# FOREST COVER ANALYSIS
# WITH MULTITEMPORAL AND MULTISPECTRAL IMAGES
# A CASE STUDY IN THE DOLOMITES (NORTHERN ITALY)


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## ABSTRACT


Since its creation in 1967, the Natural Park of Paneveggio - Pale di Saint Martino Agency in the Italian Dolomites has accumulated quite a remarkable mass of research data on various aspects of the management of local territory, such as the use of forestry resources, the control of tourist activities, the management of hunting reserves and high-altitude agricultural activities.

In the main, this mass of data has not been archived in a uniform or systematic manner, and thus its knowledge potential cannot be realised in a convenient way.

Many aspects of territorial management can be related, either directly or indirectly, to forest coverage and the ecosystems which the woodland supports. A deeper understanding of the evolutionary dynamics of forest coverage can thus lead to a better knowledge of such systems.

The author moreover felt that it would be of interest to ascertain whether it would be possible to acquire such information through easily accessible instruments at low cost, in terms of both financial and human resources, to allow for continuous modernization of available data.

From this point of view, multi-temporal factors become a fundamental aspect in the management of a natural park.

The correlation of multidisciplinary data relating to territorial management and ongoing temporal evaluation are fundamentally important in an attempt to acquire in-depth knowledge of local phenomena, and definitely allow for more efficient and effective planning of development policies and activities related to such a unique, natural, economic and cultural environment.

The main scope of the study was to understand and define the methodology and levels of approximation suitable for determining variations in wooded forestry coverage in a sample area of the Park and over a twenty year time span.

The selected area is characterized by a high degree of morphological complexity, typical of Italian alpine territory.


## INTRODUCTION

The main scope of this study is to understand and define the methodology and levels of approximation capable of determining variations in wooded forestry coverage in mountainous areas featuring a high level of morphological complexity by means of computer-aided analysis of multispectral images obtained from aerial and space platforms.

This study can thus be considered within the context of an attempt at improving the procedures of construction of a Geographical Information System (G.I.S.), which might be utilized by local public agencies and organizations as an instrument of advanced management of the territory within their jurisdiction.

The organisation which promoted this research is the Ente Parco Naturale Paneveggio Pale di San Martino itself, located in the western part of the Trentino Region in northern Italy. Created in 1967, the park extends over a total surface area of 19,711 hectares, with altitudes ranging from 1,100 to 3,200 m a.s.l. The area features the presence of morphological characteristics which are entirely alpine in nature with the chains of volcanic and metamorphic rock of the Lagorai in the west and the more typical Dolomite characteristics of the Pale di San Martino group in the east.

The park includes an area which, for a considerable length of time, has been characterized by a variety of economic activities and tourist infrastructures, which have gradually ‘shaped’ and influenced the landscape on account of their relationship with the surrounding environment (flora, fauna, water courses and forests etc).

However, in recent decades, for a series of complex reasons, there has been a progressive local abandonment of many activities which were traditionally connected with this particular territory, such as agricultural work, forestry management and animal breeding.

The possible effects of this development on the present situation and in future have never been investigated from a socio-economical and environmental point of view and the park, which unites a variety of communities and the natural environment, would very definitely be able to play a very important role in this sense.

The Park Agency has accumulated a quite considerable mass of data and results of research concerning a wide variety of aspects relating to the management of the area within which it is situated. These include the use of forestry resources, tourist migration control, data regarding the management of wildlife, the regulation of and restrictions imposed upon hunting activities, the issue of permits to gather or harvest mushrooms, biological and ethological studies of a great number of animal species (ungulates, tetraonids, chiropters, etc) and plants, and the management of summer grazing. A mass of data not always uniformly and systematically organized, the informative potential of which is under-exploited and perhaps even inhibited.

Many of these aspects may be connected, either directly or indirectly, to the forest cover and the ecosystems which it supports and thus, by a greater comprehension of its evolutional dynamics it would be possible to increase our knowledge of each individual aspect.

This was the consideration which led to an interest in understanding whether and to what extent over time the forest cover of the park had grown or receded.

A multitemporal analysis thus becomes a fundamental step to allow for management of the territory in question, and a promising solution for in-depth investigation and, consequently, for effective programming of management activities and policies for environmental, economic and socio-cultural development, and so much the better if it were possible to collect such information through the use of easily accessible, low-cost, flexible and updated instrumentation.

This is true above all for an organisation such as the Parco di Paneveggio-Pale di San Martino, in which there is a strong ambition to attain effective integration and collaboration between the organization itself and, public administration and the communities directly involved, the latter being an integrated part of the park and thus in a position to constantly require a form of sustainable equilibrium.

## MAIN SOURCES

As it was necessary to identify an area within the park territory which would be suitable for the purpose outlined above, the area under consideration was evaluated on the basis of the following aspects: roughness of the terrain, inclination of versants, exposure to irradiation during surveys, homogeneity of forest coverage, anthropization.

The selected zone was the Paneveggio area, which is supervised by the park authority personnel and which extends around the artificial basin at Forte Buso (a short distance to the north west of the Pale di San Martino).

This zone of about 40 $Km^2$ (representing about one fifth of the entire parkland area) was selected on account of its ‘average’ features in relation to the great variety of situations present within the park area (woodland, meadows, cliff formations, civil buildings and dwellings etc.). The forest coverage here is mainly (85%) formed by red spruce trees (*Picea abies*) between 1500 - 1900 m. Higher up, and up to an altitude of 2200 m, the larch (*Larix decidua*) and Swiss pine (Pinus cembra) are more frequent. There are no beech trees at all and other broad-leaf trees are very scarce.

### Remote Detection of Data

A scene recorded in June 2003 by the ASTER[1] modular sensor was used for the study.

ASTER records electromagnetic radiations of a wide portion of the spectrum in 14 bands from the visible range to thermal infrared. Spatial resolution varies in accordance with the wavelength considered, i.e., 15 m for intervals within the visible and near infrared (VNIR) ranges, 30 m for the shortwave infrared range (SWIR) and 90 m for the thermal infrared intervals (TIR) (Tab. 1).

The sensor surveys portions of the terrestrial surface measuring 60 x 60 $Km^2$, operating from a heliosynchronous sub-polar orbit at an altitude of 705 Km, with equatorial passage occurring at 10:30 am and a return time to the same locality of 16 days.

[1] Advanced Spaceborne Thermal Emission and Reflection Radiometer.
It is an imaging instrument flying on “Terra” satellite launched in December 1999 as part of NASA's Earth Observing System (EOS).

| Subsystem | Band No. | Spectral Range (µm) | Spatial Resolution, m | Quantization Levels |
|---|---|---|---|---|
| VNIR | 1 | 0.52-0.60 | 15 | 8 bits |
| | 2 | 0.63-0.69 | | |
| | 3N | 0.78-0.86 | | |
| | 3B | 0.78-0.86 | | |
| SWIR | 4 | 1.60-1.70 | 30 | 8 bits |
| | 5 | 2.145-2.185 | | |
| | 6 | 2.185-2.225 | | |
| | 7 | 2.235-2.285 | | |
| | 8 | 2.295-2.365 | | |
| | 9 | 2.360-2.430 | | |
| TIR | 10 | 8.125-8.475 | 90 | 12 bits |
| | 11 | 8.475-8.825 | | |
| | 12 | 8.925-9.275 | | |
| | 13 | 10.25-10.95 | | |
| | 14 | 10.95-11.65 | | |

**Table 1**: Characteristics of the ASTER sensor

### Format and Acquisition of ASTER Images

The acquired scene is a first-level product (L-1B) containing information related to radiance measured by the sensor, corrected by systematic effects and projected into a reference system according to the direction of movement of the satellite. In this way geographical north does not correspond with the north indication of the image itself but is rotated by about ten degrees in the anticlockwise direction.

In this specific case information contained in the three bands 1, 2 and 3N (VNIR) with a good level of geometric resolution (15 m) was used. This characteristic was in fact considered a fundamental factor given the necessity to study the development of forest cover in an area featuring complex morphological features (Fig. 1).

**Figure 1**: VNIR (Visibile and Near Infrared) Aster scene.
Composition of the bands 1, 2, and 3N

## ANCILLARY INFORMATION

### Digital Orthophotography

An orthophoto (D.O.P.) was used for this work. The photo was obtained from a photogrammetric survey produced by ‘Volo Italia 2000’ with linear geometric resolution of one metre (1 m). (Fig. 2)

**Figure 2:** Digital orthophoto Volo Italia 2000, resolution of 1 m.
Scene centred on the Paneveggio - Lago di Forte Buso area

## Geodetic and Geographic Position

The orthophoto is anchored to the Gauss-Boaga representation of the Italian national geodetic system with UTM orientation at Monte Mario, Rome 1940.

In particular, the scene shows the following geographical coordinates (Tab. 2)

| **Gauss-Boaga coordinates of Vertices** | | |
|---|---|---|
| Vertex | Orthophoto | |
| | **East** | **North** |
| **NO** | 1705080 | 5136600 |
| **NE** | 1711800 | 5136600 |
| **SE** | 1711800 | 5130720 |
| **SW** | 1705080 | 5130720 |

**Table 2:** Geographical position of the digital orthophoto

## Digital Terrain Model (D.T.M.)

The Digital Terrain Model describes the morphological features of the territory by means of a matrix structure with square cells; to each cell in this type of grid is associated an altitude at ground level expressed in metres and referring to the centre of the cell itself.

The D.T.M. used for this work was produced in 1996 by the Autonomous Trentino Region and anchored on the Gauss-Boaga representation of the Italian national geodetic system with UTM orientation at Monte Mario, Rome-1940 and with 10-metre sampling.

## Aerophotography

The only photographic material available at the park relating to periods earlier than 1994 is a series of panchromatic, zenithal aerial photos in black and white, developed on paper and produced following an aerophotogrammetric survey performed in 1984[2] (with a relative flight altitude of 6742 m; focal distance of the camera of 150 mm, and linear geometric resolution of 1.5 m)

To allow for electronic elaboration, the image was digitalized with a 600x600 dpi resolution and converted into a non-compressed, TIFF graphic format.

While it is not perfectly centred on the sector we were interested in, the scene surveyed during the 1984 flight covers an area greater than that useful for our study and therefore we proceeded to isolate the portion we wished to examine. Moreover, for reasons dictated by the Italian Ministry of Defence, the image presents masking of the sector corresponding with the Forte Buso dam and the surrounding area (Fig. 3)

[2] *Reproduction by courtesy of Compagnia Generale Riprese Aeree (auth. 76 - 2/2/84)*

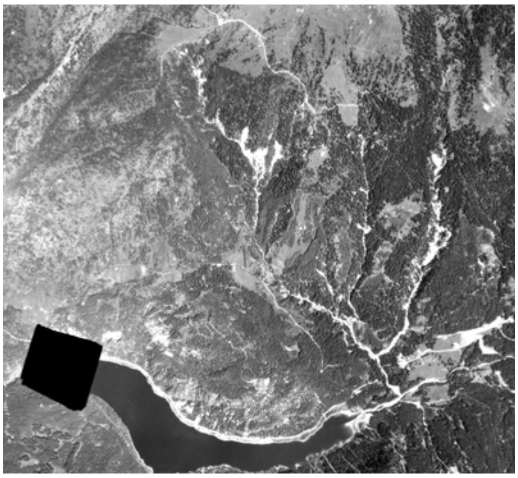

**Figure 3:** Extracted from the aerophotogrammetric survey performed in 1984
(Paneveggio - Lago di Forte Buso area)

### Software Adopted

The software used for elaboration, interpretation and classification of the thematic and geometric data was the ENVI 3.6® package developed by Research Systems Inc. This product is specifically designed to allow users to extract information from images from various sources and then integrate them.

## CREATION OF A FOREST COVER MAP FROM THE 2003 ASTER IMAGE

In this case the classical methodological approach for the realisation of this kind of product was adapted to local physiographic and morphological characteristics.

The approach is articulated in the following phases:

- elaboration of image structure and geometry, conversion from the digital format, georeferencing and masking of the areas not required;
- stratification of the area to be studied from the physiographic and morphological points of view in accordance with the exposure of versants;
- elaboration and classification of the ASTER image with detection of the single categories of soil usage (dense woodland, sparse woodland, open meadow areas, exposed soil, built-up areas) by means of appropriate training sites and quality control of the results with confusion matrices based on equally important control sites.

To produce this map we used spectral data from the three spectral bands of of the VNIR instrument as they are characterised by finer geometric resolution (15 m), which was more suitable for our needs.

### Elaboration of Image Structure and Geometry Georeferencing

Following identification in the ASTER scene of the area which we wished to examine (Paneveggio - Lago di Forte Buso), the zone was georeferenced and anchored to an appropriate geographical reference, conforming all images to a single geometric base.

For this purpose we used the digital orthophoto bound to an appropriate geodetic reference (UTM - Rome, 1940). The ASTER image was then subjected to conversion in relation to the WGS-84 (Rome, 1940) geographical reference system, and subsequently automatically compared with the geographical data of the orthophotos and the specific portion was isolated and georeferenced.

As the two products had different geometric resolutions (ASTER VNIR at 15m and the D.O.P. at 1 m) we performed a resampling of images with the nearest neighbor process, which does not alter spectral values, to obtain a common geometric resolution of 5 m.

### Masking of Unrequired Areas

So as to avoid difficulty during the classification process, we proceeded to hide, by means of the creation of a suitable mask, the covered surface of the artificial Forte Buso basin. We then also masked some areas of rocky formations (exposed soil), easily identifiable from the morphological study of the images, with the purpose of facilitating the subsequent processes of definition of the areas of detection and control (training and control sites), and in consideration of the fact that the masking of surfaces definitely not covered by vegetation, is the most practical and least costly solution for a user such as the park administration.

## Physiographic-Morphological Stratification of the Area to be Studied in Relation to Versant Exposure

The principle aim of the stratification process was that of achieving an a priori definition of homogeneous zones in physiographic and morphological terms to optimize the classification process through the identification of spatial images. The result of the classification is directly proportional to the precision and *significance* of the stratification itself.

In this case we performed a physiographic-morphological stratification based on slope exposure. This was carried out because we considered that this was a preponderant aspect with respect to others such as altimetry, and also considering an application of such techniques in the study of other, less uniform and less favourable areas of the park.

From the digital model of the park with 10-metre resolution we first of all obtained a model of exposure levels; and then, through the creation and application of specific masks, we performed individual extrapolation of all exposed surfaces according to the four directions NE, SE, SW, and NW.

## Elaboration and Classification of Images

The ASTER image was classified by means of a supervised classification (supervised classification) procedure applied independently to each single stratification zone.

## Control Sites and Training Sites

The control sites necessary for the classification procedure were determined for each specific stratification zone through careful analysis and precise sampling of the classes we were interested in. The validity and accuracy of this procedure were verified by means of study of spectral separation of the control sites, (Computing ROI separability), performed by means of two specific control algorithms[3]

The following tables show the data referring to the evaluation of the control sites selected for each versant (Tables. 3 a, b, c, and d ).

**Tables 3 a, b, c, d:** ENVI ‘Computing ROI separability’
Verification of the accuracy of control site selection with reference to individual versants.

a) **Training sites – NORTH EAST versants**

| Classes | Meadow land | | Thick woodland | | Sparse woodland | |
|---|---|---|---|---|---|---|
| | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div |
| Meadow land | | | 2.00 | 2.00 | 1.96 | 2.00 |
| Thick woodland | 2.00 | 2.00 | | | 1.92 | 2.00 |
| Sparse woodland | 1.96 | 2.00 | 1.92 | 2.00 | | |

b) **Training sites – NORTH WEST versants**

| Classes | Meadow land | | Thick woodland | | Sparse woodland | |
|---|---|---|---|---|---|---|
| | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div |
| Meadow land | | | 2.00 | 2.00 | 1.94 | 2.00 |
| Thick woodland | 2.00 | 2.00 | | | 1.98 | 2.00 |
| Sparse woodland | 1.94 | 2.00 | 1.98 | 2.00 | | |

c) **Training sites – SOUTH-EAST versants**

| Classes | Meadow land | | Thick woodland | | Sparse woodland | |
|---|---|---|---|---|---|---|
| | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div |
| Meadow land | | | 2.00 | 2.00 | 1.94 | 2.00 |
| Thick woodland | 2.00 | 2.00 | | | 1.98 | 2.00 |
| Sparse woodland | 1.94 | 2.00 | 1.98 | 2.00 | | |

d) **Training sites – SOUTH-WEST versants**

| Classes | Meadow land | | Thick woodland | | Sparse woodland | | Built-up areas | |
|---|---|---|---|---|---|---|---|---|
| | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div | Jeff-Mat | Trans Div |
| Meadow land | | | 2.00 | 2.00 | 1.96 | 2.00 | 1.85 | 2.00 |
| Thick woodland | 2.00 | 2.00 | | | 1.96 | 2.00 | 2.00 | 2.00 |
| Sparse woodland | 1.96 | 2.00 | 1.96 | 2.00 | | | 1.70 | 2.00 |
| Built-up areas | 1.85 | 2.00 | 2.00 | 2.00 | 1.70 | 2.00 | | |

[3] Jeffries-Matusita and ‘Transformed Divergence’.
These two algorithms, comparing pairs of control sites of diverse classes (e.g.. sparse woodland with thick woodland), assume values which vary between 0 and 2.0, statistically indicating the degree of separation between classes: values greater than 1.9 indicate an excellent spectral separation of selected control sites; values between 1.8 and 1.9 indicate a good level of separation; between 1.5 and 1.8 a moderate level, and poor separation is indicated by the lowest values.

In examining the data we reached two conclusions concerning the identification of the 'built-up areas' class. The first of these considerations emphasizes that these zones, given the morphology of the areas and their smallness, are concentrated exclusively on the exposed, south-eastern versants, which are more suitable for human habitation on account of their greater solar irradiation throughout the year.

The second consideration highlights the fact that, given the frequent proximity between vegetation and man-made objects, it is rather difficult to identify in a precise way the built-up areas class, also on account of limits imposed by the resolution of the ASTER sensor (15 m).

## Choice of the Classifier

Amongst the various classifiers mentioned in literature, the so-called maximum likelihood algorithm was selected on account of its adaptability to a statistic study of populations of pixels with a normal multivariate distribution of the spectral response.

Each stratified zone was treated separately and independently of the others.

## Classes of Use Identified by the Classifier

On the basis of the use of the described classifier, the following classes of soil usage were identified:

- Thick woodland: intended as an area in which the wooded forest cover appears more compact and stable and whose margins appear to be more easily identifiable.
- Sparse woodland: intended as areas in which the forest cover appears to be more sparse with fuzzier boundaries, as is typical in zones which are being renewed or in the neo-colonization of open areas.
- Meadow land: intended as all open, green areas, inside forests or beyond the edges of vegetation, and characterised by the absence or sparse human control or intervention.
- Built-up areas: intended as anthropized areas. This class was sought only in the stratification zone of the exposed areas in the south-western portion, as explained above

**Table 5:** Confusion matrix for North East versants

| **Confusion matrix for NORTH EAST versants** | | | | |
|---|---|---|---|---|
| **Control sites (pixels)** | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Total |
| Not classified | 1804 | 86 | 208 | 2098 |
| Thick woodland | 7494 | 20 | 0 | 7514 |
| Sparse woodland | 51 | 1980 | 1 | 2032 |
| Meadow land | 0 | 5 | 3801 | 3806 |
| Total | 9349 | 2091 | 4010 | 15450 |
| **Control sites (percentage)** | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Total |
| Not classified | 19.30 | 4.11 | 5.19 | 13.58 |
| Thick woodland | 80.16 | 0.96 | 0.00 | 48.63 |
| Sparse woodland | 0.55 | 94.69 | 0,02 | 13.15 |
| Meadow land | 0.00 | 0.24 | 94.79 | 24.63 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 |
| **Errors** | | | | |
| Classes | Commission (percentage) | Omission (percentage) | Commission (pixels) | Omission (pixels) |
| Thick woodland | 0.27 | 19.84 | 20/7514 | 1855/9349 |
| Sparse woodland | 2.56 | 5.31 | 52/2032 | 111/2091 |
| Meadow land | 0.13 | 5.21 | 5/3806 | 209/4010 |
| | | | | |
| **Total accuracy =** | **85.92%** | 13275/15450 | | |
| **Total kappa (KIA) =** | **0.7744** | | | |

## Quality Control of Classification

For the critical evaluation of results we used the confusion matrix or 'contingency tables' method, which constitutes one of the most significant statistical representations for describing an actual correspondence between 'terrain-truth' and the classification adopted.

Quality control was performed individually for homogeneous areas in accordance with the previous stratification by exposure. The number of pixels attributed to the control sites for each class of soil usage, sampled independently and not used before in the classification process, is compared with that calculated by the classifier on the basis of the training sites.

The comparison between these homologous groups of pixels provided three types of information:

- The population of pixels, expressed as a number and as a percentage, of the various categories correctly attributed to the control sites;
- The percentage error 'by omission' (percentage of pixels not recognized as belonging to the correspondent class of control sites);
- The percentage error 'by commission' (percentage of pixels erroneously recognized as belonging to the corresponding category of control sites).

In the matrices given below (Tables 5, 6, 7, and 8) the columns refer to the control sites, while the lines refer to the result of the classification based on the training sites.

In the theoretical case of a classification with 100% recognition, all matrix elements not belonging to the cells of the diagonal would be null.

For verification of the accuracy of the classification it is necessary to consider the kappa coefficient or kappa index of agreement (KIA), which expresses the proportional reduction in the range comprised between 0 and 1 of the error made by the classifier used, with respect to the error of a totally casual classifier (e.g., coefficient K = 1: excellent; and, K<0.7 insufficient).

| Confusion matrix for SOUTH EAST versants | | | | |
|---|---|---|---|---|
| **Control sites (pixels)** | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Total |
| Not classified | 0 | 125 | 0 | 125 |
| Thick woodland | 1558 | 0 | 0 | 1558 |
| Sparse woodland | 0 | 1346 | 24 | 1370 |
| Meadow land | 0 | 91 | 1440 | 1531 |
| Total | 1558 | 1562 | 1464 | 4584 |
| **Control sites (percentage)** | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Total |
| Not classified | 0.00 | 8.00 | 0.00 | 2.73 |
| Thick woodland | 100.00 | 0.00 | 0.00 | 33.99 |
| Sparse woodland | 0.00 | 86.17 | 1.64 | 29.89 |
| Meadow land | 0.00 | 5.83 | 98.36 | 33.40 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 |
| **Errors** | | | | |
| Classes | Commission (percentage) | Omission (percentage) | Commission (pixels) | Omission (pixels) |
| Thick woodland | 0.00 | 0.00 | 0/1558 | 0/1558 |
| Sparse woodland | 1.75 | 13.83 | 24/1370 | 216/1562 |
| Meadow land | 5.94 | 1.64 | 91/1531 | 24/1464 |
| | | | | |
| **Total accuracy =** | | **94.76%** | 4344/4584 | |
| **Total kappa (KIA) =** | | **0.9225** | | |

**Table 6, 7:** for North East versants

Confusion matrix West and South

| Confusion matrix for NORTH WEST versants | | | | |
|---|---|---|---|---|
| **Control sites (pixels)** | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Total |
| Not classified | 41 | 59 | 4 | 104 |
| Thick woodland | 1683 | 0 | 0 | 1683 |
| Sparse woodland | 0 | 1416 | 0 | 1416 |
| Meadow land | 0 | 27 | 1403 | 1430 |
| Total | 1724 | 1502 | 1407 | 4633 |
| **Control sites (percentage)** | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Total |
| Not classified | 2.38 | 3.93 | 0.28 | 2.24 |
| Thick woodland | 97.62 | 0.00 | 0.00 | 36.33 |
| Sparse woodland | 0.00 | 94.27 | 0.00 | 30.56 |
| Meadow land | 0.00 | 1.80 | 99.72 | 30.87 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 |
| **Errors** | | | | |
| Classes | Commission (percentage) | Omission (percentage) | Commission (pixels) | Omission (pixels) |
| Thick woodland | 0.00 | 2.38 | 0/1683 | 41/1724 |
| Sparse woodland | 0.00 | 5.73 | 0/1416 | 86/1502 |
| Meadow land | 1.89 | 0.28 | 27/1430 | 4/1407 |
| | | | | |
| **Total accuracy =** | | **97.17%** | 4502/4633 | |
| **Total kappa (KIA) =** | | **0.9579** | | |

**Table 8:** Confusion matrix for South West versants

| **Confusion matrix for SOUTH WEST versants** | | | | | |
|---|---|---|---|---|---|
| **Control sites (pixels)** | | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Built-up areas | Total |
| Not classified | 21 | 497 | 0 | 0 | 518 |
| Thick woodland | 1947 | 0 | 0 | 0 | 1947 |
| Sparse woodland | 0 | 2364 | 25 | 9 | 2398 |
| Meadow land | 0 | 122 | 2025 | 5 | 2152 |
| Built-up areas | 0 | 247 | 36 | 93 | 376 |
| Total | 1968 | 3230 | 2086 | 107 | 7391 |
| **Control sites (percentage)** | | | | | |
| Classes | Thick woodland | Sparse woodland | Meadow land | Built-up areas | Total |
| Not classified | 1.07 | 15.39 | 0.00 | 0.00 | 7.01 |
| Thick woodland | 98.93 | 0.00 | 0.00 | 0.00 | 26.34 |
| Sparse woodland | 0.00 | 73.19 | 1.20 | 8.41 | 32.44 |
| Meadow land | 0.00 | 3.78 | 97.08 | 4.67 | 29.12 |
| Built-up areas | 0.00 | 7.65 | 1.73 | 86.92 | 5.09 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| **Errors** | | | | | |
| Classes | Commission (percentage) | Omission (percentage) | Commission (pixels) | Omission (pixels) | |
| Thick woodland | 0.00 | 1.07 | 0/1947 | 21/1968 | |
| Sparse woodland | 1.42 | 26.81 | 34/2398 | 866/3230 | |
| Meadow land | 5.90 | 2.92 | 127/2152 | 61/2086 | |
| Built-up areas | 75.27 | 13.08 | 283/376 | 14/107 | |
| | | | | | |
| **Total accuracy =** | | **86.98%** | 6429/7391 | | |
| **Total kappa (KIA) =** | | **0.8154** | | | |

From the statistical data given above we find a mean kappa coefficient of 0.8676 and a total mean accuracy level (percentage of classified pixels) of 91.21 %, corresponding to a total error of corrected classification of ‘pixels’ of 8.79% across the entire area studied.

Such good results were obtained thanks to a precise stratification process based on physiographic-morphological and spectral aspects.

## ELABORATION OF THE FOREST COVER MAP FROM AN AERIAL PHOTO (1984)

To produce this map we first of all identified the area to be studied in the photo and then isolated it and performed georeferencing through direct comparison with a congruous number of control points established in the digital orthophoto, applying a third-degree, polynomial model and ‘nearest-neighbour’ sampling. Here too, we performed appropriate masking to isolate the artifical basin area.

### The Classifier Used and Classification

As there was just a sole black and white panchromatic band and no available secure data regarding forest coverage of the area in the period considered, we used a non-controlled classification process based on the classification algorithm called the Interactive Self-Organizing Data Analysis, or ISODATA (Tou e Gonzalez, 1974). This method calculates mean classes regularly distributed in the data space and subsequently regroups the remaining pixels, using minimum-distance techniques. Each interaction recalculates the means and reclassifies the pixels with respect to the new mean values. The iteration of the subdivision, of the reunification and deletion of the classes is performed on the basis of the inserted threshold parameters. All the pixels are attributed to the closest class unless a standard deviation is specified (‘threshold distance’), which excludes the pixels which do not satisfy the assigned criteria. This iterative process is concluded when the number of pixels in each class varies less then the pre-established threshold value.

Non-controlled classification by means of automatic definition, initially of 20 mean classes and their subsequent reduction and attribution by direct comparison with the aerial photograph, produced a soil-usage map identifying the same classes as the former map[4], moreover deemed indicative of the state of forest coverage in 1984 on the basis of the experience of personnel at the Ente Parco Naturale di Paneveggio Pale di San Martino (Fig. 6).

[4] ‘Built-up areas’ and ‘Exposed soil’ are in this case incorporated in the same class in order to facilitate comparison with “terrain-truth”, as the two categories have similar ‘spectral signatures’.

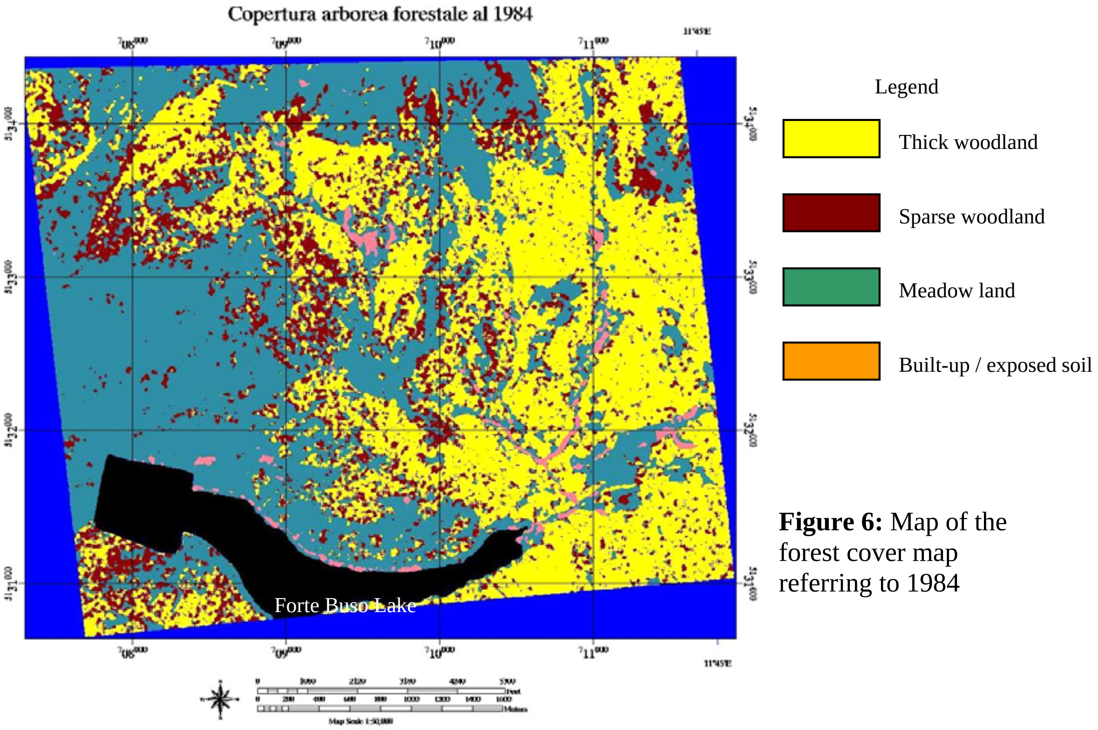


**Figure 6:** Map of the forest cover map referring to 1984

## COMPARISON OF DATA

As the 2003 map refers to a surface area greater than the analyzed map covered by the aerial survey in 1984, the area we were interested in (Figure 7) was duly isolated.

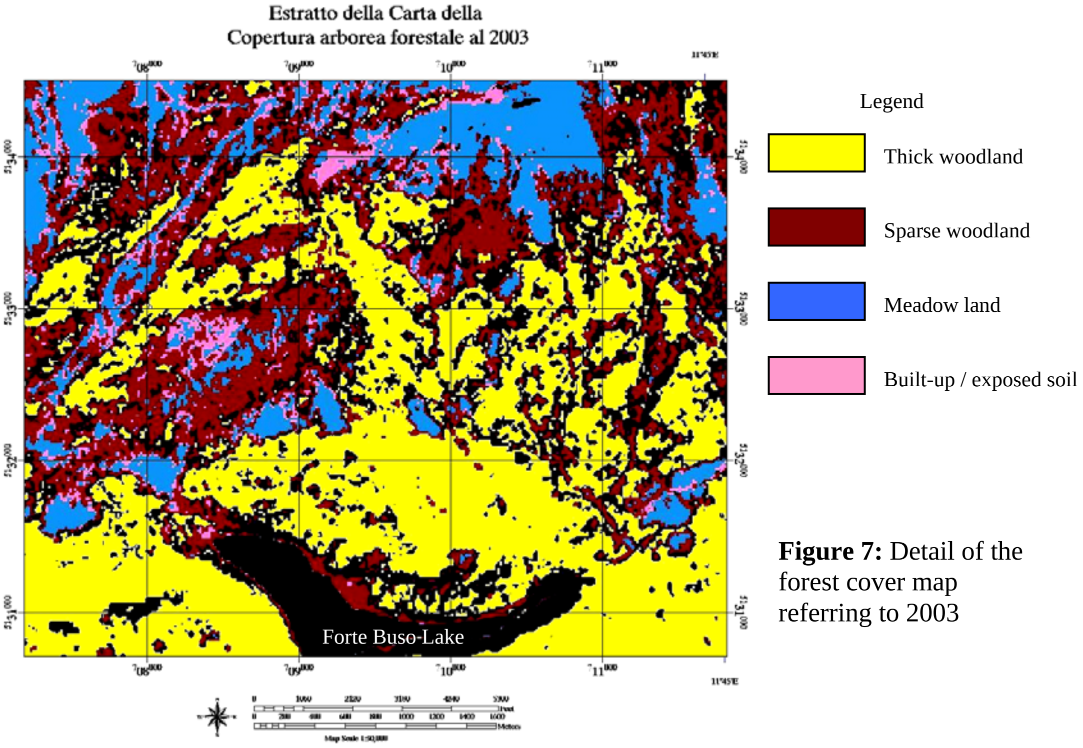


**Figure 7:** Detail of the forest cover map referring to 2003

| | 1984 | | | 2003 | | | |
|---|---|---|---|---|---|---|---|
| Classes | Total (pixels) | Total $Km^2$ | Total ha | Total (pixels) | Total $Km^2$ | Total ha | Variation |
| Thick woodland | 226102 | 5.6526 | 565.26 | 270652 | 6.7663 | 676.63 | 19.70 % |
| Sparse woodland | 93858 | 2.3465 | 234.65 | 161246 | 4.0312 | 403.12 | 71.80 % |
| Meadow land | 236279 | 5.9070 | 590.70 | 85543 | 2.1386 | 213.86 | - 63.80 % |
| Built-up areas | 12365 | 0.3091 | 30.91 | 21981 | 0.5495 | 54.95 | 77.76% |

**Table 9:** Percentage variation of the classified categories of soil usage for the years 1984 and 2003

From the analysis of the cartographic products obtained and thus from the count of pixels forming part each class of soil usage, it was possible to identify - in consideration of the fact the geometric size of the pixel used is 5x5 m and the relative surface area is 25 $m^2$ – the extension of each classified category of soil usage.

From a comparison of data thus obtained it was possible to calculate the corresponding percentage variations (Tab 9).

## RESULTS AND FINAL CONSIDERATIONS

This work stemmed from a desire to find an answer to the need to comprehend over time the evolution of the level of wooded forest cover inside the *Parco Naturale di Paneveggio - Pale di San Martino*, a very precious area of natural parkland which presents environmental conditions typical of vast areas of the alpine range. To achieve this goal we relied on an important and very valid instrument: the ASTER instrumental platform. The characteristics of the images recorded by this sensor in the very near infrared (VNIR) bands, with a geometric resolution of 15 m, were found to be suitable for the purpose. The use of satellite data, with respect to what can be obtained from orthphotos, allows for the collection of information over close time intervals, which is easily manageable and inexpensive. Moreover, the information obtained can be easily utilized to carry out statistical investigation at varying levels of sensibility according to what information is sought. The work performed was based on the differentiation of dense and sparse woodland. For other uses, this datum can be detailed at higher levels depending on the goals to be attained.

Improvement of the physiographic-morphological and spectral stratification procedures allowed for the limitation of error during the controlled classification phase in a mountainous area characterized by a high level of morphological complexity.

The acquisition of these images by a private organization was particularly easy and fast, and was also relatively inexpensive. It is thus proposed as a valid instrument for the acquisition of spectral information useful for environmental evolution studies performed by organizations or agencies such as the Paneveggio Park that are called upon to control and manage the environment. There remains the necessity however to ensure dynamic instrumentation is available, and instruments which can which can be easily accessed, utilized and adapted to changing requirements.

From the analysis of the re-aggregated data a significant result emerges as far as meadow land is concerned, indicating that, with respect to the situation in 1984, in 2003 this type of land had become reduced to quite a considerable extent (-63.80%) in favour of a progressive increase of areas classified as sparse woodland (71.80%).

This datum can be explained by a series of linked or concomitant causes such as:

- The spontaneous colonization of forest species occurring generally around the edges of woodland owing to the abandonment of agricultural areas and grazing land and because of the concomitant improvement of the climactic conditions occurring in recent years as indicated by the Forestry Authorities of the Province of Trent;
- The progressive abandonment by the local population of forest/ woodland and pastoral activities, and in particular summer grazing;
- Fewer grazing animals;
- Fewer woodland and pastoral activities in pre-existing wooded areas.

The percentage difference between the datum relating to the decrease in meadow land and a corresponding increase of sparse woodland can be explained if we consider the classification based on subjective criteria (diversity of the perception of the tones of grey in the photographs taken in 1984), and the geometric resolution of 15 m of the ASTER instrument, which does not allow for optimum distinction between built-up/urban areas and the woodland areas closest to them.

With regard to the surface classified as dense woodland, an increase of 19.70% was found with respect to 1984. This datum can be explained by the increase in volume of crowns of trees already present in 1984. The data obtained by means of this work can be taken as a point of departure for possible future development, considering that until the present day the Park Authority had not acquired any data allowing for an evaluation of the evolution of woodland surface areas.

The monitoring of such evolution will allow for the adoption of forestry-management plans based on objective data and the possible suggestion to Public Administration agencies that ad-hoc environmental policies be adopted with effects which can be evaluated also in the short term.

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