Object-oriented classification modelling for fuel type mapping in the Mediterranean, using LANDSAT TM and IKONOS imagery—preliminary results

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Keywords: fuel type mapping, object-oriented classification, model, LANDSAT TM, IKONOS

ABSTRACT: Fuel type, as well as topography and microclimatic conditions, are some of the most important factors that should be taken into consideration for pre-fire planning. These factors have additional importance in the areas of forest protection and regeneration. A problem that remains unsolved is that an adequate classification method which is able to provide satisfactory results, has still not been developed. Until now, most of the techniques that have employed aerial photography or satellite imagery are based on differences within spectral information. The aim of this paper is to use a more accurate technique, Object Oriented Classification, which is based not only on spectral but also on spatial information (such as shape, texture and neighbouring objects). The main dataset consisted of a LANDSAT TM image (1985) and an IKONOS image (2000). The method comprised the following steps: image correction (including atmospheric, geometric, and topographic correction), modification for each type of satellite imagery of a widely accepted fuel type standardization system, model construction using Object-Oriented Classification, and Comparison of the results obtained from the model developed on the LANDSAT TM image with those obtained from that developed on the IKONOS image. The aim was to build two operational models based on Object-Oriented analysis that could be used as tools for fuel type mapping. The LANDSAT TM model included 5 sub-classes and was employed to obtain information at a macroscopic level, while IKONOS included 6 sub-classes and was considered more appropriate for the detection of spatial features.
1 INTRODUCTION

In pre-fire planning, an important factor that should be considered is fuel type. Fuel maps are essential for computing spatial fire hazard and risk and simulating fire growth and intensity across a landscape (Keane, 2001). Fuel type classification is a mapping technique developed in certain areas that is adapted not only according to the topographical and geographical characteristics of the area being investigated, but also to the specific climatic conditions, the prevalent negative human activities (Trabaud, 2000), etc. This is why fuel mapping is an extremely difficult and complex process requiring expertise in remotely sensed image classification, fire behavior, fuel modeling, ecology, and Geographical Information Systems (GIS).

Supervised classification is the most commonly used method in Remote Sensing for identification of spectrally similar objects on an image (Jensen, 1996).

Data that can be used for classification come mainly from satellite images, aerial-photography and field measurements. However, there is still the need to find an appropriate and accurate method for fuel type mapping (Wagtendonk, 1997). Until now, most of the techniques that have employed aerial photography or satellite imagery have been based on differences within spectral information.

In **Object Oriented Classification**, which is the technique that was adopted in this work, not only the spectral signature but also some spatial characteristics – such as shape, texture and neighbouring objects – were taken as the main classification factors. Any information provided by the abovementioned features was be combined with information afforded by the relationships among objects, super-objects and sub-objects contained either in neighbouring classes, super-classes or sub-classes in the same or a different level of segmentation in order to retrieve the desired information. According to Keane (2001), four approaches to mapping fuels are acceptable: (1) field reconnaissance; (2) direct mapping methods; (3) indirect mapping methods; and (4) gradient modeling. The proposed fuel mapping method uses current remote sensing and image processing technology. A well accepted class system, which takes into consideration the specific characteristics of the area under investigation, is also needed (Loveland, 2001).

Within Greece, the system referred to as “PROMETHEUS” deals with the composition and the sorting of various types of vegetation within the ecosystem of Greek forests. According to this system, fuels are divided into 7 types (classes). In this study a modification of this system (taking into consideration the satellite type and its properties) was used to accompany each satellite image.

The aim of this study was to develop two object-oriented models for fuel type mapping using medium-high (LANDSAT TM) and very high (IKONOS) resolution data. Our attention focused on the following objectives:

- to determine which of the aforementioned fuel types (PROMETHEUS system) could be detected via Remote Sensing in the case of a medium - high resolution image (such as LANDSAT) and that of a very high resolution image (such as IKONOS), and to apply the modified standardization in each case;
- to compare the results of the two satellite images and detect their respective advantages and disadvantages.
2 DESCRIPTION OF THE STUDY AREA

Figure 1. Thasos island in the Northern Aegean Sea

The island of Thasos (Figure 1) is located in the Northern Aegean Sea, south of Kavala city. It extends from 24°30’ to 24°48’ East and 40°33’ to 40°49’ North. Its total surface area is 39,000 ha, and its perimeter approximately 104 km. The mean annual precipitation is 783.48 mm, of which approximately 65% falls in the period between September and April. The dry/hot season (xerothermic period) starts in May and lasts for 4-5 months up to mid September, with August being the driest and July the warmest month of the year.

Based on the above, the combination of hot, dry summers and wet winters satisfies the conditions required to classify the climate of Thasos as a Mediterranean climate. Furthermore, Gitas (1999) used the Emberger (1971) method to define the subclass of the Mediterranean bioclimatic type of Thasos, which was found to be cool and sub-humid.

Landcover and vegetation description: Before the forest fire of 1984, which was one of the three largest fires occurring between 1984 and 1989, forest and forested lands covered 47.5% of the island (Gitas, 1999), making forests the dominant landcover type at the time. Other landcover types include bare land, barren land, shrublands, fields, orchards and human settlements. After the fires of 1984 and 1985, forests and forested lands covered 37.95% of the island (Makedos, 1987). To-
day, as a result of fires, illegal logging, intensive grazing and bad management, the remaining forest has a spatial extent of approximately 2000 ha in the Northern and Eastern parts of the island (Gitas, 1999).

*Pinus brutia* is the dominant species of the forests at elevations ranging from sea level up to 800 m, while *Pinus nigra* is the dominant species of the forests found in the mountainous areas of the island (sub-alpine zone).

3 METHODOLOGY

In order to compare the information provided by the LANDSAT and IKONOS images, all the necessary corrections in both images were made, and the same standardization (PROMETHEUS) was used but in a modified form according to the characteristics of the two image types. Subsequently, both images were processed, models were created and thematic maps were obtained, according to the following diagram (Figure 2)

![Methodology structure diagram](image-url)

Figure 2. Methodology structure diagram
3.1 **Satellite data pre-processing**

Satellite images of medium-high (LANDSAT TM) and very high resolution (IKONOS) were used as original data. Atmospheric, geometric and topographic corrections for LANDSAT (Figure 3) and geometric for IKONOS (Figure 4) were performed using the appropriate software. A LANDSAT TM image was sensed on 24 September 1985, shortly after the big fire that destroyed the south part of the island. An IKONOS image of the north-east part of the island, which was the only part that had not suffered from fires in the previous twenty years, was sensed on 14 July 2000.

3.2 **Prometheus adaptation**

The organization and ordering of classes was determined by the “Prometheus” system. The various types of forest fuel, in accordance with the above-mentioned standardization, are:

1) **Land Fuel**: This category comprises grasslands consisting of agricultural and herbaceous vegetation. Such fuel is thin and dry during the summer period, and consequently fires spread quickly and at a low flame altitude.

2) **Low-lying Shrubs**: This category comprises grasslands, low-lying shrubs (30-60cm) and a high percentage (30-40%) of herbs. In this category are also included lumbered areas in which lumbered remnants still exist.

3) **Medium Shrubs**: This category comprises medium to large-sized shrubs (0.60-2.0m). Land coverage can be greater than 50%. Areas of natural or artificial regeneration can also be included.

4) **Tall Shrubs**: This category comprises tall shrubs (>2.0m) and areas consisting of young tree groves, resulting from regeneration.

5) **Forest areas with no understory**: This category comprises areas where undergrowth has purposely been removed, either by controlled burning (not done in Greece) or via mechanical or chemical methods. In this category, low-spreading fires are the most common.

6) **Forest areas with medium understory**: This category comprises forests where the leafy part of the tree is much higher than the uppermost parts of the understory. The understory usually consists of low-lying shrubs. Fires characteristic of this category are low with various densities and can sometimes develop to much larger fires under extreme climate conditions.

7) **Forest areas with high and dense understory**: This category comprises forests with high and dense undergrowth where the distance between the leafy part of the tree and the undergrowth is small, or there is a merging of the two. This type favors severe and high density fires.
3.2.1 Recognition of each category

In cases of satellite imagery it is not always possible to recognize all these classes in their exact form. The main problem lies in the detection of the understory that may exist in a forest area. Even though the understory constitutes a very important factor in fuel mapping, it is hard to detect in cases of a relatively dense forest. Additionally, the first 4 classes can be condensed into 2, as satellites cannot provide enough information for such a detailed classification.

However a new class - broadleaved trees – can be used, not only because the trees in this class exhibit completely different behavior compared to coniferous trees (that co-exists in the same area), but also because their specific spectral characteristics can be detected.

Finally, for the LANDSAT TM image (Figure6), the following classes were used:

1) No vegetation: Consists of bare land areas, resulting from fires or human activities such as settlements, streets, fire cuts etc;
2) Low, sparse shrubs, agricultural land: This class includes the first 2 classes of the Prometheus system;
3) Dense shrubs: This category comprises the 3rd and 4th classes of the Prometheus system;
4) Broadleaved trees.
5) Coniferous forest: Includes the 5th, 6th and 7th classes of the Prometheus Standardization and comprises mainly Pinus Brutia and Pinus Nigra.

In the case of the IKONOS image (Fig7), the 5th class was divided into two subclasses: low density and high density forest.

3.3 Model construction

Segmentation and classification was applied to both images. To achieve the latter, object-oriented classification software was used. The advantage of the above-mentioned method in obtaining results is that not only does it provide complete development and adjustment of the control functions, but also allows class organization according to super-classes and sub-classes. Moreover, it is possible to control the classification procedure, both through spectral identification and shape and texture, and also to consider relations between objects of the same, superior or inferior level of segmentation and classes that belong to the same or different super-classes (Object-Oriented Classification).

3.3.1 LANDSAT TM model

In the case of LANDSAT TM imagery, we received data through 6 of the 7 bands (Figure5), (thermal band was ignored) under a 30m resolution. The relatively medium resolution of LANDSAT imagery does not provide enough information about the shape and texture of single objects, but rather provides information of a macroscopic nature. Thus, it was quite difficult to detect features such as the density of a forest.

This “drawback” can be overcome by means of advanced spectral information (Mertikas, 1999), which is considered to be adequate for the creation of a thematic map that includes all the basic classes.

Objects should have a minimum dimension of 900 m² (usually at least 3600 m²), in order to be recognized; therefore, individual objects, such as olive trees in a field, are usually not visible.

To this particular application, two more thematic Layers were added:

Normalized Difference Vegetation Index (NDVI) = [(band4-band3)/(band4+band3)], which is especially useful in distinguishing between areas covered by water (-0.8 to -0.15), no or almost no vegetation (-0.15 to 0.4), sparse vegetation (0.4 to 0.6) and areas covered by dense vegetation (0.6 to 0.9)

Digital Elevation Model (DEM): Provides information about the elevation of the area and can be used to distinguish objects existing at different altitudes.

Thus, we had at our disposal 8 thematic Layers to be used for classification of the area (Figure6).
The above classification was performed at three different segmentation levels. The higher the level, the bigger the polygons, hence a less detailed but a clearer thematic map. Conversely, small polygons mean more detail but, after a certain point, the image becomes too complicated to read. In order to provide as detailed an image as possible, but nevertheless a readable one, the limit for a segmentation parameter was found to be 10. In most cases, more than one control function had to be set in order to improve the model algorithm.

An attempt was also made to recognise the two species of pines trees that exist on the island, considering the DEM and the fact that Pinus Nigra usually grows at high altitudes (above 600m).

3.3.2 IKONOS model
In the case of IKONOS imagery, the data is received from 4 spectral bands: the 1\textsuperscript{st} for blue, the 2\textsuperscript{nd} for green, the 3\textsuperscript{rd} for red and the 4\textsuperscript{th} for NIR (corresponding to the first 4 bands of LANDSAT). IKONOS spectral information is sufficient to distinguish some basic classes (water - land, vegetation – bare land, coniferous – broadleaved and shrubs). However, after a certain stage, spectral identification in these 4 bands appears to be the same for particular classes, such as broadleaved trees and grasses, making it difficult to distinguish among them. This can be overcome, to a certain degree, by advanced information according to shape and texture characteristics. Where IKONOS imagery actually provides valuable information is in its recognition of single units of a class within the whole area of another class (Figure7).
It is often the case that this property, in combination with texture information, can also distinguish objects of different classes with the same or almost the same spectral signature (Property of Object Oriented Classification). In order to achieve this, a segmentation of very small polygons is needed (segmentation parameter < 10)

Example 1: Broadleaved trees and grass, though they look the same, can be distinguished if an additional threshold that considers neighbouring objects with some specific ones (for example, bare land) is set.

Example 2: Coniferous and Olive trees appear to be the same according to the spectrum. However, the area where olive trees exist is recognized as agricultural land at a higher-level classification (bigger polygons). This can be used as a feature in the attempt to recognize olive trees, but this condition cannot ensure that every single tree that is recognized as an olive tree is, in fact, one (not only olive trees exist in a larger agricultural area).

Because of the complicated characteristics of Mediterranean forests, the accuracy of the results that were obtained using conditions based on shape and texture characteristics are still under investigation. Further field surveys will help us to make verifications and set additional parameters into the control functions to improve the results, when necessary.

In our investigation, a NDVI layer of the area was also added and the study area was classified according to the following diagram (Figure8):
4 RESULTS AND DISCUSSION

The two thematic maps that resulted from the two models provided the different kinds of information previously mentioned according to the specific properties of each satellite.

In the case of LANDSAT TM, the thematic map in Figure 9 was obtained. All main classes, except the two different species of pines (*Pinus Brutia* and *Pinus Nigra*), were well recognized. The problem in this last case, taking elevation to be the main criterion, is that forest areas above a certain altitude (600m) are recognised as *Pinus Nigra* forests even if this is not the case. Additional characteristics need to be found in order to define the exact area where *Pinus Nigra* exists.

GIS software (Sileos, 2000) was used to provide the statistical results of Land Cover (Figure 10).
In the case of the IKONOS image, the model was much more complicated as a result of the advanced information provided, mainly in spatial characteristics. The thematic map in Figure 11 was the result of the classification based on the previously mentioned diagram (Figure 8) and the statistic results are summarized in the following diagram in Figure 12.
The conclusion drawn is that LANDSAT provides enough information to be able to recognize the main classes (water, bare land, shrubs and forest) and the subclasses (coniferous, broad leaved trees etc). However, as previously mentioned, no information is obtained about individual objects smaller than 30m and no clues are given as to the forest understory.
Conversely, IKONOS can provide us with the information necessary to recognize individual objects, detect texture differences among them, and irregularities in the areas under investigation (openings in a forest area etc.). However, when increased spectral information is needed, we need to take more features into consideration and set more, and usually complex, conditions in order to overcome its “weakness”. This advanced shape and texture information also incurs a cost. Not only the objects under investigation, but also the appearance of several spots (shades), are viewed as unclassified areas. Further investigations, such as a field survey, are needed to identify these shaded areas. Additionally, previously burned areas that are covered with low vegetation (shrubs, grasses, etc.) in this specific month of the year (July) reflect in the same wavelength -considering the 4 spectral bands of IKONOS- as the areas covered with coniferous trees, and are therefore recognized accordingly. Neither shape nor texture information was satisfactory enough for their identification. The likelihood is that if we had had height information from a LIDAR system or another image of the same area, sensed at a different time of the year at our disposal, we might have been able to overcome this problem (see Hame et al., 1998).

Needless to say, IKONOS images are often too large in terms of memory demands, so it is usually necessary to divide the area into smaller parts in order to be processed.

5 CONCLUSIONS

In this work two Object-Oriented Models for fuel type mapping based on the PROMITHEUS fuel type classification system were created; one for LANDSAT TM and one for IKONOS. Preliminary results were satisfactory.

The main advantage of LANDSAT TM imagery is the large number of spectral bands resulting in an easier discrimination of the basic classes. However, compared to IKONOS imagery, the relatively lower resolution of the sensor resulted in non recognition of the small objects within larger areas. This was illustrated by its inability to measure forest density.

IKONOS, on the other hand, was more useful for the creation of detailed thematic maps of subsets of the study extent, especially when certain objects needed to be identified. As a result, the use of IKONOS imagery made possible forest density measurement. However, because of its poor spectral information, different classes with similar reflectance required several complex functions to be recognized. Additionally, due to the very high resolution of IKONOS imagery, unnecessary data (shaded areas) were included in the results as ‘unclassified’ areas (noise).

In the case where both types of satellite images are available, the best policy would be to start classifying the whole area using a LANDSAT image in order to recognize the main classes and then to select a certain part of the area for further and more detailed investigation and decide on which IKONOS features to use, depending on the specific classes or individual objects we are interested in.

It is important to emphasize that these are preliminary results and that a real assessment should include a field survey.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. David Riano for providing us with the relevant scientific papers and references. The authors are thankful to Ms Linda Lucas for her careful review of the English language content of this paper.
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