Paper presented at the 22nd Asian Conference on Remote Sensing, 5 - 9 November 2001, Singapore.

EVALUATION OF LANDSAT 7 ETM+ DATA FOR COASTAL HABITAT ASSESSMENT IN SUPPORT OF FISHERIES MANAGEMENT

Randy John N. Vinluan and Jose Don T. De Alban
Department of Geodetic Engineering
University of the Philippines, Diliman
1101 Metro Manila, The Philippines
Fax: (63 2) 9208924; E-mail: rjnv@up.edu.ph

KEY WORDS: Coastal habitat, Fisheries management, Landsat 7, Mapping, Remote sensing

ABSTRACT. Coastal habitats such as coral reefs, mangroves, seagrasses, and algae are important to fisheries management since these serve as indicators of fish stock, the health status of the coastal environment, and others. The suitability of Landsat 7 ETM+ data for mapping these coastal habitats was evaluated by the study. The study areas are two bays located in the province of Palawan in the Philippines, namely Puerto Princesa Bay and Honda Bay. Although adjacent to one another, the two bays actually represent different environmental conditions. Typical algorithms for the correction for the effects of water depth, radiometry, the atmosphere, and scene orientation were applied to the image. The resulting satellite image map was evaluated for visual interpretability of the coastal habitats under consideration. The appearance of these habitats, as well as that of some coastal landforms, in selected combinations of Landsat 7 ETM+ bands, is shown in the paper. Limitations in the level of habitat classification that are possible with Landsat 7 ETM+ data are also enumerated. The preprocessed satellite image was also subjected to digital classification techniques using field and other data gathered during site visits conducted in November 2000 and April 2001. Results of the classification are also discussed in the paper.

1. INTRODUCTION

The agriculture and fisheries sector is one of the most important sectors in the Philippines employing about 38 percent of the total workforce and with an annual total production valued at P557.3 billion (or US$ 10.4 billion). In cognizance of the valuable contributions made by this sector to the national economy, concrete actions have been taken to address various problems concerning the development of this sector. On the fisheries side, these problems include fisheries declining, coral reefs battered, mangrove forests under threat, pollution levels rising, and coastal communities experiencing increased poverty (Courtney and White, 2000).

Improved management approaches are needed in order to reduce the rate at which humans are depleting fishery populations and degrading marine ecosystems (Murray *et al*., 1999). The Fisheries Resource Management Project (FRMP), being implemented by the Bureau of Fisheries and Aquatic Resources (BFAR), is one such approach. FRMP aims to strengthen fisheries regulations, rationalize the utilization of fisheries resources, and rehabilitate damaged fish habitats.

An essential component of FRMP is the updating of land use and coastal habitat information for the 18 bays covered by the project. These two themes are important because it has been found that impacts on land-use and coastal habitats lead to significant ecological problems such as saltwater intrusion and loss of coastal wetlands, among others (Chesney *et al*., 2000). In addition, it has been found that protective habitat management and habitat restoration mitigates the degradation or loss of habitat structure while maintaining healthy sustainable fisheries (Turner *et al*., 1999). Coastal habitats themselves serve as indicators of fish stock, the health status of the coastal environment, and others.

It is a well-known fact that remote sensing plays an important role in the mapping of such themes. Literature reports the use of aerial photographs and multispectral data, and Landsat MSS/TM and SPOT XS/Pan images for coastal land use and habitat mapping with varying degrees of success (*e.g.* Zainal *et al*., 1993; Maritorena, 1996; Chauvaud *et al.*, 1998).

This study evaluates the suitability of the latest satellite in the Landsat series, namely Landsat 7, for coastal habitat mapping. The satellite carries a new sensor called Enhanced Thematic Mapper (ETM+), which is an improvement over the Thematic Mapper sensor carried by Landsat 4 and 5. For a detailed technical description of the Landsat 7 mission, one is referred to the special issue of Earth Observation Magazine on Landsat 7 that came out in March 1999 or to the Landsat Program Web site (URL: geo.arc.nasa.gov/esdstaff/landsat/tofc.html).

The study area is Puerto Princesa Bay and Honda Bay, both located at the eastern side (Sulu Sea-side) of Puerto Princesa City, the capital of the province of Palawan in the Philippines. Although adjacent to one another, the two bays actually represent different environmental conditions. The former is a busy commercial sea-lane with passenger ships and fishing vessels plying their routes in its waters. The latter, on the other hand, is the site of several national and international programs for conservation and tourism.

2. METHODS

A Landsat 7 ETM+ image (path = 117, row = 53) that covered the two bays, acquired on 9 September 1999, was used in the study. The image was already system-corrected using UTM-51 and WGS-84 as the projection and reference ellipsoid respectively. Figure 1a displays bands 4, 2, and 1 in red, green, and blue respectively.

Radiometric calibration, which aimed to compensate for atmospheric effects and to produce imagery that was ready for depth-correction, consisted of conversion of the digital numbers (DNs) to at-sensor radiance using the equation: at_sensor radiance = DN $\times$ gain + bias, and conversion of the at_sensor radiance to surface radiance by the dark-object subtraction method. The gain and bias coefficients for each Landsat band were listed in the image header. Chavez (1988) gives details of the dark-object subtraction method.

Water depth correction was applied to the radiometrically-corrected image in order to compensate for the attenuating effect of variable water depth on the spectral radiance recorded by the sensor. It has been reported that the accuracy of habitat maps showed significant improvement once water depth correction had been implemented (Green *et al*., 2000). The procedures for water depth correction described by Lyzenga (1978; 1981) were used in the study.

The resulting satellite image map was evaluated for visual interpretability of the coastal habitats (and other land cover types) under consideration using elements of interpretation that included tone, shape, size, orientation, and context. The preprocessed satellite image was also subjected to digital classification techniques, after masking out the land area and the off-map region, using field and other data gathered during site visits conducted in November 2000 and April 2001. The accuracy of the classification was assessed using a test dataset that was independent of the training dataset.

3. RESULTS

3.1 Visual interpretation

Figure 2 shows the appearance of different coastal habitats and land cover in the Landsat 7 ETM+ image of the study area in both false color (RGB = 421) and true color (RGB = 321) schemes. In general, the objects under study appear quite distinctly.

Figure 2a is an image of white-sand beach at the northwest side of Makesi Island in Honda Bay. It appears very bright in both color modes. Figure 2b shows a coconut plantation at the lower side of the national highway, which itself appears a long bright line. The plantation appears bright red and dark green in false and true color modes respectively. The dark lines that run almost parallel to the road are small creeks.

Figure 2c is an image of a fringing coral reef surrounding Fondeado Island (which appears bright red or light green tones in false and true color modes respectively) and the adjacent mangroves, also in Honda Bay. The coral reef appears as a bright ring surrounding the island. The reef in this area is a mixture of dead and living corals of varying density and species. In this case, it is difficult to identify more specific information categories for coral reefs. Some coral reef pixels also appear similar to pixels corresponding to a sandy bottom type or shallow water with a muddy bottom type.

Figure 2d is an image of deep water. It appears almost pitch black in both color modes because of the attenuation of incoming light as the light is transmitted through the water column. Figure 2e is an image of an estuary, where the Babuyan River meets Honda Bay. The mouth of the river appears bright because of the high reflectance resulting from the vigorous mixing of sediments carried by the river into the receiving bay.

Figure 2f is an image of an island, particularly Arrecife Island in Honda Bay, where the world-famous Dos Palmas Resort is situated. The structures in the western side of the island appear bright and are distinguished from the mangroves (which appear dark red) and the fringing coral reef (which appears as a bright ring around the island). Figure 2g is an image of mangroves on a portion of the coast of Puerto Princesa City. Mangroves appear in dark red tones and are distinguished from other vegetation types, which appear in lighter tones of red. This, however, is not a general rule.

Figure 2h is an image of an exposed sand bar. The long sand bar, stretching almost three kilometers, is part of what is called the Snake Island and appears as a bright line on the image. Figure 2i is an image of very dense seagrass beds in Puerto Princesa Bay. Seagrass, whose blades may reach a height of more than one meter, appears in patches of light and dark green pixels.

Figure 2j depicts shallow water and appears bright because of bottom reflectance. Figure 2k is a spit formed by longshore currents and appears as light red or light green in false and true color modes respectively. Finally, the northeastern part of figure 2l shows sand submerged in shallow water. During periods of low tide, this part of the bay is exposed.

3.2 Digital classification

Seven coastal land cover and habitat types were identified in the two bays. These were coral reef, deep water, mangroves, other vegetation, sandy bottom, seagrass, and shallow water. One hundred training pixels for each class were selected by one analyst. This dataset was used to generate decision rules for classification using the maximum likelihood algorithm. Another hundred pixels for each class were selected by another analyst, and this dataset was used to evaluate the accuracy of the classification.

Figure 1b shows the result of the classification. It is apparent that the area covered by coral reefs appears to be overestimated as its spectral response had been confused with that of sandy bottom. Mangroves along the coast have been excluded from the classification as these were within the mask that was built for the analysis.

An overall classification accuracy of about 67 percent (or a kappa coefficient of 0.62) was achieved. An inspection of the confusion matrix reveals a clearer picture of the results of the classification (please refer to table 1). Twenty-eight percent of identified coral reef pixels were misclassified as sandy bottom and seagrass. As had been shown earlier, the similar bright appearance of the three classes on the image was confusing. Thus, for the same reason, twenty-seven percent of sandy bottom pixels and 42 percent of seagrass pixels were misclassified as coral reef pixels.

Twenty percent of mangrove pixels were misclassified as other vegetation types. The converse was also true—10 percent of other vegetation pixels were misclassified as mangrove pixels. This seems to be a common problem with remote sensing of mangroves in a mixed vegetation environment.

Table 1. Confusion matrix resulting from the classification of the Landsat 7 ETM+ image of the study area.

CLASS	CR	MN	SB	DW	SW	SG	OV	Total
CR	60	2	27	0	33	42	0	**164**
MN	0	76	0	0	0	1	10	**87**
SB	14	2	60	1	15	1	0	**93**
DW	8	0	2	89	3	6	0	**108**
SW	4	0	0	10	46	1	0	**61**
SG	14	0	3	0	3	49	0	**69**
OV	0	20	8	0	0	0	90	**118**
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**700**

Note: CR = coral reefs, MN = mangroves, SB = sandy bottom, DW = deep water, SW = shallow water, SG = seagrass, OV = other vegetation.

4. DISCUSSION

For visual interpretation of Landsat 7 ETM+ imagery, this type of data seems to be suitable for mapping coastal land cover, landforms, and habitats. This is notwithstanding the similarity in the appearance, for example, of coral reefs and sandy bottom type, or mangrove and other vegetation, on the image. However, it also seems that a higher-ordered classification level scheme is not possible with this type of data. For example, while coral reef patches are, generally, easily identifiable in the image, it is not easy to assess the health condition or percent cover or density, or determine individual coral species. For fisheries management, information on the condition of the status of coral reefs (whether excellent, good, fair, or poor) and percent cover (*e.g.* 30 percent good corals, 20 percent dead corals, and 50 percent rubble bottom), among others, are important for planning and monitoring purposes. Another example is with mangroves. It appears to be quite difficult to assess the maturity of mangrove stands. This type of information is important because it allows coastal management stakeholders to determine where to focus mangrove reforestation efforts.

Digital classification does not seem to resolve satisfactorily the problem with spectral confusion between coastal habitats and land cover. The confusion matrix is illustrative of this limitation. Furthermore, the achieved accuracy of classification of 67 percent yields a coastal habitat map that is useful only for making general decisions related to fisheries management and not to site-specific planning or modeling. The spatial resolution of the satellite data may have something to do with this. Studies making use of higher-resolution data reported higher accuracies for coastal habitat classification (*e.g.* Mumby *et al*., 1998).

Some of the differences between a visually-interpreted and a digitally-classified coastal habitat map may be resolved by integrating the two maps, although, more often than not, this is a subjective exercise. A digitally-classified coastal habitat map may be improved by contextual editing and combining analyst knowledge and experience. Several dates of Landsat 7 ETM+ imagery may prove to be invaluable for monitoring dynamic changes in coastal areas.

5. CONCLUSIONS

The study evaluated the suitability of Landsat 7 ETM+ data for mapping coastal habitats. It found that Landsat 7 ETM+ imagery was suited for mapping with decent accuracy general coastal habitats only. A more detailed classification might be possible but would be generally difficult. There was spectral confusion between some coastal habitats and land cover resulting to a similar appearance on the image. Digital classification seemed to be unable to resolve this ambiguity fully. Only a 67 percent overall classification accuracy was achieved. The coastal habitat map might be improved by the complementary use of visual interpretation and digital analysis. Nevertheless, the resulting coastal habitat map could be used for general planning and several maps, derived from different dates of imagery, for monitoring purposes.

6. ACKNOWLEDGEMENTS

The authors wish to acknowledge the funding support of the Fisheries Resource Management Project of the Bureau of Fisheries and Aquatic Resources and the technical support of the staff of the Remote Sensing Image Analysis Laboratory of the University of the Philippines.

REFERENCES

Chauvaud, S., C. Bouchon and R. Manière, 1998. Remote sensing techniques adapted to high resolution mapping of tropical coastal marine ecosystems (coral reefs, seagrass beds and mangrove). International Journal of Remote Sensing 19, pp. 3625-3639.

Chavez, P. S. Jr., 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sensing of Environment 24, pp. 459-479.

Chesney, E.J., D.M. Baltz and R.G. Thomas, 2000. Louisiana estuarine and coastal fisheries and habitats: Perspectives from a fish's eye view. Ecological Applications 10(2), pp. 350-366.

Courtney, C.A. and A.T. White (2000). Integrated coastal management in the Philippines: Testing new paradigms. Coastal Management 28(1), pp. 39-53.

Green, E.P., P.J. Mumby, A.J. Edwards, C.D. Clark, 2000. Remote Sensing Handbook for Tropical Coastal Management. UNESCO Publishing, Paris.

Lyzenga, D.R., 1978. Passive remote sensing techniques for mapping water depth and bottom features. Applied Optics 17, pp. 379-383.

Lyzenga, D.R., 1981. Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. International Journal of Remote Sensing 2, pp. 71-82.

Maritorena, S., 1996. Remote sensing of the water attenuation in coral reefs: A case study in French Polynesia. International Journal of Remote Sensing 17, pp. 155-166.

Mumby, P.J., E.P. Green, C.D. Clark, and A.J. Edwards, 1998. Digital analysis of multispectral airborne imagery of coral reefs. Coral Reefs 17, pp. 59-69.

Murray, S.N., R.F. Ambrose, J.A. Bohnsack, L.W. Botsford, M.H. Carr, G.E. Davis, P.K. Dayton, D. Gotshall, D.R. Gunderson, M.A. Hixon, J. Lubchenco, M. Mangel, A. MacCall, D.A. McArdle, J.C. Ogden, J. Roughgarden, R.M. Starr, M.J. Tegner and M.M. Yoklavich (1999). "No-take reserve networks: Sustaining fishery populations and marine ecosystems". Fisheries 24(11), pp. 11-25.

Turner, S.J., S.F. Thrush, J.E. Hewitt, V.J. Cummings and G. Funnell, 1999. Fishing impacts and the degradation or loss of habitat structure. Fisheries Management & Ecology 6(5), pp. 401-420.

Zainal, A.J.M., D.H. Dalby and I.S. Robinson, 1993. Monitoring marine ecological changes on the east coast of Bahrain with Landsat TM. Photogrammetric Engineering and Remote Sensing 59(3), pp. 415-421.

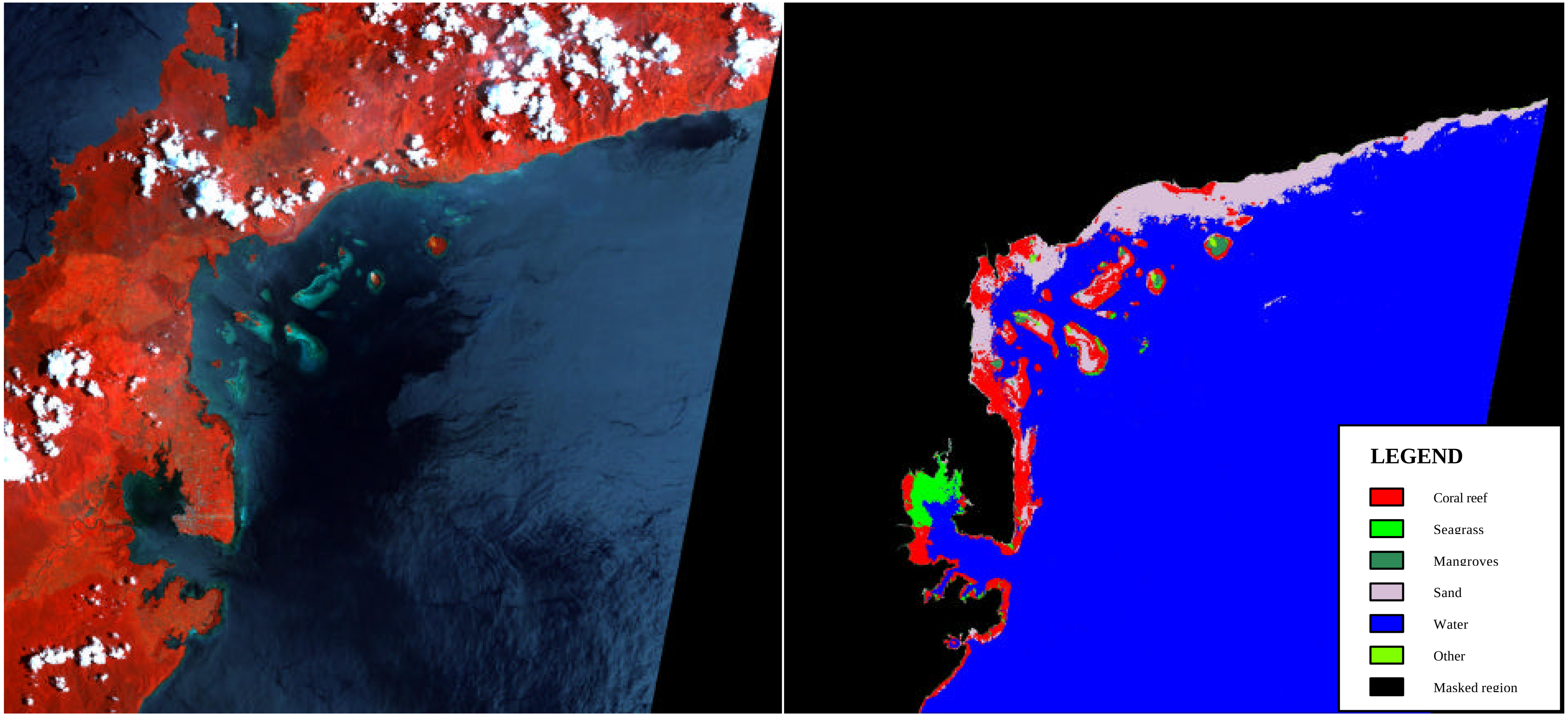

Figure 1. 1:500,000-scale plot of (a) the Landsat 7 ETM+ image of Puerto Princesa Bay and Honda Bay taken in 9 September 1999, and (b) the coastal habitat map derived from multispectral classification of the image.

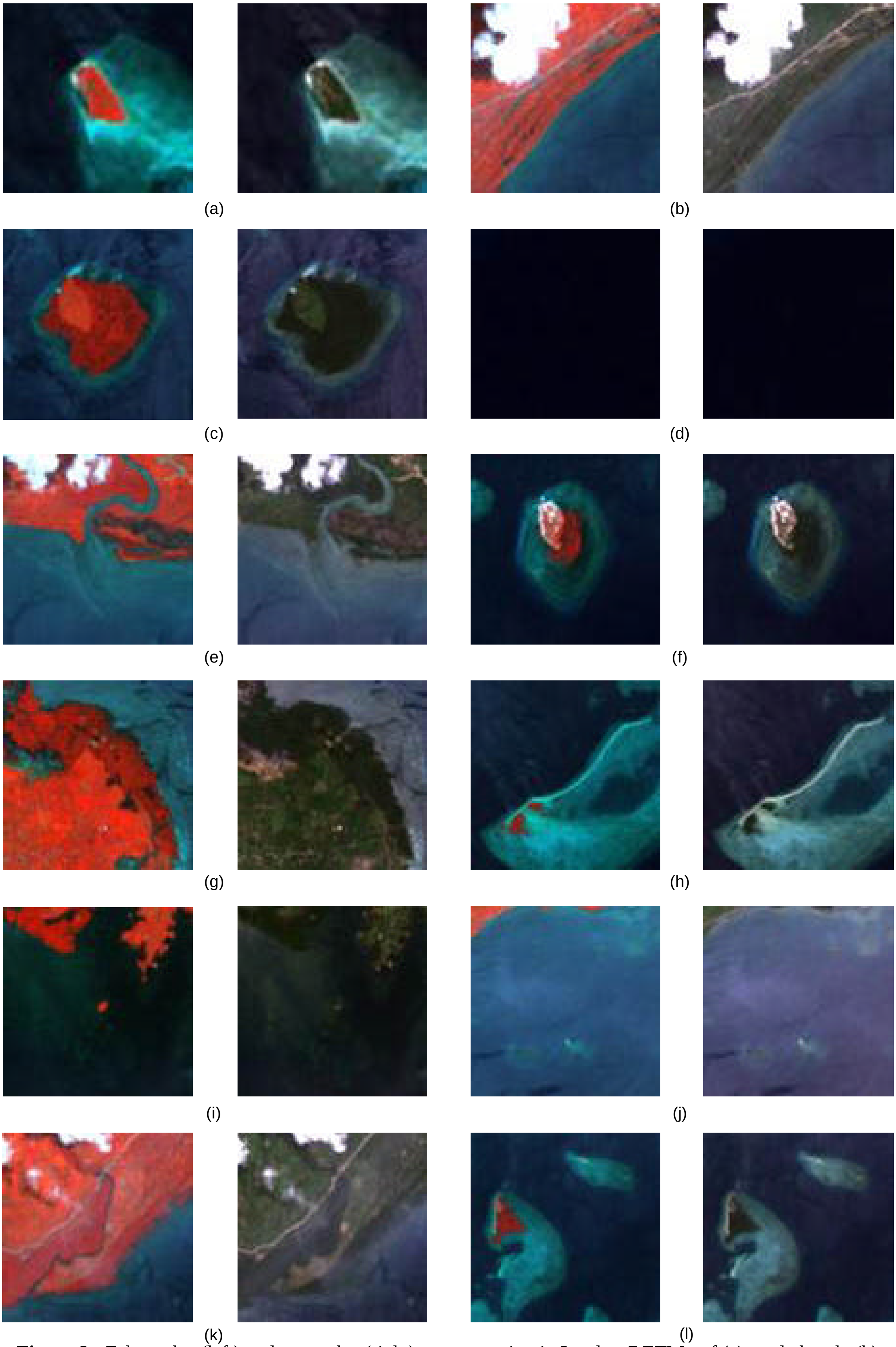

Figure 2. False color (left) and true color (right) representation in Landsat 7 ETM+ of (a) sandy beach, (b) coconut plantation, (c) coral reef, (d) deep water, (e) estuary, (f) island, (g) mangroves, (h) sand bar, (i) seagrass, (j) shallow water, (k) spit, and (l) submerged sand.