 2018) will be tested. At last, the potential of the combination of S2 MSI and GE imagery in mangrove species classification will be further explored by comparison with WorldView constellation data, based on the same texture extraction technique, the same classifier, and the same samples.

5. CONCLUSIONS

This study validated the potential suitability of the combination of freely access S2 MSI data and GE imagery for mapping mangrove species. In the classification feature groups, the spectral bands were from the S2 MSI data and the textural features were based on GE imagery. Our results indicated that taking both computation amount and classification accuracy into account, the spatial resolution of GE imagery was 2m, and spectral bands of S2 MSI data are 10m and 20m bands. This study will provide a technique reference for other forest species classification by costing little.

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